STEARATE ROBOT PRODUCTION CELL

Graduation Internship – Final Report

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Preface

This is the graduation internship report of the internship assignment to make a design proposition for a stearate coating production cell. The internship assignment has been carried out by Per Kerssens as a conclusion of his Mechatronics course at The Hague University located in Delft. This report will focus on both the feasibility study and design process of the project.

System engineering experts can find the system's architecture in chapter 7. The design phase is discussed in chapter 8. Robot simulations experts can resort to chapter 9 for a detailed production cycle simulation. Financial experts can refer to chapter 11 for a financial overview.

This project would not have been possible without the help of Pawanee Niemwongse and Narongrit Koupratoom. A special thanks to Rob van der Werf for allowing the continuation of the project in these difficult times.

Eenigenburg, May, 2020

Per Martinus Kerssens

Summary

The current configuration of the robotic stearate coating process only supports certain bead sizes, the rest is coated manually. The current configuration lacks capacity and requires a lot of maintenance due to the age of the used robots. To be able to support all bead sizes, increase the daily capacity, reduce operator stearate dust exposure, and to reduce maintenance cost, Michelin requested a redesign of the current system.

This report discusses the new design proposal for the stearate coating production cell. This is done on the basis of a cycle time study and corresponding robot simulations. A new gripping tool is designed, and a new robot manipulator is chosen. Furthermore, a recommendation is made for a cart conveyor system. And finally, a safety analysis was performed with corresponding mitigations.

A detailed robot simulation shows that the required daily capacity and cycle time can be reached with the proposed design. The gripping mechanism can pick up all bead sizes from the original production carts. All within the set budget.

The situation has changed during the project due to the global COVID-19 pandemic. This resulted in the project being continued virtually and no prototypes could be made.

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1 List of abbreviations

Abbreviation	Explanation
AGV	Automated guided vehicle
ATEX	Atmosphères explosibles (European guideline)
BDD	Block definition diagram (systems engineering)
EE	End-effector
EOAT	End of arm tooling
FEA	Finite element analysis
FIFO	First in first out
LIFO	Last in first out
LOTOTO	Lock Out – Tag Out – Try Out
PLC	Programmable logic controller
SD	Sequence diagram (systems engineering)
TBM	Tyre Building Machine shop (factory)

2 Introduction

In this day of age, where retail is moving more and more towards online sales and where the world's poverty is at an all-time low, there is an ever-increasing demand for goods. Wherever the goods originate from, there is a point at which most goods need to travel by road to reach their destination. Lorries account for a large part of the transportation of goods. The logistics sector but also the road transportation sector benefit greatly from good and efficient tyres.

Truck and bus tyres consist of several layers and parts, each with their own function. The edge of the tyre that sits on the wheel is reinforced by a so-called bead. The beads are coated to reduce friction during the tyre building process. The current coating process is only partly automated and is lacking the required output capacity. To increase the overall capacity and quality of the coating, the coating process must be fully automated.

The purpose of this report is to propose a new production cell design for the bead stearate coating process and to elaborate the design decisions. This is done based on research into which layout is best suited, which gripping methods can be used, how the products can be supplied and removed, which robot can be used for the handling, and how to ensure a safe operation. Furthermore, time studies have been done on the different concepts.

The structure of this report is as follows. Chapter 3 describes the current production process and the problem that needs to be solved. Chapter 4 describes the requirements for the project. Chapter 5 elaborates the functions of the system. Chapter 6 gives a description of the chosen concept and its substantiation and discusses the time study that was done based on this concept. The system's architecture is elaborated in chapter 7. Project results can be found in chapters 8, 9, and 10. The cost of the production cell is discussed in chapter 11. Finally, the conclusion and recommendations are discussed in chapter 12.

2.1 Important note

Due to the global COVID-19 disease pandemic, the situation has changed during the project. In agreement with the client, it was decided to terminate the practical part of the graduation internship and return to the Netherlands. The graduation internship project was virtually continued and Mr. R. van der Werf took on the business mentoring task, who has wide experience in production automation and tyre manufacturing. It has been decided to refer to the original client and business mentor in the report. The time lost is approximately three to four weeks, causing the scope to slightly reduce after close discussion with the university and company representative. No additional time was needed.

The chosen concept and time studies were verified and approved by the client prior to the situation change. Despite this approval, a few things have been changed due to the situation change. First of all, the Michelin safety requirements are replaced by machine safety at the discretion of the student. Another major change is that prototyping for the EOAT cannot be made. This has been partially solved by making an FEA simulation. In addition, due to the loss of the original team, it was decided with the fictitious client not to work out the conveyor system in detail and not to provide detailed 2D drawings. The CAD software used is changed from Solidworks to Autodesk Inventor, for which a student license is available.

The final design and simulation results are not shared with Michelin and remain virtual.

3 Background

This internship project is executed at Michelin. Michelin is a French tyre manufacturer that produces tyres for aircraft, automobiles, heavy equipment, motorcycles, and bicycles. The company consists of sixty-nine facilities located in seventeen countries employing over 110.000 people.

Michelin Siam Co. Ltd (NKE) is a business unit that is specialized in the manufacturing of bus, truck, and aircraft tyres, seen in figure 1 respectively. The bus, truck, and aircraft tyres are manufactured in Nong Khae, Thailand. The department manufacturing engineering is focused on analysing and improving production methods for the various production processes on-site.

An important production process in the manufacturing of truck and bus tyres is the application of Zinc stearate powder to a part called the bead, indicated by arrows in figure 2. The purpose of the stearate powder is to reduce friction during the successive tyre building production step. The stearate is applied to the bead by a stearate coating unit and the beads are loaded and unloaded by two industrial robot arms. The current production cell, however, only supports robotic loading and unloading of four bead sizes. Furthermore, the industrial robot arms that are currently being used are starting to show their age, require an increasing amount of maintenance, are causing a lot of production downtime, and are not certified to work in an explosive dust environment. Lastly, the current stearate coating machine is not quick enough and does not apply a uniform coating. The current layout can be seen in appendix A.

This project aims to modify and improve the current robot production cell to fully support the five different stearate sizes, increase the daily production capacity, and to improve operator dust exposure. The initiative of this project comes from Yooklin Pratheep, who is the production manager of the preparation shop, and Pawanee Niemwongse, who is the engineering manager of the Nong Khae facility. The planned duration for this project is seventeen weeks. The deadline is on 28 May 2020.

The project is executed by Per Kerssens as part of his graduation internship for the course BSc Mechatronics. Reports will be made to both The Hague University's supervisor and the company's internship supervisor. The internship is supervised by Narongrit Koupratoom.

The main stakeholders of this project include the preparation shop production team, the tyre building machine shop (TBM), manufacturing engineering, quality assurance, and the final customer.

Figure 1: bus, truck, and aircraft tyre

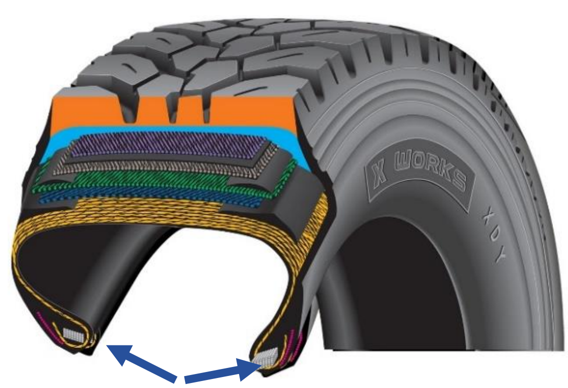

Figure 2: tyre cross-section and indicated bead locations

3.1 Product details

A bead consists of a multi-layered rubber-wound core from metal or plastic, see figure 3. The beads come in different sizes and are grouped according to the wheel's rim diameter. Each group contains small variations of the height, thickness or diameter of the bead. An overview of the different bead sizes can be found in appendix A.

The beads arrive at the stearate coating process on carts in batches of 120 or 200 (16-inch TPFR). The beads are placed alternately to prevent them from sticking together. The cart on which the beads arrive can be seen in figure 4.

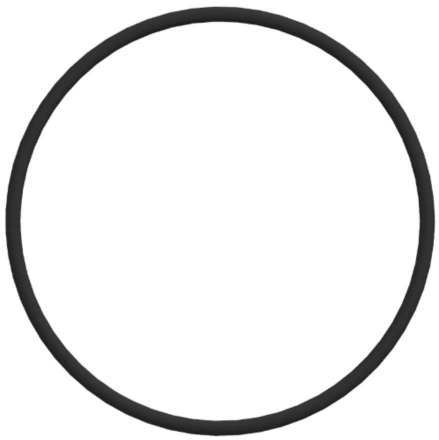

Figure 3: side view of a 22,5-inch bead

Figure 4: bead-shop cart

3.2 Current process details

The current configuration of the robotic stearate coating process only supports 22,5-inch beads and two of the 19.5-inch variant, the rest is coated manually. The manual coating is done by dipping and rotating a bead in a container of stearate powder. The capacity of the robotic process is 2.741 beads per day. The beads are transferred from the bead-shop cart to a so-called magazine cart, see figure 5.

The magazine cart, which holds 120 beads, is placed in the production cell at a designated spot. Only one magazine cart can be placed in the loading station and there is no cart buffer. A Kuka robotic arm (kr2180) then picks one bead at a time from the magazine cart and places it on a conveyor belt. The conveyor transports the bead inside a stearate coating room. A second Kuka robotic arm picks two beads from the conveyor belt and places them in a stearate coating unit. The stearate coating unit rotate the beads through a layer of powder until the robot picks them up again. The duration of the coating process is around 10 seconds. The robot places the coated beads on a so-called TBM cart, on which the beads continue their journey through the factory. The TBM cart can be seen in figure 5.

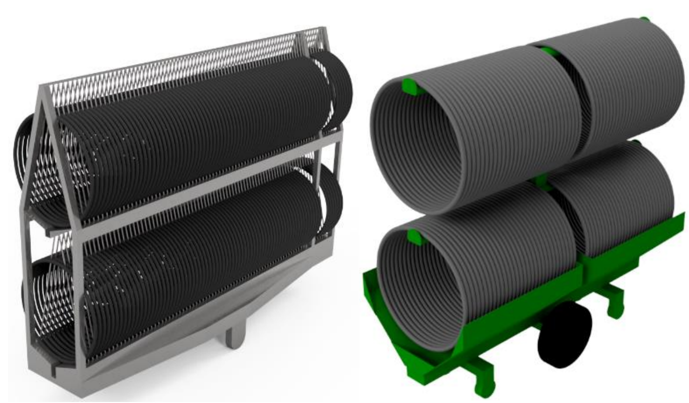

Figure 5: magazine cart(left); TBM cart(right)

A schematic overview of the current process can be seen in figure 6. A detailed overview of the current production cell layout can be found in appendix A.

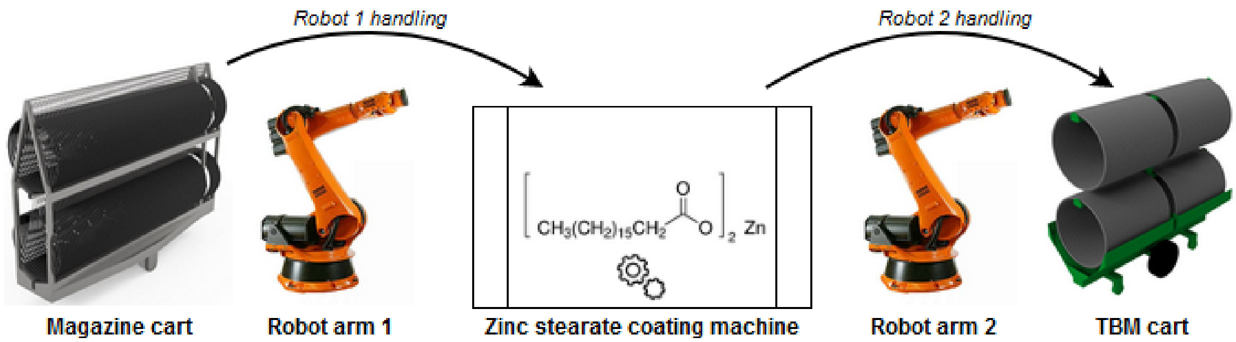

Figure 6: schematic overview of the current production process (Photo of robot: Kuka)

3.3 VENUS coating unit

An existing automated stearate coating system that supports all bead sizes is part of the fully automated bead production line called VENUS. The VENUS system is developed by Michelin France and operational in the Shenyang factory in China. The VENUS system creates a complete bead and outputs a pallet with coated beads.

Michelin Thailand decided not to implement the complete VENUS system in the factory due to its sheer size and lacking capacity, with the rubber wrapping operation being the bottleneck. Different bead sizes are supported; however, the gripper jaws need to be changed manually in case of a size change. Additionally, the industrial robots that are currently being used are from ABB, which is not an approved Michelin supplier.

A part of the complete VENUS system that should be used in the design is the specially developed stearate coating unit. This unit uses an electrostatic charge to apply the stearate powder to the bead. Since Zinc stearate is an explosion hazard, this unit comes with an ATEX certified dust collection and filtration system. The stearate coating unit can be seen in figure 7. A coating cycle in the VENUS stearate unit takes four seconds and can coat two beads simultaneously. The beads are spaced 130 mm apart.

Figure 7: VENUS stearate coating unit loaded with two 22,5-inch beads

4 Requirements

For the project to succeed, certain requirements must be met. The requirements were drawn up based on several meetings with the client and listed in table 1. The requirements are ordered according to the MoSCoW method, which indicate their importance. The letters M, S, C, and W represent the following:

M: Must have requirements. If these requirements are not met, the desired project result has not been achieved.
S: Should have requirements. These are important but not critical for the result.
C: Could have requirements. These are desired, yet not necessary.
W: Won't have requirements. These requirements are beyond the scope of this project.

Table 1: requirements

Requirements	
M	- Design is compliant with Michelin safety standards (refer to Michelin wikiME). - Design is compliant with Michelin design standards (refer to Michelin WikiME). - Time study is based on preventive maintenance downtime that does not exceed 2%. - Time study is based on a machine breakdown of 4%. - Daily capacity is at least 11.224 beads. - Cycle time is at least ten beads per minute. - VENUS stearate coating unit, dust collector, and exhaust system is used. - The coating production process from magazine cart to TBM cart is automated. - All 12 bead types are supported by the system (see appendix A). - A maximum of two industrial robots are used in the design.
S	- Industrial robot is limited to the brands Yaskawa or Fanuc. - Daily setup time is not more than 1 hour. - Loading station supports existing magazine cart. - Coated beads are automatically placed on existing TBM cart. - Production cell can run 23 hours at seven days a week (excluding maintenance). - Total cost of production cell does not exceed 18.500.000 THB (≈550.000 EUR). - Final production cell fits within allocated factory space. - EOAT detects whether a bead is present after picking it up. - The EOAT can grip all 12 bead types without the need for a tool change or manual readjustment. - The bead is securely hold in the event of a power failure. - Production cell process state is indicated by a light tower.
C	- Product identification using existing barcode tags. - Computer vision system to counter variability in output cart height. - Direct unloading from bead-shop cart.
W	- System is implemented and tested. - System can detect bead indicator arrow and adjust orientation accordingly.

5 System functions and solutions

The main function of the system is to coat a bead with Zinc stearate from input to output batch, magazine cart and TBM cart respectively. This chapter describes the specific system functions as well as the possible solutions for each function.

5.1 System functions

The main function consist of three sub-functions (figure 8), which in turn consist of auxiliary functions (figure 9). The process starts off at the loading of uncoated beads. The loading function comprises all steps needed for a bead to go from the input batch to the VENUS coating unit. The same applies to the unloading function, although now from the VENUS coating unit to the output batch. The bead coating function is not discussed, since it is a self-contained system. Parallel to this is the monitor safety function, which encompasses everything to ensure safe operation at all times.

The load bead function starts with the input batch being transported and buffered so the robot can access the batch. The system checks whether a bead is present and picks it up. Then, the beads are moved from the input batch and placed in the VENUS coating unit.

The unloading function detects if the beads are present in the VENUS coating unit after the coating cycle. After the bead is picked up, the height of the beams of the TBM cart (where the bead is placed on) is determined on the TBM cart. The beads are placed and buffered onto the TBM cart until it is full and changed for a new empty cart.

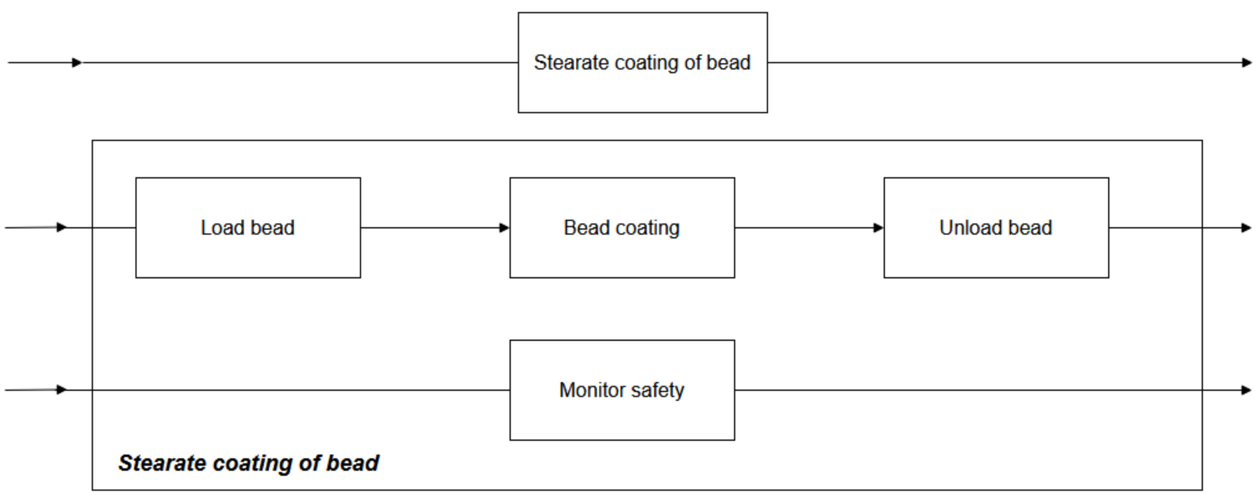

Figure 8: main and sub functions

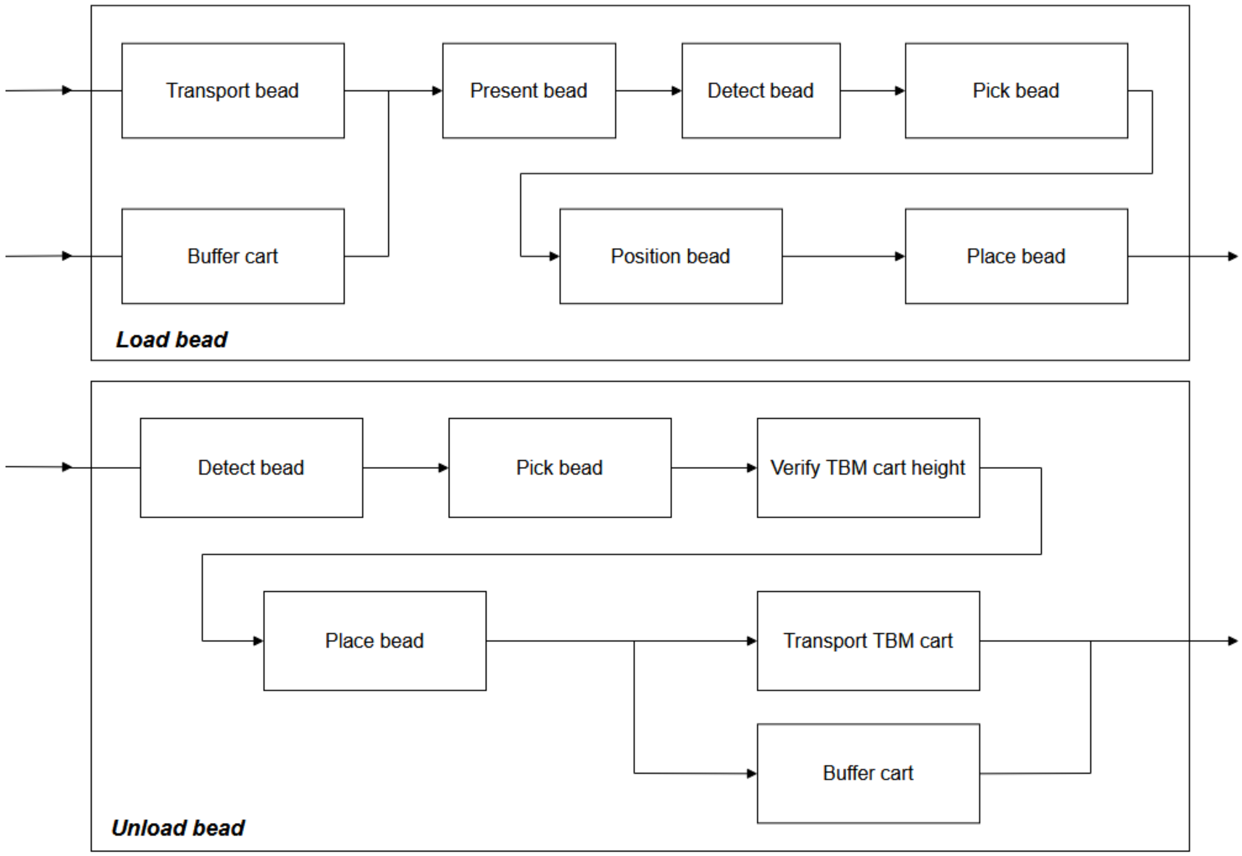

Figure 9: auxiliary functions

5.2 Function-specific solutions

Potential solutions on how to fulfil each system function are listed in appendix C. There are also solutions listed that make the entire magazine cart redundant, thus omitting the changeover step from bead-shop cart to magazine cart. The next chapter will discuss the selected concept.

6 Concepts and time studies

A total of five concepts have been compiled according to the functions and corresponding solutions. The assessment criterion for the best concept is the daily capacity figure. The daily capacity of each concept has been determined by means of a time study. The times from the time studies are partly estimates and partly based on the existing VENUS machine. The performance of the most suitable concept was then validated using ROBOGUIDE robot simulation software and approved by the client. Only the chosen concept is discussed in this chapter. For other concepts and a morphological overview see appendix D and E, respectively.

The time study for each concept is based on the project's requirement values from table 2, additionally see chapter 3.

Table 2: performance requirements

Requirement	Max. daily time [s]
Preventive maintenance (2%)	1.728
Breakdown (4%)	3.456
Setup	3.600

6.1 Chosen concept: description

The chosen concept is elaborated in this chapter and its components can be seen in table 3. A sketch representation of the concept can be seen in figure 10.

Transportation of the carts to and from the robot is done using a chain conveyor system. The carts sit on a dual track chain suitable for carrying and conveying heavy loads. Loads on a chain conveyor can be moved sideways using a transfer system, which is another dual track conveyor placed perpendicular. In comparison to a towline or overhanging conveyor, which requires an arched track to steer or turn the carts, the chain conveyor solution can be more compact and thus resulting in a lower factory footprint. The carts are aligned with the use of guideways and pushers, so the carts are always in the same position relative to the robot. The conveyor systems have four cart positions: two full carts, and two empty carts. This results in a net buffer size of two carts. Reason for a buffer size of two is that the system can run for some time without operator interference whilst still maintaining a small footprint. It was discussed with the client that a buffer size of more than two carts was not preferred.

The beads are stored in the magazine cart with the default batch size of 120 beads. The 16-inch TPFR sized beads (with batches of 200 beads) are split into a batch of 120 beads and a batch of 80 beads. The reason to use the magazine cart is that it can be easily filled by the operator, ensures equal and proper bead alignment, can hold a complete batch of beads (except the 16-inch TPFR), and the beads can be easily accessed by the robot.

The beads will be gripped using a friction gripper. The 9,5 mm spacing between beads placed in the magazine cart, plus the requirement to pick different sized beads make this gripping method the most suitable but also keeps the mechanism simple. The friction gripper also ensures the beads to align with the gripping jaws and to prevent the bead to swing during robot movements. Two beads can be picked at the same time and adjusted to match the slots in the VENUS coating unit using two independent gripping units with a sliding mechanism.

The robot will monitor whether a bead is present between gripping jaws using a photoelectric sensor. Using a sensor with an adjustable sensing range, the different positions of the beads (depending on the size) can be accounted for. A proximity sensor has only a limited sensing range.

This concept uses two robots: a robot that handles the uncoated beads, and a robot that handles the coated beads. Both robots use the same EOAT to reduce cost and maintenance difficulty. The reason two robots are used is because a single robot arm is not fast enough to keep up with the coating machine. This will be discussed in the next chapter. A robot arm is also much more flexible compared to a custom-made pick and place unit and can be easily reprogrammed.

To counter slight variations in the height of the TBM carts, the beads are released slightly above the beams on which they will be placed. After the beads are dropped, they are pushed together by the robot.

The complete cell is surrounded by a safety fence to prevent people from entering the cell during robot operation and kitted with several emergency stop buttons. Cart loading and unloading stations are equipped with light curtains to stop certain parts of the system in case of human presence. Maintenance access doors are locked during normal operation using door interlock systems.

Table 3: solutions per function for chosen concept

Function	**Solution**
Transport bead	Chain conveyor system
Buffering	2 carts in conveyor
Present bead	Direct from magazine cart
Detect bead	Photoelectric sensor on EOAT
Pick bead	Friction grip
Place bead	Dual robot
Position	Adjust by actuator
Place on cart	Pusher on robot
Verify cart height	Pre-programmed height offset
Transport TBM cart	Custom magazine cart conveyor
Buffering TBM carts	2 carts in conveyor
Monitor Safety	Fence, light curtains, e-stop, door interlock

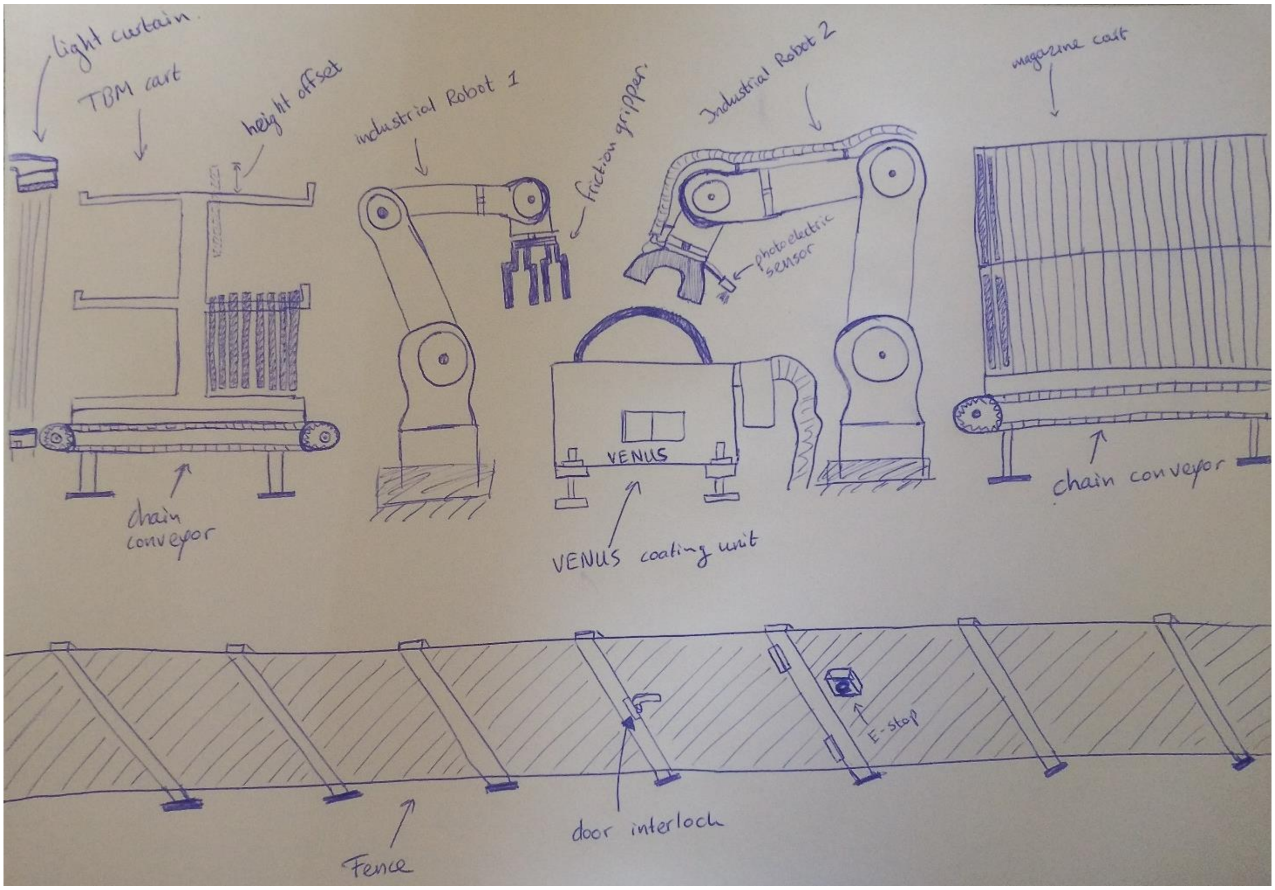

Figure 10: sketch of chosen concept

6.2 Chosen concept: time study

The cycle time per two beads is calculated based on different tasks, some of which can be executed in parallel, for example: new beads can be picked from the magazine cart whilst the stearate coating task is in process. The cycle time is calculated and visualised using Simogram (an Excel macro used within Michelin). The Simogram and corresponding tasks can be seen figure 11 and table 4, respectively.

Table 4: Simogram tasks

II	Stearate coating
III	Pick uncoated beads
IV	Place new beads
V	Pick coated tringles
VI	Move to unload station and unload

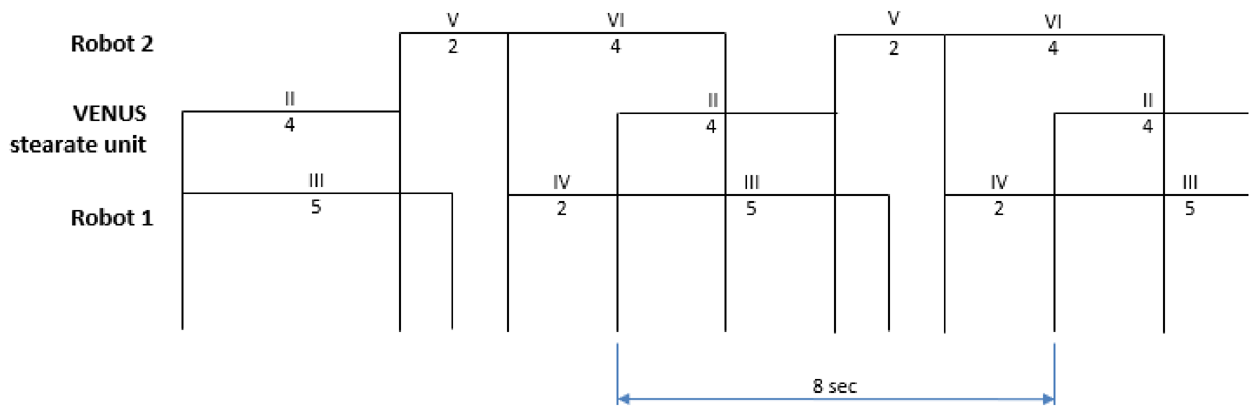

Figure 11: Simogram of cycle time per two beads

The cycle time study is validated using a production cycle simulation in ROBOGUIDE. This simulation software uses realistic robot motions and timings. The coating machine is included and set to four seconds cycle time. Two Fanuc M-71-iC/50 robots are used for this simulation. The payload of each robot is also set to a standard of 40 kg and set to 45 kg when the parts are picked up. An overview of the simulation environment can be seen in figure 12.

The simulation timing results can be seen in figure 13. The total cycle time of 30 beads is 140,5 seconds. Since two beads are processed simultaneously, the total time is divided by 15, giving a cycle time per two beads of approximately 9 seconds. It should be noted that the simulation is not optimized. The robot motion trajectories and delay times can be improved. The cycle time profile seen in figure 13 shows the simulation time of the robot that takes the beads out of the magazine cart. This robot is the master of the simulation and runs a parallel program thread to simulate the cycle time of the coating process (this is the reason the application time is 0 seconds). The simulation stops after the slave robot finishes storing the last bead on the TBM cart.

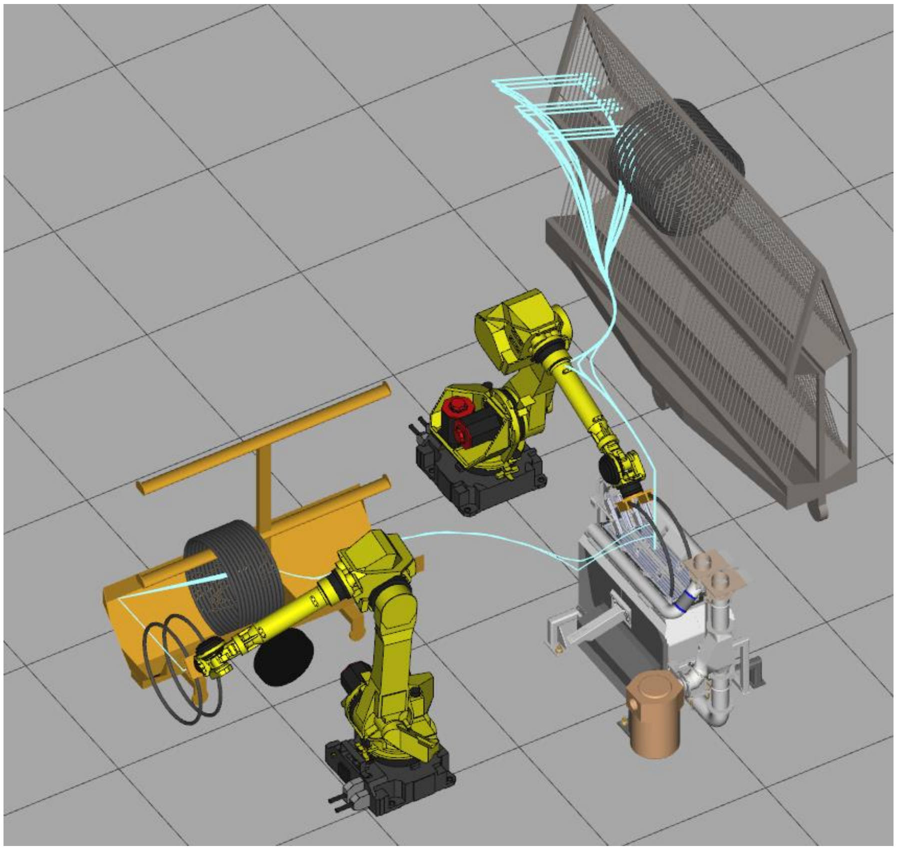

Figure 12: overview cycle time simulation in ROBOGUIDE

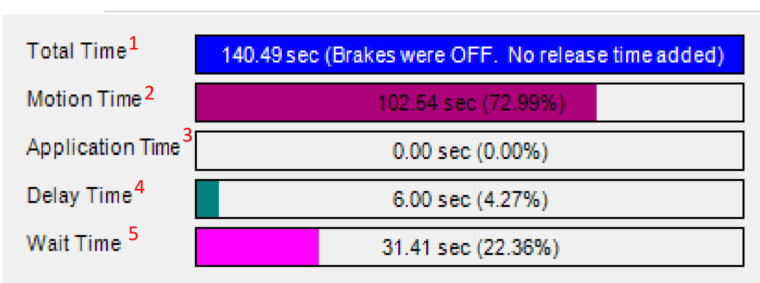

Figure 13: cycle time profile of a 30 bead simulation in ROBOGUIDE

1) The total time the simulation took to finish the program.
2) Total time the master robot was in motion.
3) Application time is simulated in a parallel program thread and is thus not shown. This should be 4 seconds times 30 beads, which is 120 seconds.
4) Preprogramed wait time for the EOAT to finish actuating.
5) Total time the master robot had to wait for the coating process to finish.

The cycle time per two beads is used to calculate the theoretical daily capacity of the system. The calculations are made for a batch of 120 beads per cart, since a batch of 80 beads (in case of the 16-inch TPFR) is not common. There are 60 seconds allocated for automatic cart changeovers. The estimated daily capacity of 14.083 exceeds the required capacity of 11.224 beads by 25%. The estimated capacity can be seen in table 5. For an explanation on how the calculations were made, refer to appendix F.

Table 5: capacity calculation figures

Time per 2 beads	9	seconds
Beads per cart	120	
Cart change over time	60	seconds
Cart buffer size	2	
Shifts per day	3	
Net time per cart	600	seconds
Beads per minute	12,0	
Beads per hour	720	
Buffer-break time loss[1]	7.200	seconds
Additional losses[2]	8.784	seconds
Total time lost	15.984	seconds
Potential beads per day	17.280	
Net beads per day	**14.083**	

1) This is the time lost due to the cart buffer not supporting 1 hour of operator lunch break.

2) The sum of the breakdown, maintenance and setup times.

The concept meets the capacity requirements and is supported by an initial cycle time simulation. The client has agreed to this concept and it is worked out in detail in the following chapters. Additionally, the final design is validated using an optimized cycle time simulation.

7 System architecture

This chapter describes both the physical components that make up the system and the behavior of the system, using the systems modeling language SysML. The production cell its physical parts are describes in a block definition diagram (BDD). The overall behavior of the system is described in a sequence diagram (SD). The behavior of each sub system is described in a state machine diagram (STM).

7.1 Block definition diagram (BDD)

The system consists of several different sub-systems, denoted as blocks in the BDD. The carts where the beads are (or will be) stored on and the VENUS coating system both have an aggregation relationship since they are independent of the system. The rest of the parts have a composite relationship because they form the system. A compact version of the BDD can be seen in figure 14. The detailed version can be found in appendix G.

The HMI handles all interaction between operator and system. The control system handles all interaction within the system and tells the other systems when to perform a certain task. The cart conveyor system consists of all parts needed for the carts to be transported within the system. The handling robots pick and place the beads using an EOAT. The safety system consists of all the parts needed to ensure safe operation of the system.

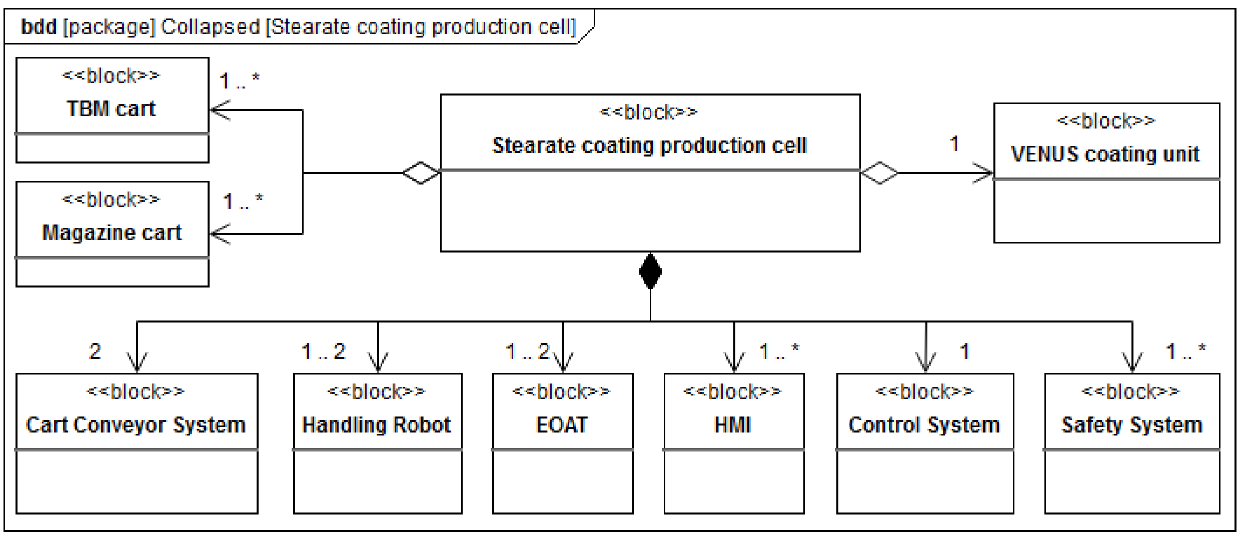

Figure 14: compact BDD of the system

7.2 Sequence diagram (SD)

The sequence diagram describes the global interaction between subsystems and when their tasks are executed. The sequence diagram can be found in appendix H.

The control system is the master of the system and gives every subsystem a certain task. A runtime sequence starts whenever the system is powered on. If a cold start (all actuators need to be recalibrated) is required, the control system commands every subsystem to do a initialize routine. In this routine the subsystems cycle the actuators and compare it to the corresponding expected sensor signals. The initializing process is done asynchronous.

Once the system is initialized the program enters a loop condition. All activities inside the boundaries of the loop box are executed until the program cycle is interrupted (because of an error, cycle stop command, etc). The control system commands the conveyor systems to make sure the expected carts are in their expected locations. If the carts are in the correct position, a pick signal is sent to the uncoated handling robot to pick and place the first beads into the stearate coating unit.

The program enters another loop, which will terminate once the number of beads in the current cart is reached. The control system then sends the robot another signal, this time only to pick two new beads. The stearate coating is started shortly after that. After the coating process is finished, the second robot receives a signal to pick the two coated beads from the stearate unit and places them on the TBM cart. It should be noted that this robot sends a reply to the master once it has removed the two finished beads from the stearate unit. This way the other robot can now place two new beads in parallel. After the two coated beads are placed on the TBM cart, this cycle will repeat.

8 Design

Now the system's architecture and requirements are compiled, the modules can be worked out in detail. This chapter will elaborate on the design decisions for each subsystem, starting with the layout of the production cell.

8.1 Production cell layout

Before the subsystems can be designed, it is important to determine the layout of the cell. The robots must be able to reach all the locations a bead can be in, but also reach the coating machine. There needs to be enough clearance around the robot to prevent a coalition during movement operations. Furthermore, the VENUS stearate powder storage unit needs to be placed close to the coating unit to prevent pressure drop in the powder supply lines. There needs to be clearance around the VENUS dust filtration unit for safety and maintenance purposes. Additionally, the new design must fit within the allocated factory space. The layout was chosen by the client based on various concepts. All considered layout concepts can be found in appendix I.

Layout concept 2 is chosen by the client because this layout has the best cart flow and overall layout. The magazine carts can be driven straight into the system after they are loaded with beads, this is preferred since the magazine carts are difficult to steer (especially when fully loaded). The TBM carts are loaded and unloaded from the side of the system. After the production cell is installed and fully operational, the manual area will be used as a TBM cart storage area. The VENUS powder unit can be accessed from the front of the machine. The operator desk is also located in front of the machine and has a clear view of the production area. The filtration unit blower motor is placed at the back of the system to reduce operator noise exposure. The cart conveyors, robot arms, robot controllers, and coating unit are enclosed with a safety fence and can be accessed through a maintenance access door on the left side of the system. The cart conveyor systems have a rectangular shape to make them as compact as possible. The system's layout can be seen from up close in figure 15.

The chosen layout is based on a robot reach of 2 m. With this reach, each robot can reach all necessary locations to move the beads from cart to coating unit, or vice versa. The reach per robot is displayed as a grey circle in figure 16.

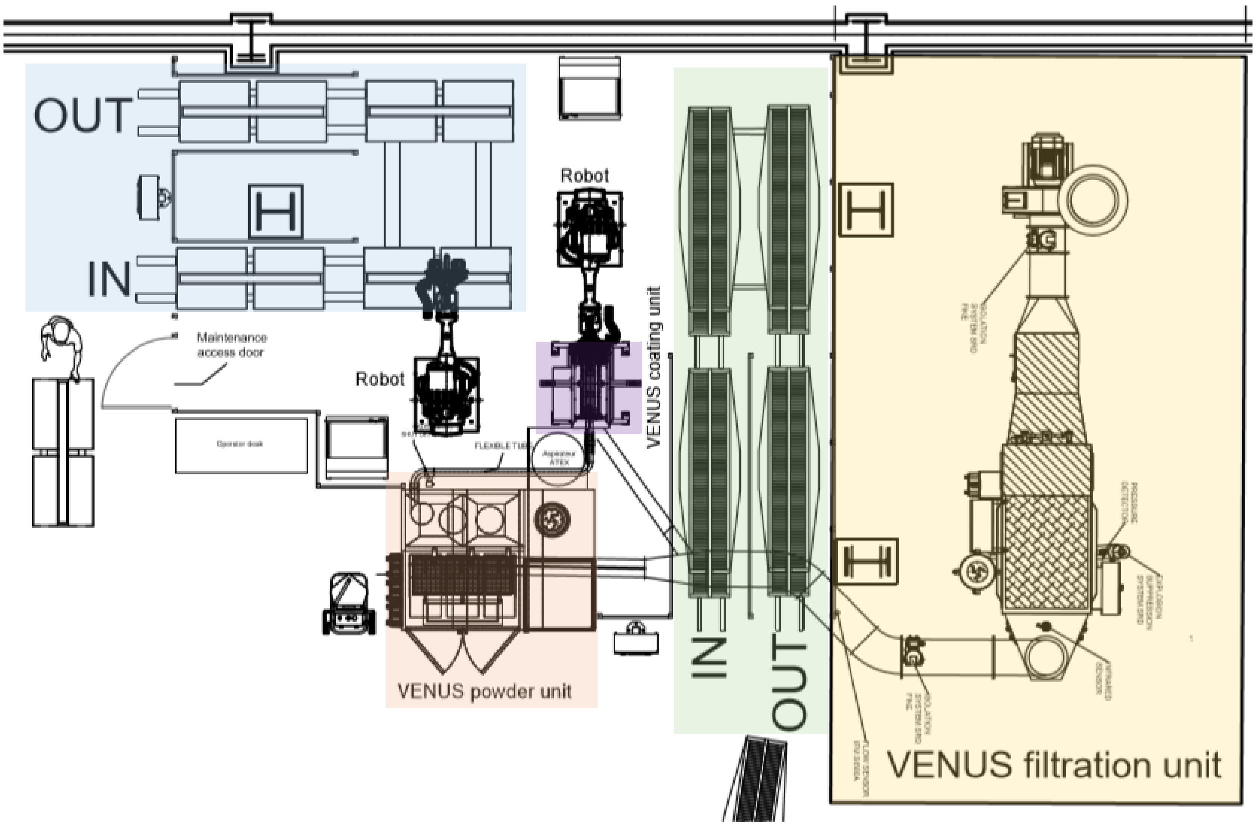

Figure 15: close-up view of layout concept 2

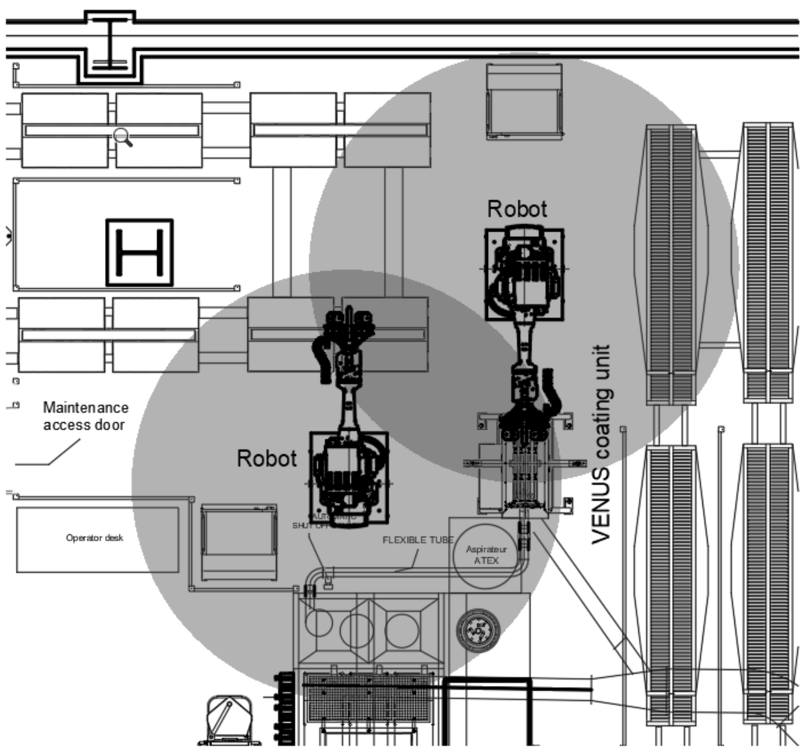

Figure 16: reach per robot, displayed as a grey circle

8.2 End of arm tool (EOAT)

To be able to pick up the different bead sizes and to account for the high accelerations that occur during robot movements, the EOAT needs a gripping mechanism that supports different bead sizes whilst still holding the beads firmly. Tool changes should be avoided to keep production procedures simple, but also to ensure the cycle time is not affected. This chapter will elaborate on the decisions that went into the design of the EOAT.

The uncoated beads are stored in the magazine cart inside slots. Each slot is 32,0 mm wide and the distance between each slot is 9,5 mm, see figure 17. A side view of how the different beads sit inside a slot can be seen in figure 18.

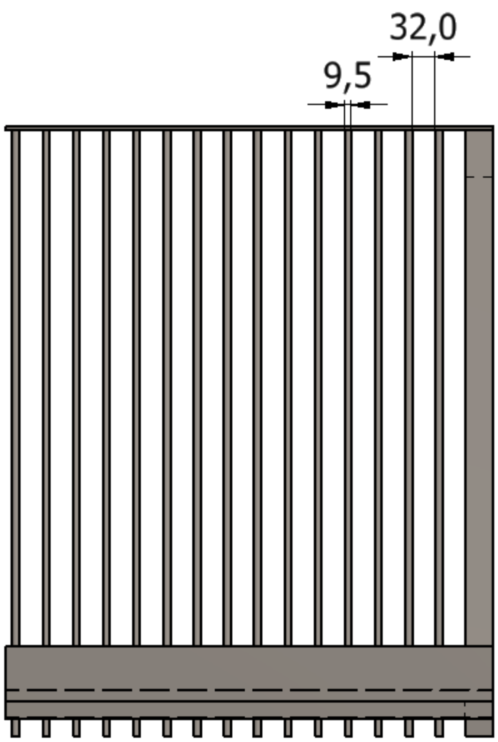

Figure 17: the slots on the magazine cart

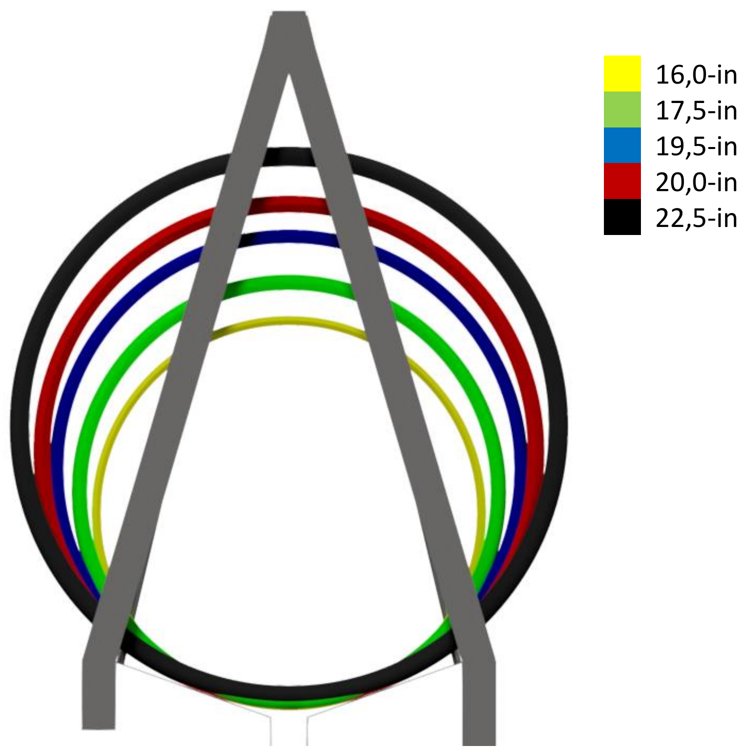

Figure 18: the position of the five major bead sizes

Because of the narrow gap between two beads and the limited amount of space on the inside of the beads, a friction grip with parallel jaws is best suited. The gripping jaws are placed so that a bead sits between them. When the jaws close, a force is applied to the bead. This force is converted into a frictional force based on the coefficient of friction between the two materials. Enough force must be applied to the bead so that the force of static friction does not exceed the force of gravity of the bead during movements. To calculate the minimum amount of gripping force needed, the maximum acceleration that applies to the bead must first be determined. This is done by analysing the robot's trajectory and acceleration profile of the cycle time simulation made in chapter 5. Using a tool called MotionPRO, it is possible to plot a graph of the robot's tool center point (TCP) velocity during the simulation. The robot is set to use 100% of its maximum acceleration. Looking at figure 19, the acceleration is calculated between the two arrows and gives a TCP acceleration of 6 m/s^2.

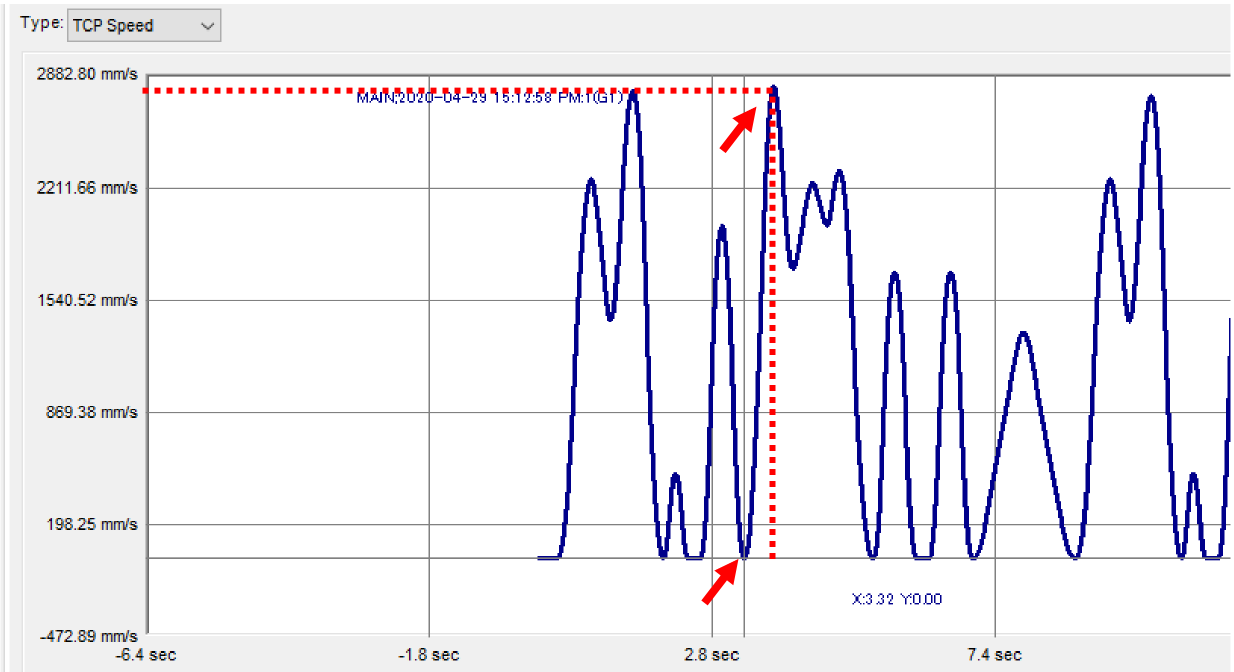

Figure 19: TCP speed graph in ROBOGUIDE MotionPro

Now the maximum acceleration is known, the required gripping force can be calculated. A gripper with bead and the associated free-body diagram are schematically shown in figure 20. Using Newton's second law and the fact that the bead will remain motionless relative to the gripping jaws, the forces that are applied on the bead can be calculated using equation 1. Note, the forces in the x-direction and the moments are omitted because they are irrelevant.

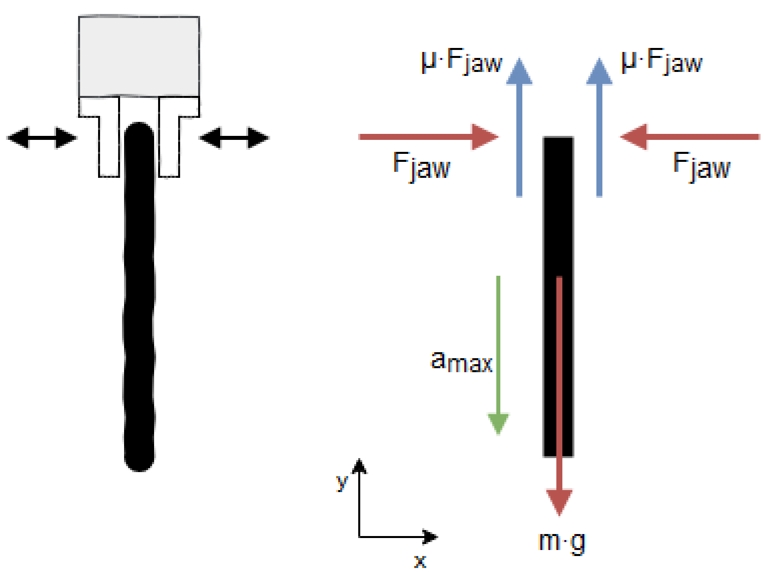

Figure 20: gripper with bead and associated free-body diagram

The static coefficient of friction of dry rubber on dry aluminium is 0,8 [1]. Using equation 1 and $\mu = 0{,}8$; $m = 2{,}6$ kg; $g = 9{,}81$ m/s^2; $a_{max} = 6$ m/s^2; SF = 4 (as recommended [3], this takes high accelerations during an emergency stop into account); gives a required force per jaw of $F_{jaw} \approx 102$ N.

$$\sum F_y : 0 = 2\mu F_{jaw} - m(g + a_{max}) \xrightarrow{yields} F_{jaw} = \frac{m(g+a_{max})}{2\mu} SF \qquad \textit{Eq. 1}$$

F_{jaw}: force per jaw [N]
m: mass of bead [kg]
g: acceleration due to gravity [m/s^2]
μ: coefficient of friction
a_{max}: max robot acceleration [m/s^2]
SF: safety factor

The designed gripping jaws that can grip the different bead sizes can be seen in figure 21, which shows the jaws on the 16 inch and 22,5 inch beads whilst they are stored in the magazine cart. As can be seen in figure 21, the EOAT location relative to the magazine cart is dependent on the bead size. The location will be adjusted by the robot using an offset waypoint based on which bead size is in the cart.

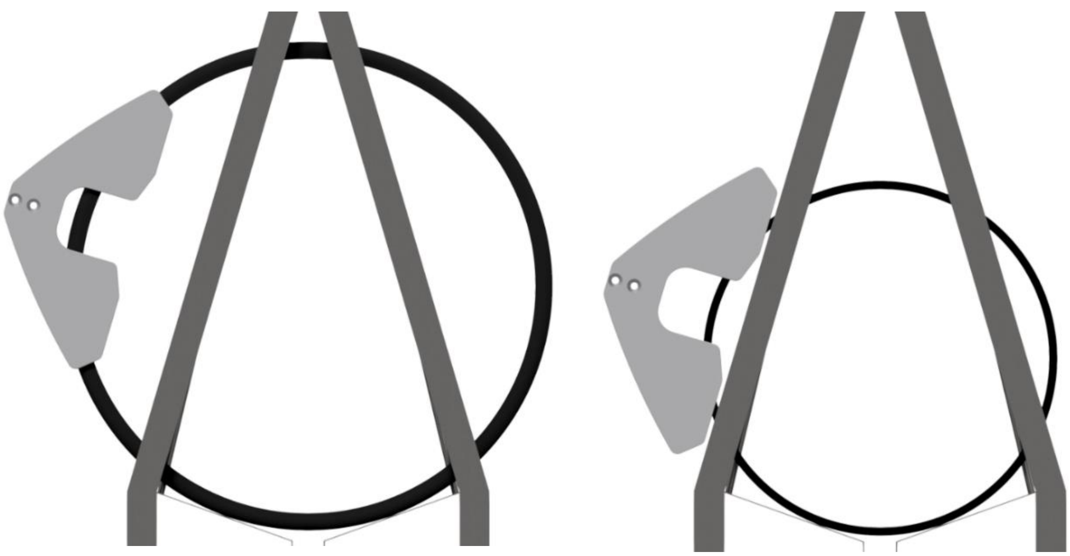

Figure 21: gripping jaw location on 22,5 inch and 16 inch beads

To pick two beads at the same time, two pairs of grippings jaws are needed. Since the space between two slots is 9,5 mm, a gripping jaw should not be thicker than this. All beads are narrower than 32 mm, which allows for a margin of error in case the beads are slightly rotated inside their slot or in case the robot has a position deviation (general industrial robot repetability is <0,1 mm). However, because the two beads are next to eachother, the gripping jaws on the inside of the EOAT cannot have a combined thickness of more than 9,5 mm.

The Festo HGPD-63-A (figure 23) pneumatic parallel gripper is used to grip the beads, details of this gripper can be found in appendix J. This gripping model has a protection rating of IP65 and is thus safe to use in an environment with potential exposure to stearate dust. It can be read from the datasheet that the selected gripper model can exert a force of 300 N per gripper jaw at a maximum distance of 140 mm with a supply pressure of 3 bar (0,3 MPa), the graph can be seen in figure 22. This model meets the minimum required force of 102 N.

Figure 23: Festo HGPD-63-A (Photo: Festo)

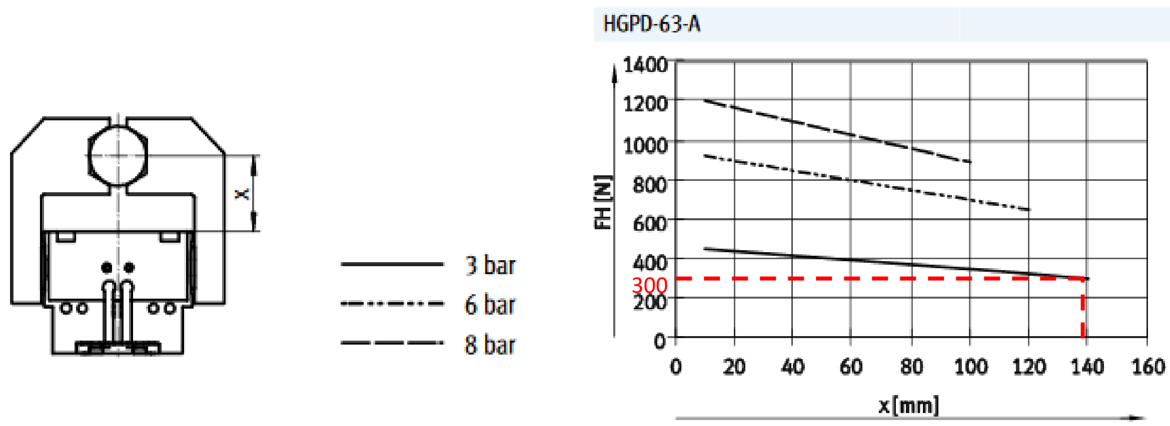

Figure 22: force per gripper jaw Festo HGPD-63-A (Illustration: Festo)

The gripper jaws are designed based on the information collected and can be seen assembled to the Festo gripper module in figure figure 24. The distance from the gripper module to the end of the gripper jaw is 120 mm, which is within the specifications of the gripper. The gripper jaws are made from aluminium 6061 T6, resulting in a mass of 1,2 kg for the heaviest gripper jaw. According to the

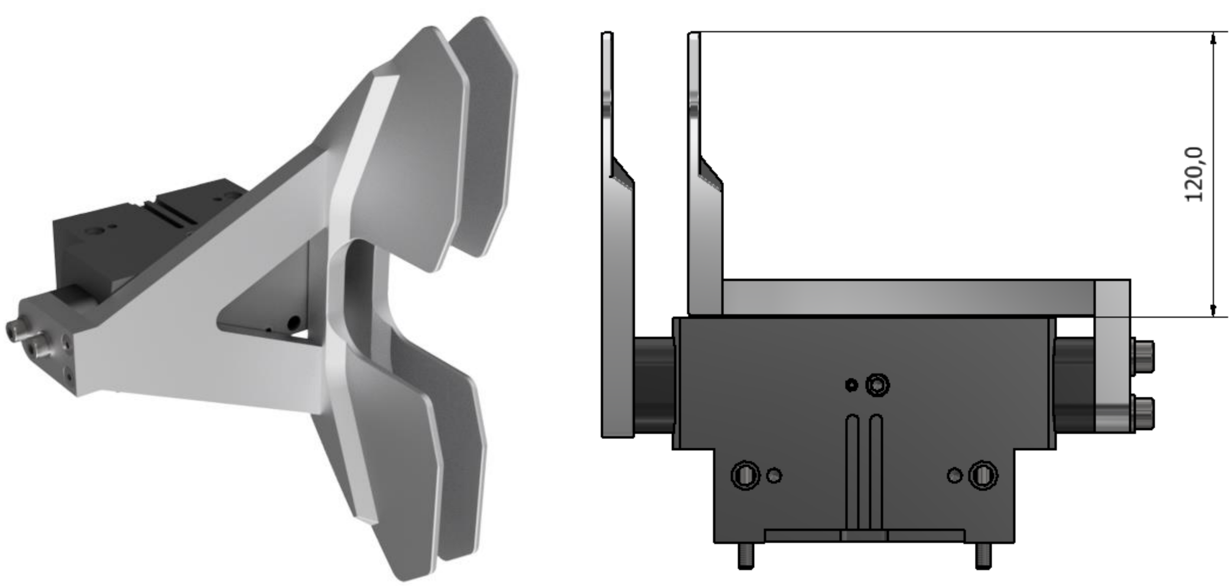

Figure 24: gripper jaw assembly

datasheet, the HGPD-63-A has a maximum load per external gripper finger of 1,34 kg. The gripper heaviest gripper jaw is therefore within specifications.

A FEA has been performed to check whether the gripper jaws are strong and stiff enough. Autodesk Nastran was used for this. The details of the complete analysis can be seen in appendix K. The analysis gives a maximum Von Mises stress of 4,18 MPa and a maximum displacement of 0,016 mm. The maximum occurring stress is lower than the fatigue limit of 75 MPa, which can be seen in the s-n curve of aluminium 6061 T6 [2] in figure 25. Because the stress is lower than the fatigue limit, the gripper jaws will have a theoretical infinite life. A fatigue analysis is therefore omitted.

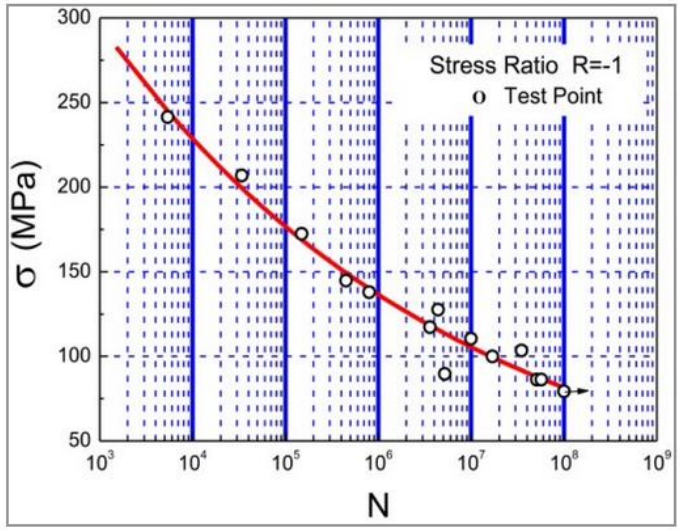

Figure 25: s-n curve for aluminium 6061-T6 (Graph: Shi Bai)

The complete EOAT assembly can be seen in figure 26. The Festo DFM-40-100-B-P-A-GF (appendix L) guided drive is used to extent the two beads after they are picked up to match the slots of the coating machine. The guided drive is pushed against a stopper which can be adjusted to finetune the extended position, seen in figure 28. A top view of the retracted and extended positions of the EOAT can be seen in figure 27.

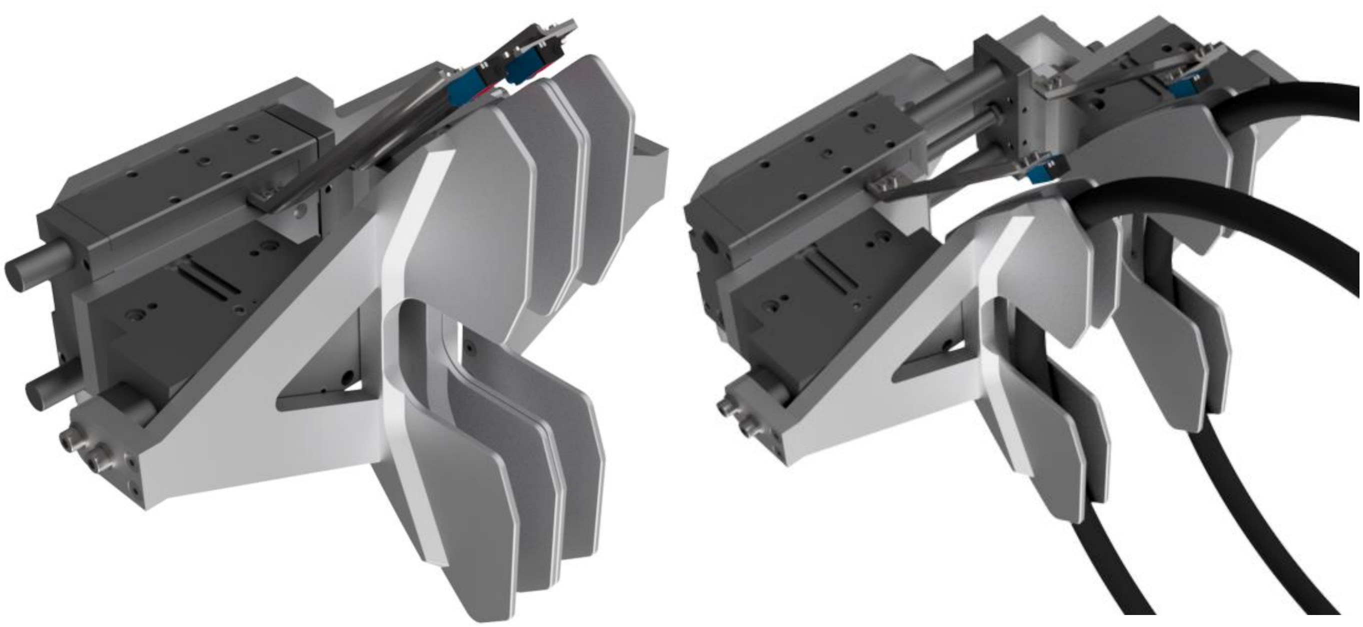

Figure 26: (left) EOAT empty and retracted; (right) extended with beads

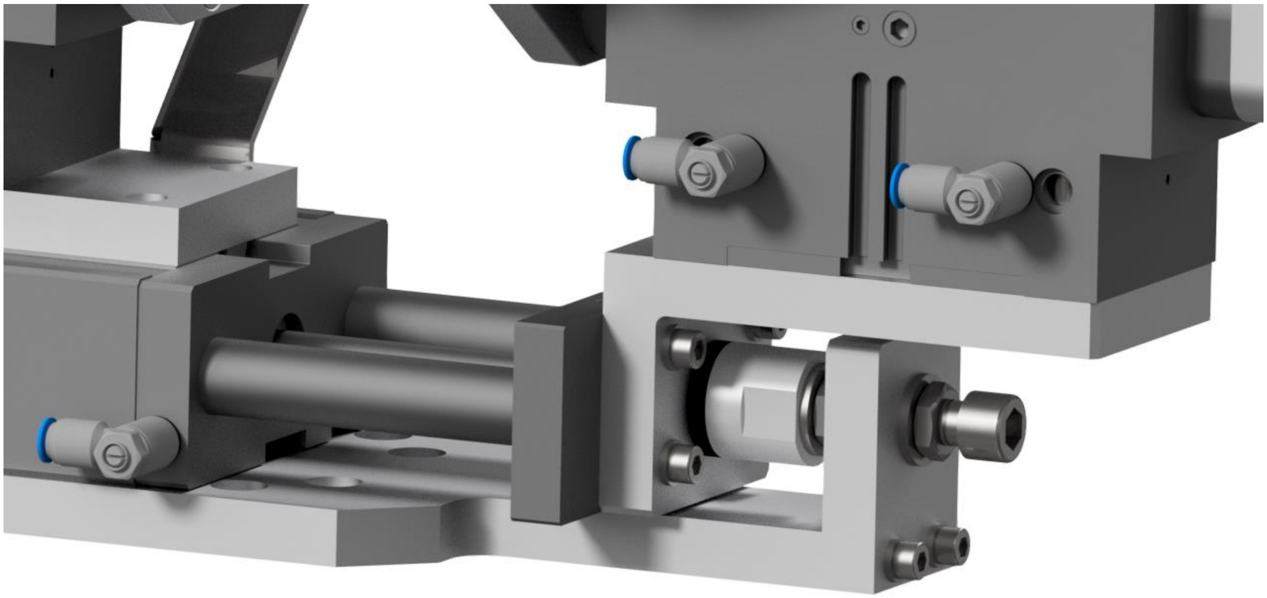

Figure 28: guided drive adjustable stopper

Figure 27: (left) EOAT retracted; (right) EOAT extended

A photoelectric sensor is used to detect whether a bead is present in the gripper, seen in figure 29. This sensor is of the type Sick WTB4-3P2261 and has a minimum detection range of 4 mm. The maximum detection range can be set using a potentiometer, see figure 30 for details. The distance between the sensor and the 22,5-inch bead once picked is approximately 15 mm, while the 16-inch bead is approximately 70 mm from the sensor when gripped.

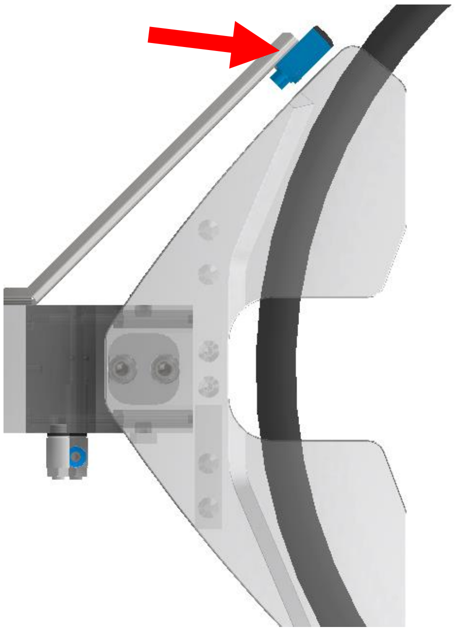

Figure 29: bead detection sensor

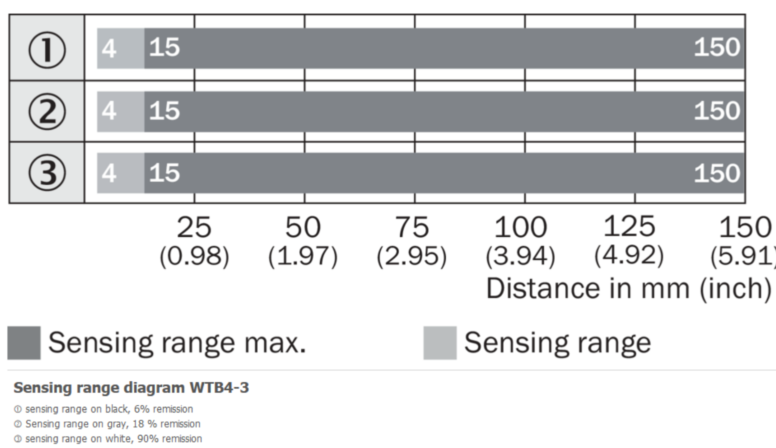

Figure 30: Sick WTB4-3P2261 sensing range (Graph: Sick)

To check if an actuator has reached its required position, proximity sensors are used. The Festo SMT-8G-PS-24V-E-03Q-M8D is used to monitor the gripper actuators. To monitor the positions of the extension cylinder, the Festo SMT-8M-A-PS-24V-E-0.3-M8D is used.

The pneumatic diagram of the EOAT can be found in appendix N. The exhaust ports (depending on the direction of actuation) use a throttle valve to adjust the speed at which the actuators are extended or retracted. To ensure the beads are held between jaws in case of a power or pneumatic failure, a piloted check valve is used. This valve blocks the air channel to the gripper if the air pressure drops, keeping the gripper in position. An important part of using pneumatic energy in automation is to choose the right tubing to transport the pressurized air. Because the robot is constantly in motion, the tubes that run to the EOAT are constantly under stress. The Festo PUN-CM tubing is suitable for energy chains in applications with high cycle rates. Furthermore, this tubing is antistatic to prevent stearate dust from sticking to the tube, which can create an explosion hazard. The corresponding Festo NPQM push-in fittings are be used.

During simulations it turned out that the robot had trouble picking up beads that are in the middle of the cart. This was due to a phenomenon called wrist singularity. This singularity happens when the 4th and 6th axis of the robot line up with each other. This can cause these joints to try and spin 180 degrees instantaneously [4], see figure 31 for a schematic illustration. This resulted in an error during runtime when the robot was approaching the center of the magazine cart. Furthermore, the axis of the robot's wrist became quite hot according to the simulation software.

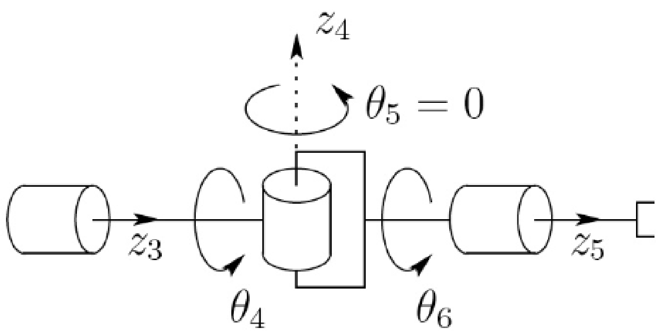

Figure 31: wrist singularity when vector z3 is parallel to vector z5

The wrist singularity is prevented by placing the EOAT at an angle of 45 degrees to the robot tool mount. Further simulations showed that this solved the singularity and prevented the axis from running hot. The EOAT with the angular offset can be seen in figure 32.

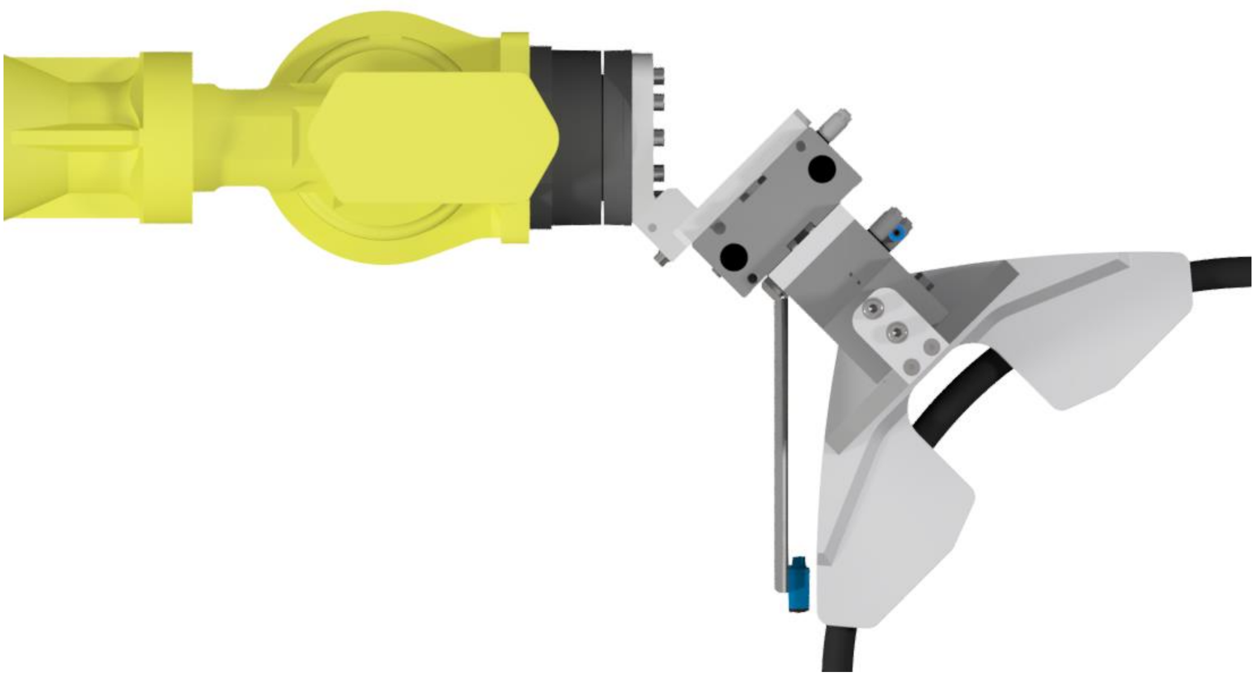

Figure 32: EOAT with a 45 degrees angular offset to prevent wrist singularity

The weight of the complete EOAT including two 22,5-inch beads is 20,6 kg.

8.3 Handling robot choice

Two industrial robots are used to bring the beads from the magazine cart to the stearate coating unit and from the coating unit to the TBM cart. An industrial robot is selected in this chapter. According to Michelin guidelines, only Fanuc or Yaskawa robots can be used.

During the initial cycle time simulation, it was determined that the preferred reach of the robot is 2 m. With this reach, the uncoated bead handling robot can pick every bead in the magazine cart and place it in the stearate coating unit. The coated bead handling robot is also able to reach the beads in the stearate coating unit and can reach all the bead positions on the TBM cart.

A comparison of the considered industrial robots can be found in table 6. Initially the Fanuc M-710iC/50 was chosen to be used in the production cell. During robot simulations, however, it turned out that this robot did not have enough range. Instead the Fanuc M-710iC/45M is selected to be used in the production cell. This robot has a reach of over 2,6 meters and a maximum payload of 45 kg. Due to the increased reach, both robots can be mounted directly on the ground, making a pedestal unnecessary.

The weight of the EOAT is 20,3 kg, which means that even with a control box and cable chain mounted on the arm there is still a large payload margin. The robot is in use almost continuously at maximum speed. A large payload margin reduces the chance of motors overheating. The reason the Fanuc robot is chosen over the Yaskawa is because the maintenance engineers and factory engineers on-site are trained to work with Fanuc robots. Additionally, there is a ROBOGUIDE license already available to program the robot or in case offline troubleshooting is required.

Specifications and work envelope of the Fanuc M-710iC/45M can be found in appendix O.

Table 6: comparison table industrial robots

Brand	**Type**	**Horizontal reach [mm]**	**Payload [kg]**	**Repeatability ± [mm]**	**Delivery time**	**Price [THB]**
Fanuc	M-20iA/35M	1.813	35	0,03	17 weeks	1.350.000
Fanuc	M-20iA/35S	1.445	35	0,02	17 weeks	1.350.000
Fanuc	M-710iC/45M	2.606	45	0,06	17 weeks	1.600.000
Fanuc	M-710iC/50	2.050	50	0,03	17 weeks	1.600.000
Yaskawa	GP50	2.061	50	0,07	17 weeks	1.250.000

8.4 EOAT connectivity

The compressed air and signal cables required to control the actuators on the EOAT are supplied to the EOAT via internal air and signal cables. These internal cables run from the J1-axis to the J3-axis, this is shown in figure 33. An external air hose and signal cable then run from the J3-axis to the control box mounted on the J3-axis of the arm. The air and signal cables run from that control box to the relevant actuators on the EOAT (J6 axis).

The EOAT is controlled via the robot's EE interface, RI and RO for in and output signals. The robot will monitor the EOAT sensors and supply air pressure and inform the production cell's master control system in case there is an anomaly.

External cables that run from the control box to the EOAT are protected using an igus triflex cable jacket, see figure 34 for a visual representation of such a system. This photo is only to illustrate the cable jacket and is in no way the design choice, further elaboration of the energy chain is beyond the scope of this project.

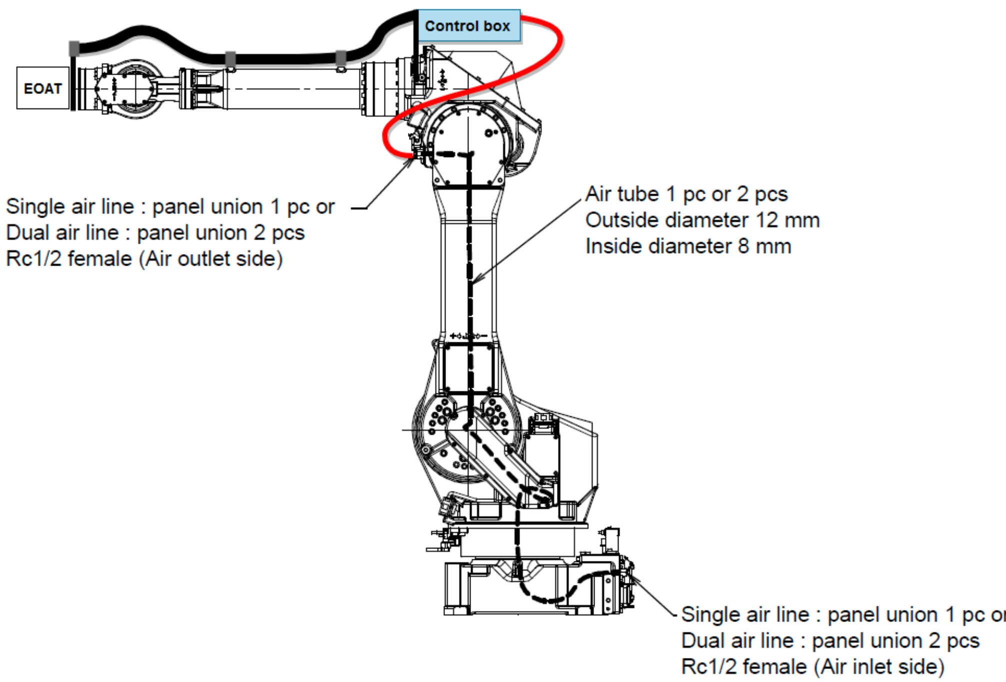

Figure 33: EOAT air and signal cable wiring (Adjusted illustration: Fanuc M-710iC Operator Manual)

Figure 34: visual representation of igus triflex cable (Photo: igus)

8.5 Cart conveyor system

Beads are supplied in magazine carts in batches of 120 beads per cart. After the coating process, the beads are placed on a TBM cart. To realize a continuous supply and removal of carts, a conveyor system is used. Because the situation has changed during the project, but also because of the complexity of such a conveyor system, no detailed design has been made. However, a description is given on how such a system might look like. It is up to the client to decide whether or not to develop this concept further.

The described conveyor system is the same in principle for both the magazine and TBM cart, the only difference is the dimensions of the conveyor. For this reason, only the conveyor system for a TBM cart is shown in figure 35. The main function of the conveyor system is to move and buffer carts to and from the robot.

The process starts with the operator who places a loaded magazine cart in the loading station. A barcode is placed on the magazine carts that contains information about the type of bead that is in the cart. This barcode comes from the bead-shop cart during the transfer. The operator scans this barcode to inform the system which bead size is in the cart. The system will instruct the robots to use a predefined offset based on the bead size, making it easy to change to a different type of bead. After the cart is placed and the barcode is scanned, the operator closes the sliding safety door and marks the station as ready by pressing a button on the operator's panel.

The loading station consists of a lift mechanism that lifts the cart from the ground. Before the cart is lifted, the cart is secured against moving using a locking mechanism. The lifting is done by means of one or more pneumatic cylinders. The cart rests on two tracks of roller bearings after it has been lifted off the ground. After the cart has been lifted, it is ready to continue the journey. This is only possible when the process station is empty. If this is the case, the cart is secured by another mechanism, the guiding mechanism. This mechanism ensures the cart stays in place whilst it is moved to the next station. The guiding mechanism is attached to a linear guide that runs parallel to the roller track. Another track of roller bearings run from the loading station to the process station and ensure that the cart is supported during transportation. The guiding mechanism is driven by a servo motor. In the chosen concept description, a chain conveyor was chosen as a solution to move the carts. After further investigation, this turned out to be an expensive and complex solution. Each station had to have its own motor and appropriate motor driver. In addition, the use of a chain belt in the loading and unloading station proved difficult due to the limited space available underneath the carts. Finally, a chain conveyor is more maintenance-intensive than a linear guide. By using a servo motor, only one motor is needed instead of two to move the cart from loading station to process station. A servo motor can be set so that, in addition to accelerating, it can also brake prematurely. This is of course also possible if a VFD is used in the case of an induction motor, but that braking action will be triggered by a sensor, which causes a deviation in the positioning with a difference in weight of a cart.

After arriving at the process station, the cart is disconnected from the guiding mechanism and clamped by another mechanism so that the cart does not move during the robot's cycle. After the robot's cycle is completed the cart can be moved to the transfer station. The cart will now be moved in the width direction. The wheels of the cart are a problem here, because they must pass through the rollers, as it were. A solution here is to use a lifting mechanism that lowers the cart slightly until it rests on the vertical roller track. If the lift mechanism then drops further below the wheels of the cart, the path of the wheels is clear, and the cart can be brought to the transfer station. The transport from process station to transfer station is again done using a guiding mechanism and servo motor.

The process from the transfer station to the unloading station is basically the same as from the loading station to the process station only reversed and will therefore not be explained further. Once at the unloading station, the cart is put back on the ground and the operator is informed that the cart can be unloaded.

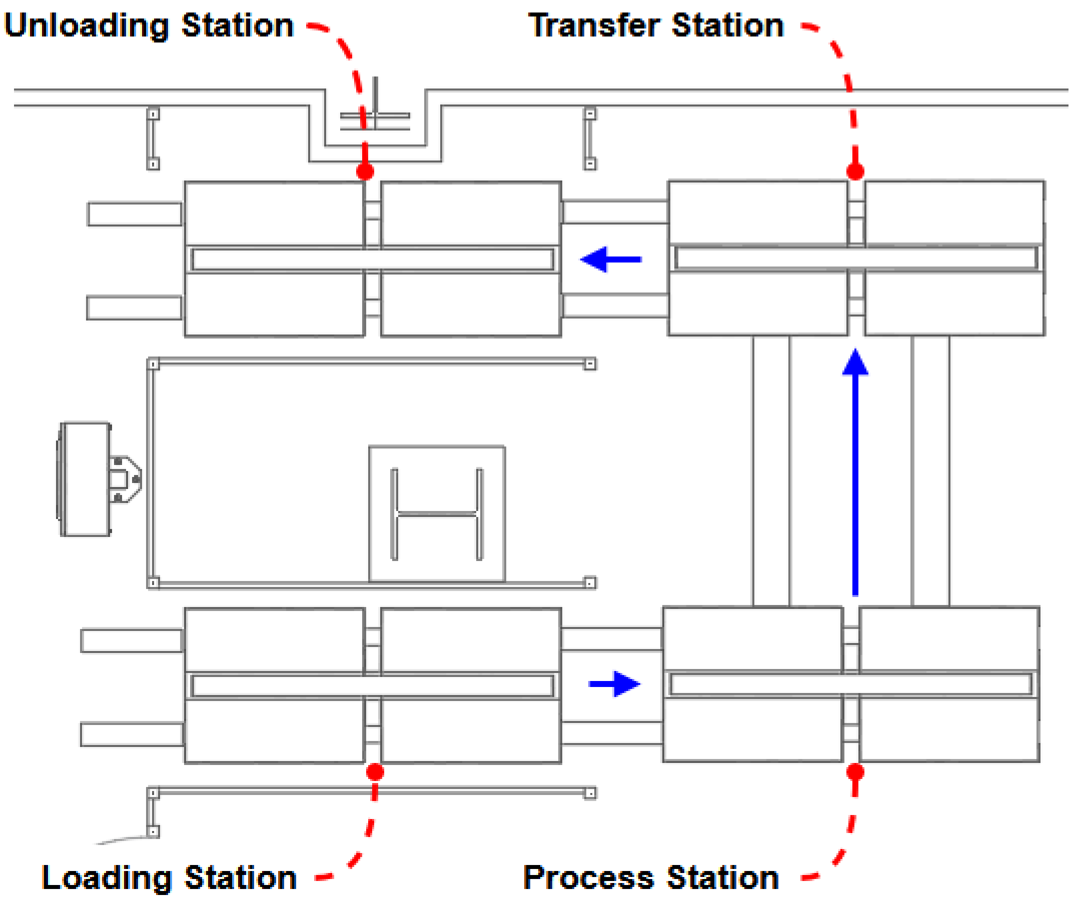

Figure 35: cart conveyor system stations

8.6 Safety measures

Safety measures are one of the most important aspects of the system. Without proper safety equipment, dangerous or even fatal accidents may occur. To prevent such accidents from happening, the production cell is equipped with various safety components. Not only is safety important during normal operation, maintenance and set-up work must also be considered. First, the risks and their severity have been assessed and are listed in table 7. Subsequently, measures were taken to mitigate these risks and are explained in the rest of this chapter.

Table 7: risk assessment

	Initial assessment				***Second assessment***		
Risk	**S**	**L**	**Risk level**	**Mitigation**	**S**	**L**	**Risk level**
Crushed in the lifting mechanism during cart loading	4	3	12	Sliding guard door with interlock system	4	1	4
Crushed in the lifting mechanism during cart unloading	4	3	12	Sliding guard door with interlock system	4	1	4
Electrical shock at operators' panel	3	3	9	Proper connections and earthed	3	1	3
Trapped between robot and object	4	2	8	Safety fence and light curtain	4	1	4
Trapped between moving conveyor	4	2	8	Safety fence and light curtain	4	1	4
Collision with robot	3	2	6	Safety fence and light curtain	3	1	3
Cut to sharp edge on operators' panel	2	3	6	Check operator box for sharp edges	2	1	2
Crushed between gripper jaws	4	1	4	Safety fence and light curtain	4	1	4
Crushed between EOAT extension mechanism	4	1	4	Safety fence and light curtain	4	1	4
Machine suddenly starts during maintenance	4	1	4	LOTOTO method and train personnel	4	1	4
Dust cloud explosion	4	1	4	Daily cleaning	4	1	4
Electrical shock in control cabinet	4	1	4	Proper connections, earthed, authorized personnel	4	1	4
Hit by a detached bead	2	1	2	Safety fence and check valve	2	1	2
Inhale stearate dust	1	1	1	Daily cleaning and training	1	1	1
Machine continues after accident happened	4	3	12	Install emergency stop buttons	4	1	4

S: Severity			**L: Likelihood**	
1	Minor	No treatment needed	1	Remote
2	Moderate	First aid treatment	2	Occasional
3	Serious	Medical treatment	3	Frequent
4	Catastrophic	Fatal or permanent injury		

The complete production cell is enclosed with a safety fence to prevent unauthorized personnel from entering. The safety fence has a height of 2,2 m, preventing even tall people from gaining access to the system. The fence is made of steel mesh, so the operator is still able to see through it. The location of the safety fence is illustrated in blue seen in figure 36. The production cell can be entered through a maintenance door located on the left side. This door is locked by default and can only be opened after an access request has been made by the operator and the system reached its secure state. Access can be requested by pushing the appropriate button on the interlock door handle. The control system makes sure the robots are done with their current movement cycle, the VENUS coating machine cycle is finished, and the conveyor systems are halted. After the complete production cell reached its secure state, only then is the maintenance access door unlocked.

The loading and unloading zones (zone 2) of the cart conveyor systems are illustrated in orange and can be seen in figure 36. These zones contain the lifting mechanism to lift the carts off the ground, and pose a risk of crushing. Pneumatic cylinders can be stopped using a 5/3 pneumatic valve, which can block all air to and from a cylinder. The entry to zone 2 is guarded with a sliding door interlock (illustrated in green). A sliding door is chosen over a light curtain because of the additional safety distance needed when using a light curtain. To access zone 2, the operator must request access in the same way as access to zone 1 is gained, although now the system will only halt operations in the corresponding zone 2.

Access from zone 2 to zone 1 is guarded by a light curtain (illustrated in green between zone 1 and 2). The light curtains have a resolution that detects anything bigger than a hand. Unauthorized entry through the light curtains will trigger an emergency system stop. To prevent the carts that are traveling on the conveyor from triggering an emergency stop, the light curtains will only monitor illegal access when the sliding door of that zone is opened.

One of the safety requirements was that the beads are held in the EOAT in the event of a power failure. This is achieved using a piloted pneumatically operated check valve. This check valve prevents airflow from exiting the gripping actuator when there is no pressurised air. See appendix N for the pneumatic diagram.

Zinc stearate dust is a potential explosion hazard. The stearate coating system has a filter and suction system from Fike. The complete VENUS coating system is safe to use according to ATEX regulations. The VENUS coating unit is considered a zone 22 (not to be confused with the previously mentioned safety zones) when implemented in this project (as per EN60079-10-2:2009). Zone 22 describes a place in which an explosive atmosphere, in the form of a cloud of combustible dust in air, is not likely to occur in normal operation but, if it does occur, will persist for a short period only [5]. The actuators used on the EOAT and chosen robots are dust-proof according to IP65 to prevent any stearate powder (in case it falls of the beads after coating) from entering the device. The VENUS coating unit and the area around it should be cleaned daily to prevent any dust build-up. This cleaning is part of the daily preventive maintenance.

To ensure safety during maintenance work, Michelin uses the so-called LOTOTO method [6]. After certain power sources are switched off, the physical switches are locked and tagged indicating the name of the person that switched the source off. Before maintenance activities can start, it is tested whether the source is turned off. This method prevents other personnel from restarting the machine. Specific systems can be controlled (e.g. move the robot) using maintenance override procedures that should only be performed by authorized and trained personnel. Maintenance override functions are outside the scope of this project.

The security measures taken greatly reduce the risk of a dangerous situation from happening. However, even with the most secure system there is always a residual risk. In order to rapidly stop a program cycle and halt all moving equipment, emergency stops buttons are placed around the production cell. By pressing one of these buttons the system will come to a complete stop and can only be reset using the appropriate procedures and trained personnel.

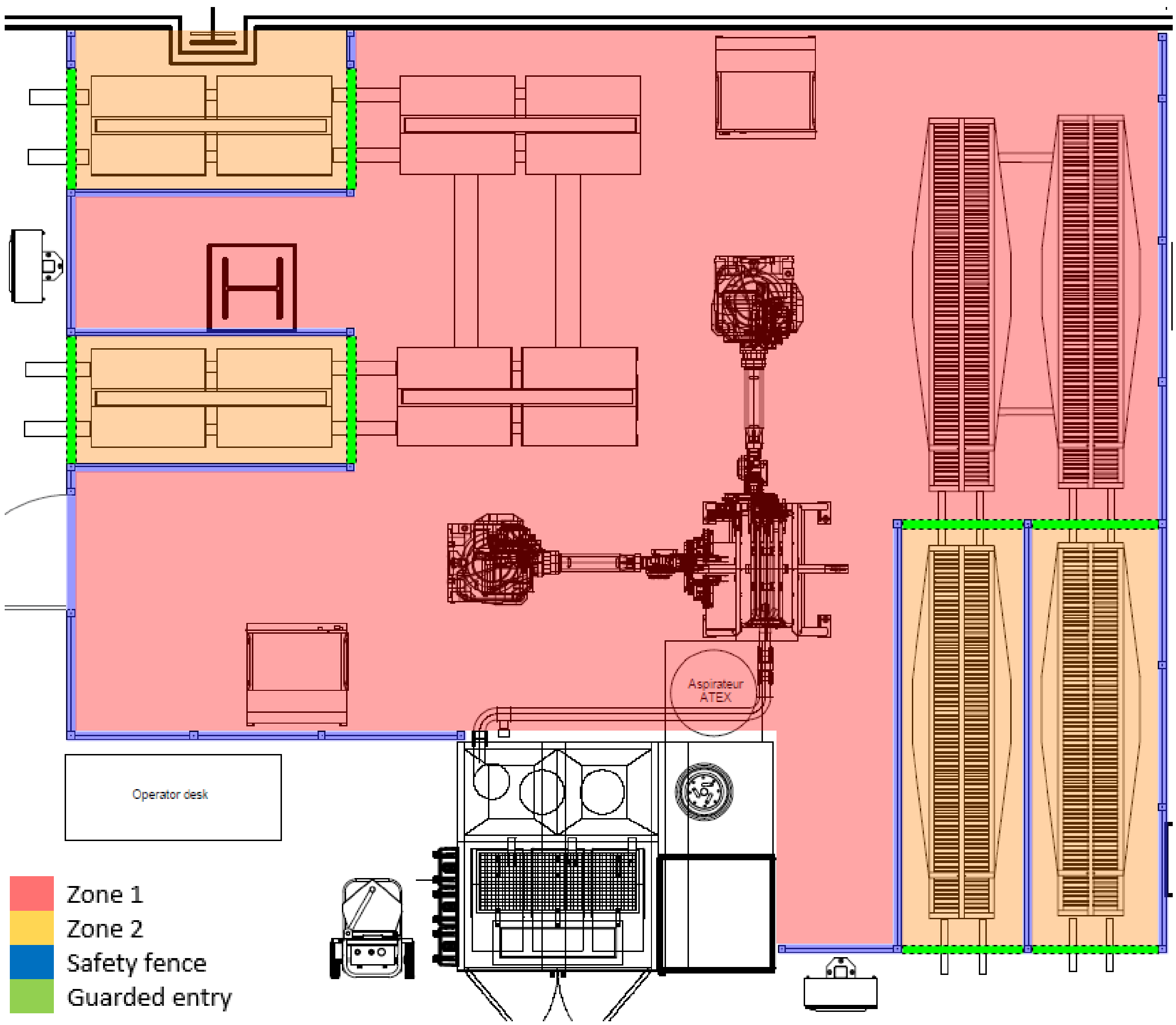

Figure 36: safety zones and elements

8.7 Complete design

Now that all components of the system have been discussed, the complete production cell is presented here. In figure 37, the production cell and labelled components in the ROBOGUIDE environment can be seen. The cart conveyor systems are represented by the positions of the carts. The factory wall is not shown (hence the gap in the fencing on one side) but closes off the rest of the cell. The fences are created using the fence generator tool in ROBOGUIDE. Furthermore, the VENUS powder station and robot controllers are shown. The complete cell is simulated in ROBOGUIDE and discussed in the next chapter.

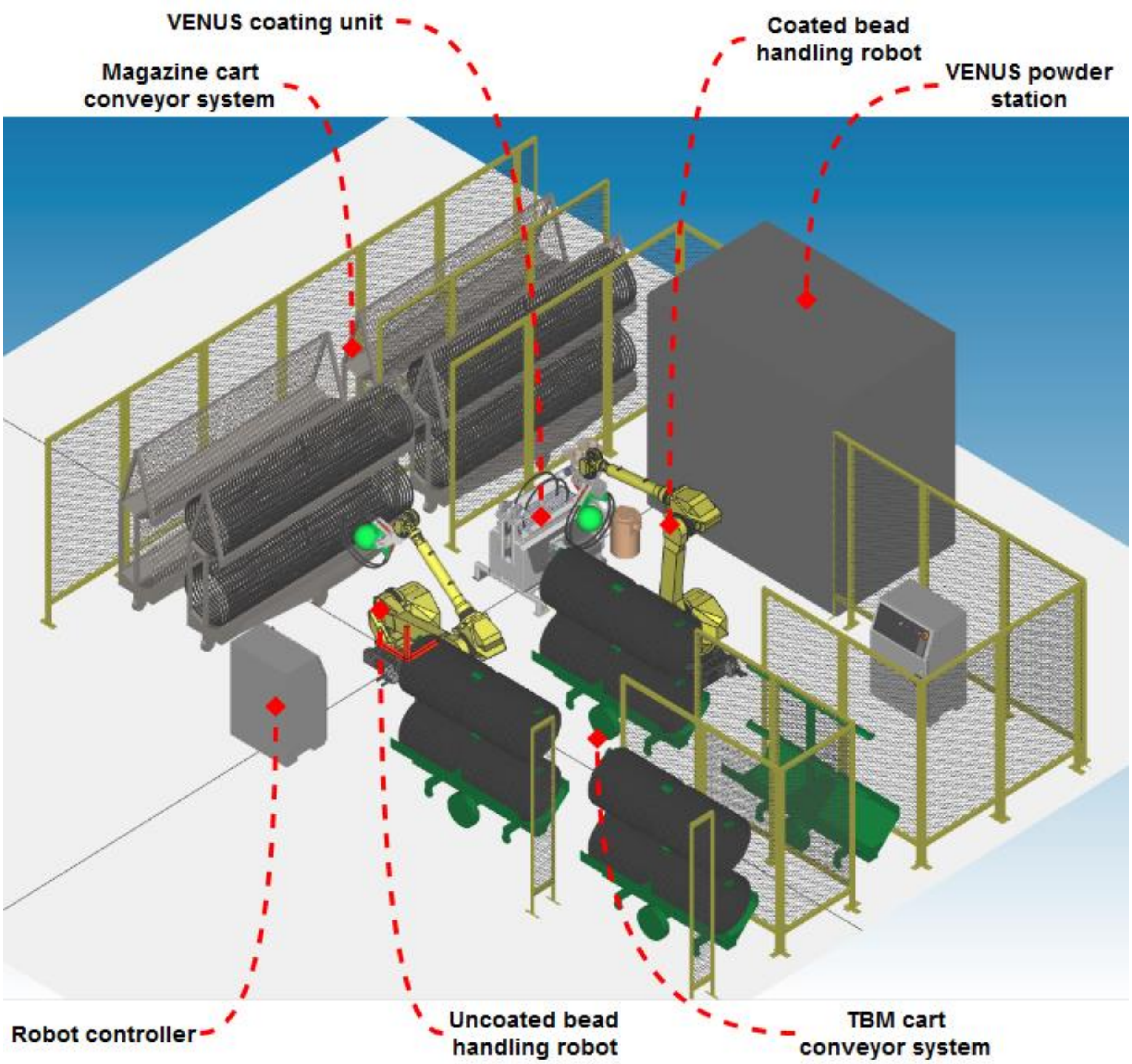

Figure 37: complete production cell in ROBOGUIDE

9 Production cycle simulation

A final simulation was performed to verify whether the robots can reach all bead locations, whether the cycle time still meets the set requirements, and if any errors occur. The mass and inertia of the EOAT are fully simulated and the actuators are controlled by the robot. The waypoints and speeds of the robots are optimized, and it is verified that no collisions occur. The coating process cycle time is set to 4 seconds and simulated using a parallel program thread on the loading robot. The robots communicate with each other to indicate when the VENUS coating unit is loaded or emptied. The simulation was set to a full cycle of 120 beads (22,5-inch). The results of the simulation can be seen in figure 38 and indicate a cycle time of 530,3 seconds. If a cart changeover time of 60 seconds is added, the total cycle time of 120 beads is approximately 590 seconds. Chapter 6 assumed 600 seconds per cart resulting in a daily capacity of 14.083 beads. It can therefore be concluded that the daily capacity requirement has been met. Furthermore, 530 seconds divided by 2 results in approximately 8,8 seconds per 2 beads, therefore also meeting the requirement.

The complete simulation is shown during the project's presentation.

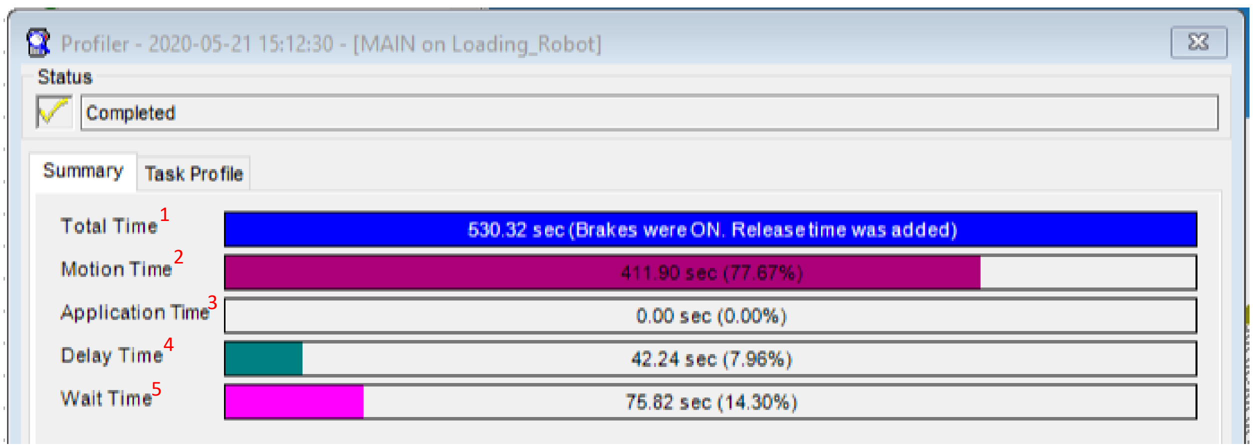

Figure 38: simulation timing profile of a batch size of 120 beads

1) The total time the simulation took to finish the program.
2) Total time the uncoated bead handling robot (master robot) was in motion.
3) Application time is simulated in a parallel program thread and is thus not shown. This should be 4 seconds times 120 beads, which is 480 seconds.
4) Preprogramed wait time for the EOAT to finish actuating.
5) Total time the master robot had to wait for the coating process to finish.

10 Prototypes and test results

Due to circumstances it was not possible to make a prototype of the EOAT. Before the situation changed (explained in chapter 1.1), a test was conducted to determine whether clamping the beads is a suitable solution. The main task was to investigate the stiffness of the beads and if the bead would swing back and forth during rapid movements. This was tested by clamping a 22,5-inch and 16-inch bead in the EOAT that is currently in use. The distance between the points at which the gripping jaws touch the beads matches the newly designed gripping jaws. The robot was programmed to move rapidly between several points, effectively simulating the movements of a full production cycle. The conclusion of the test was that the beads are stiff enough and that the designed clamping method is sufficient. Photos of the test can be seen in figure 39.

Figure 39: bead stiffness test. (left) 16-inch bead; (middle) 22,5-inch bead; (right) test setup

11 Cost of the production cell

The total cost of the complete production cell is divided into the various components of the system. Prices shown are retail prices found on the internet and any discounts that apply to Michelin have not been included. As a result, the budget has been exceeded by approximately 2,2% or 415.000 THB. Within Michelin, there is a maximum budget exceedance allowed of 5%. The indicated cost of the production cell therefore meets the set requirement. The assumption has been made that breaking down the current setup will be just as expensive as the old equipment will yield on sale. The cost overview can be seen in table 8. Installation cost can consist of engineering cost (11.911 THB per day per engineer) and/or building cost (8000 THB per day per builder).

Table 8: total cost overview

Description	Unit price [THB]	Quantity	Total [THB]	Total [EUR]
EOAT (table 9)	233.305	2	466.610	13.532
VENUS coating system	9.820.000	1	9.820.000	284.780
Fanuc M-710iC/45M	1.600.000	2	3.200.000	92.800
Safety equipment (table 10)	483.110	1	483.110	14.010
Control system (table 11)	164.511	1	164.511	4.771
Engineering cost	2.000.000	1	2.000.000	58.000
Cart conveyor system (table 12)	1.210.550	2	2.421.100	70.212
Installation cost (3 persons 15 days)	120.000	3	360.000	10.440
Grand total			**18.915.331**	**548.545**
Budget requirement			18.500.000	
Difference			*-415.331*	

Table 9: EOAT cost overview

Description	Unit price [THB]	Quantity	Total [THB]	Total [EUR]
Festo HGPD-63-A	52.000	2	104.000	3.016
Festo DFM-40-100-B-P-A-GF	10.000	1	10.000	290
Production of gripper jaws	10.000	2	20.000	580
Sick WTB4-3P2261	5.000	2	10.000	290
SMT-8G-PS-24V-E-0,3Q-M8D	1.500	2	3.000	87
SMT-8M-A-PS-24V-E-0,3-M8D	1.000	1	1.000	29
VUVG-LK14-M52-AT-G18-1R8L-S	1.500	3	4.500	131
Cable chain (ages)	10.000	1	10.000	290
Construction (1 person for 5 days)	54.555	1	54.555	1.582
Unforeseen expenses (10%)	16.250	1	16.250	471
Total			**233.305**	**6.766**

Table 10: safety cost overview

Description	Unit price [THB]	Quantity	Total [THB]	Total [EUR]
Sick Light Curtain Sender	10.000	8	80.000	2.320
Sick Light Curtain Receiver	10.000	8	80.000	2.320
Safety fence [per meter]	5.000	30	150.000	4.350
Door interlock	30.000	1	30.000	870
Construction (2 persons 5 days)	54.555	2	109.110	3.164
Unforeseen expenses (10%)	26.000	1	26.000	754
Total			**483.110**	**14.010**

Table 11: control system cost overview

Description	Unit price [THB]	Quantity	Total [THB]	Total [EUR]
PLC system	50.000	1	50.000	1.450
HMI system	25.000	1	25.000	725
Cabling, terminal, control box, etc.	20.000	1	20.000	580
Construction (1 person 5 days)	54.555	1	54.555	1.582
Unforeseen expenses (10%)	14.956	1	14.956	434
Total			**164.511**	**4.771**

Table 12: cart conveyor system cost overview

Description	Unit price [THB]	Quantity	Total [THB]	Total [EUR]
AC Geared motor and drive	50.000	3	150.000	4.350
Small pneumatic cylinder	7.500	5	37.500	1.088
Lifting pneumatic cylinder	12.000	4	48.000	1.392
Roller carriers [per meter]	3.500	50	175.000	5.075
Structural steel [per meter]	1.000	150	150.000	4.350
Sensors	1.500	50	75.000	2.175
Linear guides [per meter]	15.000	10	150.000	4.350
Production of mounting plates	75.000	1	75.000	2.175
Construction (2 persons 15 days)	120.000	2	240.000	6.960
Unforeseen expenses (10%)	110.050	1	110.050	3.191
Total			**1.210.550**	**35.106**

12 Conclusion and recommendations

To purpose of this project was to propose a new production cell design for the bead stearate coating process. The conclusion is that all requirements (except three) have been met and the assignment has therefore been successfully completed. The acceptance test of the requirements can be found in appendix P. The substantiation that the requirements have been met is as follows:

- A layout for the production cell has been designed. This layout fits within the allocated area in the factory, and thus according to the requirement. The flow of the magazine and TBM carts in and out of the production cell is separated. The current manual booth can remain in use during the installation phase of the project. When the installation is completed, this booth becomes a storage place for the TBM carts. Additionally, there is an area allocated for the operator's desk with a clear view on the production cell.
- A detailed design for the EOAT has been made, meeting all related requirements. This EOAT can pick up all bead sizes without the need for a changeover. Two beads are picked from the magazine cart simultaneously and are then automatically set to the correct distance to fit into the VENUS coating unit. The gripper jaws are designed so that the beads are aligned in a plane parallel to the gripper jaws. Beads will be detected by a sensor and held firmly to account for the high acceleration during robot movements. In addition, a pilot check valve is used to ensure that the beads are retained in the event of a power failure.
- Two Fanuc M-710iC/45M robot arm are used in the design, thus meeting the requirement, which turned out to be the most suitable robot arms. This robot has a range that makes it possible to reach all bead locations without the use of a robot pedestal. The maximum allowable payload rating and its repeatability are also enough. The current engineering personnel at Michelin also has the necessary knowledge and training to operate this type of robot.
- A proposal concept design for a cart conveyor system has been described that meets all requirements. The cart conveyor system can buffer two carts whilst maintaining a compact footprint. Cart loading and unloading can be done without the system having to stop.
- The machine safety requirements are met and consist of the following features: the production cell is enclosed by a security fence and interlock doors; the loading section of carts is secured by a sliding door and light curtains; the LOTOTO method is used to guarantee safety during maintenance work.
- The required daily capacity and cycle time is met based on a production cycle simulation in ROBOGUIDE. The simulation was also used to verify that the range of the robot is enough and that there are no collisions.
- The indicated cost of the production cell meets the set requirement.

12.1 Recommendations

The following recommendations are proposed for further development of the project:

- The current design of the EOAT is partly based on theory. A prototype of the EOAT must be made and tested to ensure it works in practice. It is also important to test whether it still works after a longer period.
- A detailed design must be made for the cart conveyor system. The concept presented in this report can be used as a guideline with the requirement that carts must be moved to the next station within 60 seconds (assumed in the time studies). It is important that it is always checked

whether the detailed conveyor design still fits within the allocated layout or whether adjustments need to be made.

- The EOAT control box and robot cabling jacket discussed in this report needs to be designed and implemented. The cabling jacket can be simulated against breakage using ROBOGUIDE.
- A complete control system, HMI, and control box must be designed. In principle, this is only possible after the conveyor system has been designed. In addition, the control system and the robot must be programmed and tested.
- It is strongly recommended that the machine safety analysis is checked and aligned with Michelin's internal safety requirements by a safety expert. This also includes proper training of personnel by an expert.

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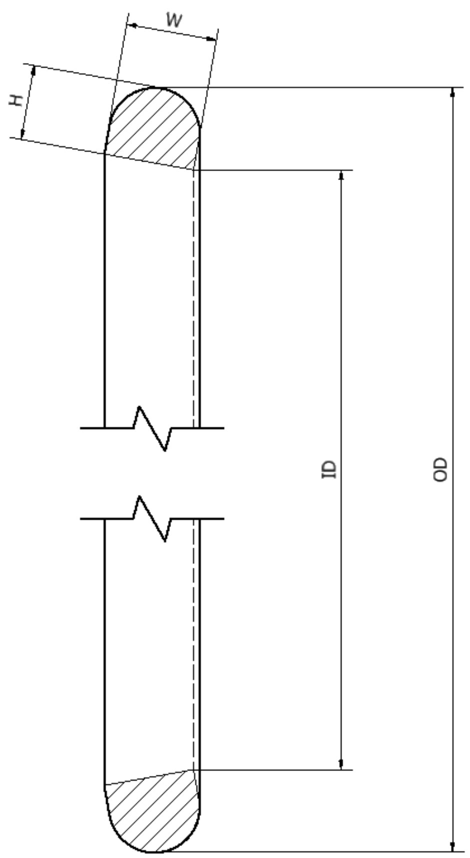
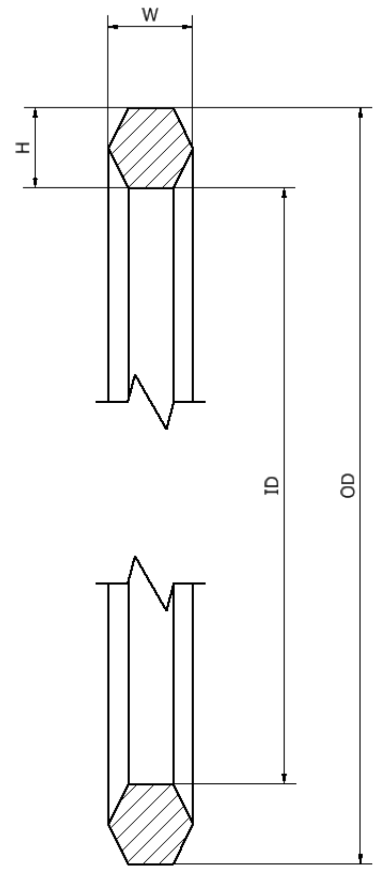
Appendix A: Bead dimensions

The list of bead sizes on which the project is based upon.

TFRC



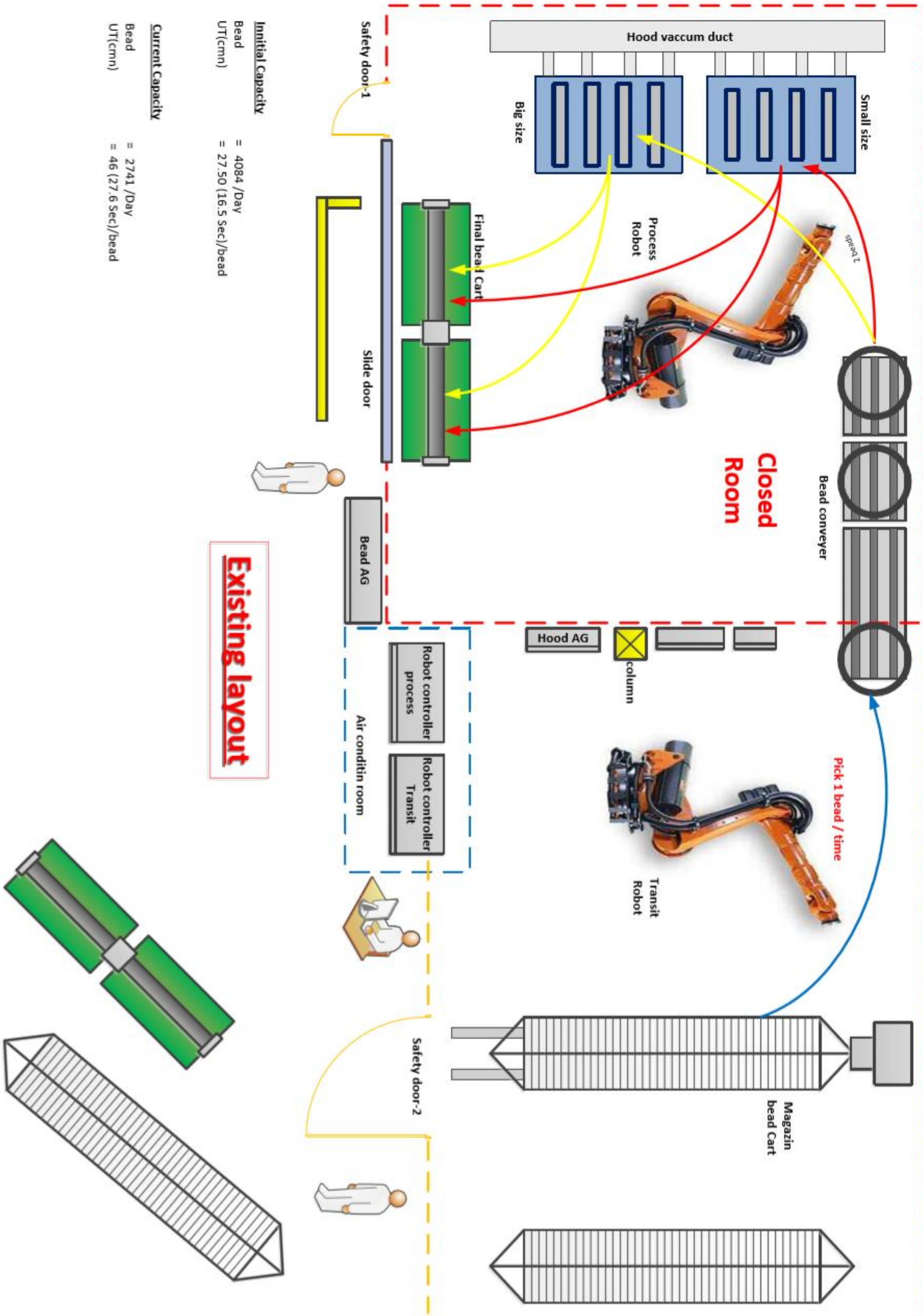
TPFR



Type	Rim Size [inch]	W [mm] ±0.1	H [mm] ±0.1	ID [mm]	OD [mm]	Bead weight [kg]
TFRC	22,5	22,5	18,9	568	616	2,3
		24,4	20,1	569	613	2,6
		23,1	18,5	566	608	2,1
	19,5	16,0	14,5	493	525	1,1
	17,5	19,2	16,0	442	477	1,2
		16,0	14,5	440	475	0,9
TPFR	16,0	11,2	10,6	412	433	0,5
		13,1	11,8	410	436	0,6
		15,2	13,6	415	442	0,8
	20,0	15,2	13,6	527	557	1,4
		16,7	16,3	522	559	1,5
		20,4	19,3	520	561	1,7

Appendix B: Current production cell layout

An overview of the current automated production cell that needs to be improved.



Robot places beads from the cart onto the conveyor(left); Loading station with magazine cart loaded with beads(right)

Stearate coating machine(left); Unloading cart(front); Incoming conveyor with beads (right back)

Appendix C: Function-specific solutions

The potential solutions for each system function.

Transport bead:

- Overhanging conveyor;
- modified VENUS cart conveyor;
- pallet conveyor system;
- conveyor belt;
- towline conveyor;
- chain conveyor;
- AGV;
- gravity ramp.

Buffer bead:

- Multiple pallets;
- multiple carts;
- LIFO;
- FIFO.

Present bead:

- VENUS ejector system;
- direct from magazine cart;
- modified VENUS ejector system;
- prepositioned on pallets.

Detect bead:

- Proximity sensor;
- electromechanical switch;
- laser sensor;
- photoelectric sensor;
- weight;
- actuator position sensor.

Pick bead:

- VENUS gripper;
- hook gripper;
- pull secure gripper;
- magnetic;
- friction gripper;
- encompassing gripper;
- sticky gripper.

Position bead:

- Picking with offset;
- one bead per time;
- pre aligned;

- adjust by actuator;
- splitting chute.

Place bead:

- Industrial robot manipulator;
- pneumatic handling system;
- pneumatic pusher;
- electrical handling system;
- electrical pusher;
- vibration slider;
- pusher on robot.

Verify cart height:

- Pre-programmed height offset;
- detection by proximity sensor;
- computer vision;
- spring loaded;
- light grid sensor.

Monitor safety:

- Fence around production cell;
- emergency stops;
- door interlock;
- safety PLC;
- light curtain;
- area scanner;
- dust sensor;
- actuator breaking mechanism.

Appendix D: Considered concepts and morphological overview

Description of concepts that have been considered and their performance. The concepts are also shown in a morphological overview.

Concept B: VENUS dual robot

The aim of this concept is to reuse existing parts of the VENUS system as much as possible. The cart conveyor systems are modified to account for the magazine and TBM cart. The original EOAT is used to pick and place the beads. Due to the design of the conveyor system and EOAT, the uncoated bead handling robot can only pick one bead at the time, resulting in reduced performance.

Function	Solution
Transport bead	Modified VENUS cart conveyor
Buffering	2 carts in conveyor
Present bead	Modified VENUS ejector system
Detect bead	Photoelectric sensor on EOAT
Pick bead	VENUS EOAT
Place bead	Dual robot
Position	One bead per time
Place on cart	Pusher on robot
Verify cart height	Pre-programmed height offset
Transport TBM cart	Modified VENUS conveyor
Buffering TBM carts	2 carts in conveyor
Monitor Safety	Fence, light curtains, e-stop, door interlock

Time per 2 beads	14	seconds
Beads per cart	120	
Cart change over time	60	seconds
Cart buffer size	2	
Shifts per day	3	
Net time per cart	900	seconds
Beads per minute	8,0	
Beads per hour	480	
Buffer-break time loss[1]	5.400	seconds
Additional losses[2]	8.784	seconds
Total time lost	14.184	seconds

Potential beads per day	11.520
Net beads per day	**9.628**

Concept C: VENUS single robot with direct placement

This concept uses a single robot to handle the coated beads. The beads are pushed into the stearate coating unit using a pusher mechanism. The mechanism requires precise control to align the pushers with the slots of the magazine cart. The pushing mechanism is complex and expensive to make.

Function	**Solution**
Transport bead	Modified VENUS cart conveyor
Buffering	2 carts in conveyor
Present bead	Modified VENUS ejector system
Detect bead	Sensor in ejector system
Pick bead	Modified cart ejector that pushes bead directly into coating machine and VENUS EOAT
Place bead	Single robot
Position	Splitting chute
Place on cart	Pusher on robot
Verify cart height	Pre-programmed height offset
Transport TBM cart	Modified VENUS conveyor
Buffering TBM carts	2 carts in conveyor
Monitor Safety	Fence, light curtains, e-stop, door interlock

Time per 2 beads	11	seconds
Beads per cart	120	
Cart change over time	60	seconds
Cart buffer size	2	
Shifts per day	3	
Net time per cart	720	seconds
Beads per minute	10,0	
Beads per hour	600	
Buffer-break time loss[1]	6.480	seconds
Additional losses[2]	8.784	seconds
Total time lost	15.264	seconds

Potential beads per day	14.400
Net beads per day	**11.856**

Concept D: No magazine cart

This concept replaces the need for the magazine cart by using a pallet conveyor system. The beads are loaded from the bead-shop cart directly onto pallets. The pallets are asynchronous and multiple pallets can be buffered. The performance of this concept will be the same as concept A (considering there are enough pallets). The number of pallets and length needed to achieve the same amount of buffer as one or two magazine cart makes this concept very expensive.

Function	**Solution**
Transport bead	Pallet conveyor (asynchronous)
Buffering	Multiple pallets
Present bead	Prepositioned on pallets
Detect bead	Photoelectric sensor on EOAT
Pick bead	VENUS EOAT
Place bead	Dual robot
Position	Pre aligned
Place on cart	Pusher on robot
Verify cart height	Pre-programmed height offset
Transport TBM cart	Modified VENUS conveyor
Buffering TBM carts	2 carts in conveyor
Monitor Safety	Fence, light curtains, e-stop, door interlock

Time per 2 beads	9	seconds
Beads per cart	120	
Cart change over time	60	seconds
Cart buffer size	2	
Shifts per day	3	
Net time per cart	600	seconds
Beads per minute	12,0	
Beads per hour	720	
Buffer-break time loss[1]	7.200	seconds
Additional losses[2]	8.784	seconds

Total time lost	15.984	seconds
Potential beads per day	17.280	
Net beads per day	**14.083**	

Concept E: VENUS single robot

One of the requests of the client was the performance of a system that uses as much parts of the VENUS system as possible but using only a single robot. This concept is the same as concept B, although now a single robot does the handling of uncoated as well as coated beads. The daily capacity is almost half of what is required.

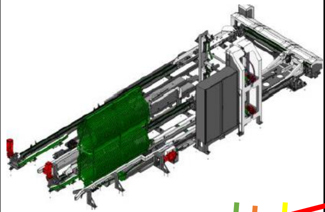
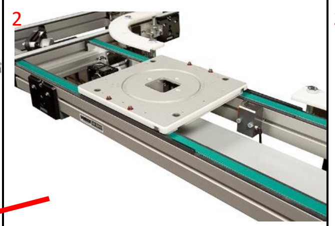
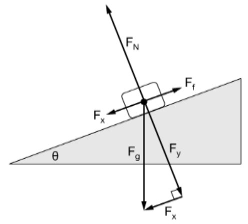
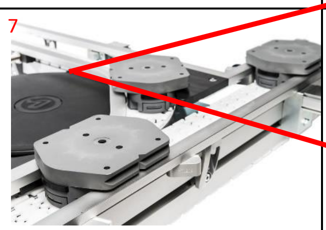
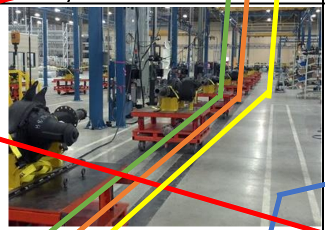
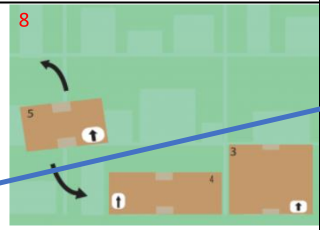
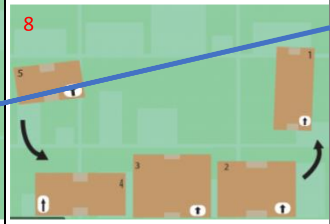
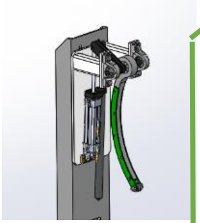
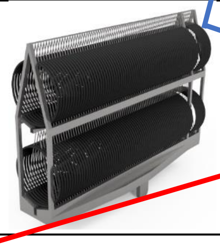
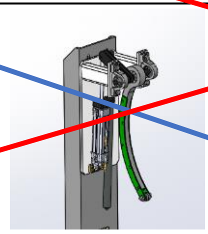
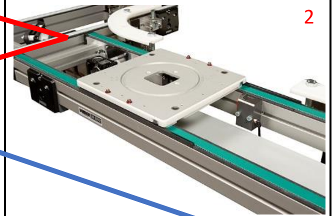
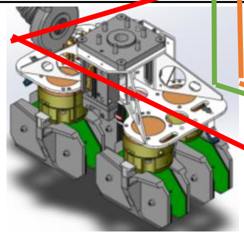
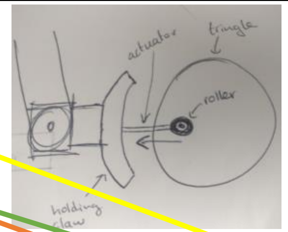
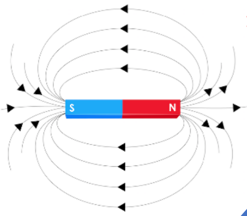
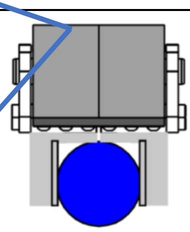
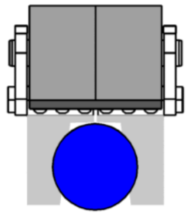
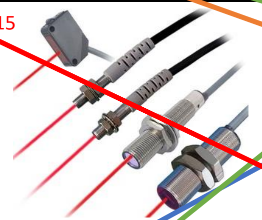
Function	**Solution**
Transport bead	Modified VENUS cart conveyor
Buffering	2 carts in conveyor
Present bead	Modified VENUS ejector system
Detect bead	Photoelectric sensor on EOAT
Pick bead	VENUS EOAT
Place bead	Single robot
Position	One bead per time
Place on cart	Pusher on robot
Verify cart height	Pre-programmed height offset
Transport TBM cart	Modified VENUS conveyor
Buffering TBM carts	2 carts in conveyor
Monitor Safety	Fence, light curtains, e-stop, door interlock

Time per 2 beads	22	seconds
Beads per cart	120	
Cart change over time	60	seconds
Cart buffer size	2	
Shifts per day	3	
Net time per cart	1380	seconds
Beads per minute	5,2	
Beads per hour	313	
Buffer-break time loss[1]	2.520	seconds

Additional losses[2]	8.784	seconds
Total time lost	11.304	seconds
Potential beads per day	7.512	
Net beads per day	**6.529**	

Appendix E: Morphologic overview

Concept A	blue
Concept B	orange
Concept C	green
Concept D	red
Concept E	yellow

Function	**Methods**							
Transport beads	1  overhanging conveyor	 VENUS magazine cart conveyor	2  pallet conveyor system	3  conveyor belt	4  towline conveyor	5  chain conveyor	6  AGV	 gravity ramp
Buffer beads	7  multiple pallets	 multiple carts 4	8  LIFO	8  FIFO				
Present bead	 VENUS ejector system	 direct from magazine cart	 modified VENUS ejector	2  Prepositioned on pallets				
Pick beads	 VENUS EOAT	9  hook gripper	 pull secure gripper	10  magnetic	11  friction gripper	11  encompassing gripper	12  sticky gripper	
Detect bead	13  proximity sensor	14  electromechanical switch	15  laser sensor	 photoelectric sensor 16	 weight	17  actuator position sensor		

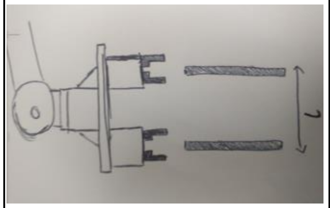
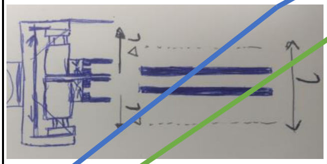
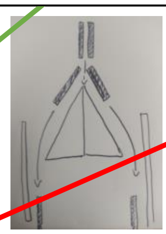
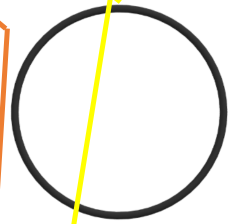
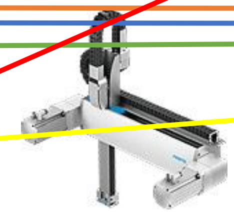
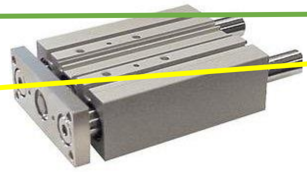
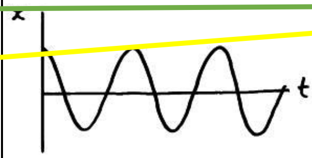
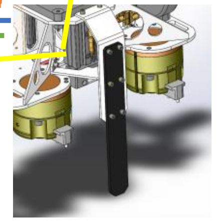
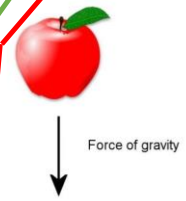
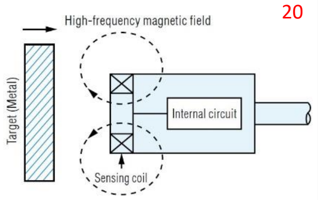
Position bead				$d_1 = d_2$					
	picking with offset	adjust by actuator	splitting chute	pre aligned	one bead per time				
Place bead	18 	 19	 19						
	industrial robot manipulator	pneumatic/electrical handling system	pneumatic/electrical pusher	vibration slider	pusher on robot				
Verify cart height		 20	 18	 21	 21				
	pre-programmed height offset	detection by proximity sensor	computer vision	spring loaded	light grid sensor				
Monitor safety									
	fence 22	emergency stops 1	door interlock 23	safety plc 1	light curtain 24	area scanner 25	dust sensor 1	actuator braking	

Photo sources:

1. *Indiamart, Krishna Enterprise*
2. *Motioncontroltips*
3. *Titan Conveyors*
4. *RSI (Rhodes Systems International)*
5. *tradeindia*
6. *ExportersIndia*
7. *FlexLink*
8. *Marketing91*
9. *Gripind*
10. *Drpawluk.com*
11. *Grippers.com*
12. *Vectorstock*
13. *Ato.com*
14. *We-online*
15. *Alibaba*
16. *Seco-Larm*
17. *Omron*
18. *Fanuc*
19. *Festo*
20. *Keyence*
21. *Spectechind*
22. *Lockers USA*
23. *Safetyswitch-shop*
24. *CGOLDENWALL*
25. *SICK*

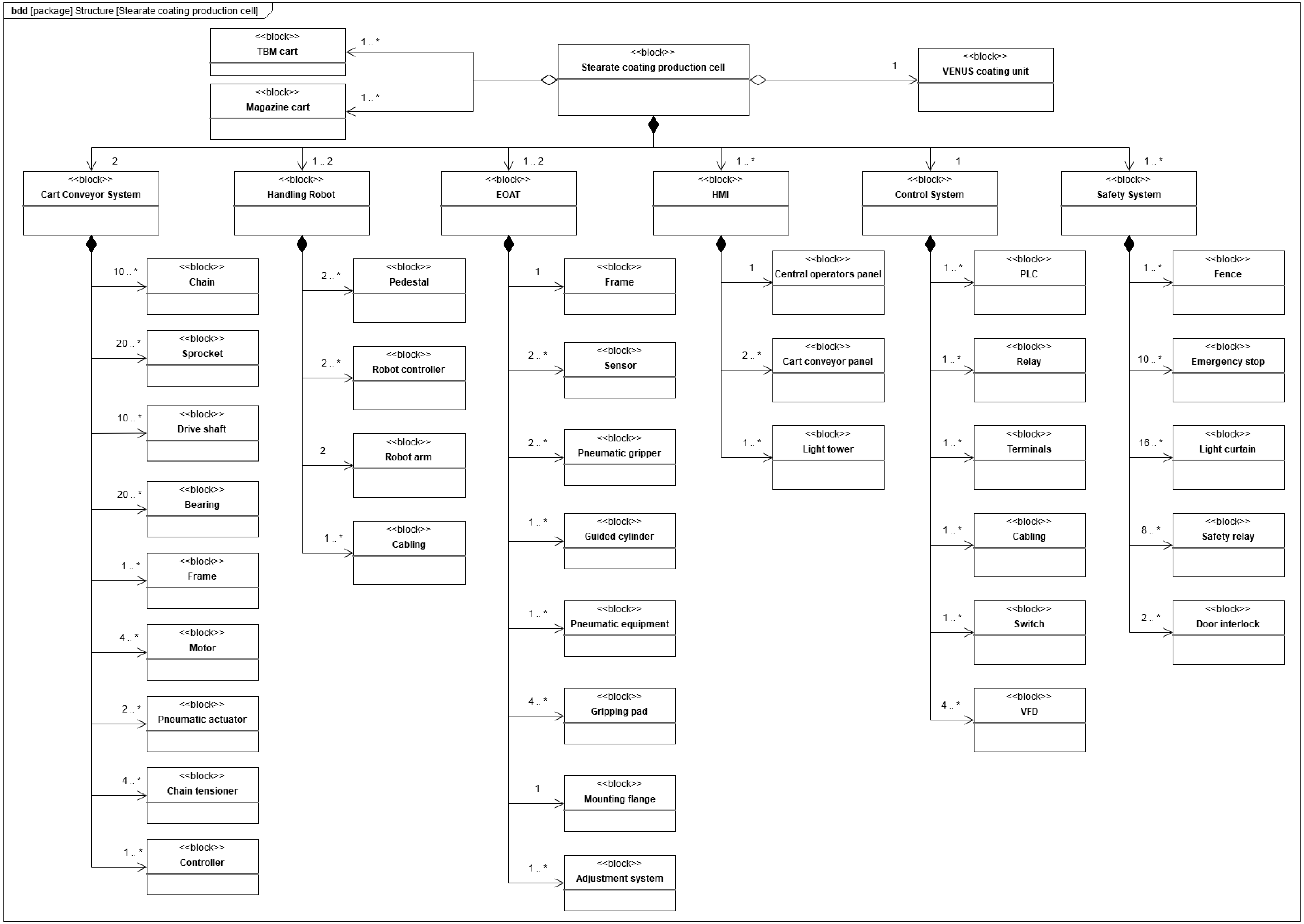
Appendix F: Explanation of capacity calculations

Requirement		**Max. daily time [s]**
Preventive maintenance (2%)	t_{main}	1.728
Breakdown (4%)	$t_{breakdown}$	3.456
Setup	t_{setup}	3.600

Time per 2 beads [s]	t_{2b}	Time between two consecutive stearate coating unit starts.
Beads per cart	B_{cart}	The number of beads that are available in a single batch without the need for a cart changeover.
Cart change over time [s]	$t_{c/o}$	The time is takes for an old cart to be replaced with a new cart inside the loading or unloading station.
Cart buffer size	C_{buf}	The number of carts that can be placed inside the machine prior to loading or unloading.
Shifts per day	S_{day}	The number of operator shifts per day.
Net time per cart [s]	t_{cart}	$t_{cart} = \frac{t_{2b}B_{cart}}{2} + t_{c/o}$
Beads per minute	B_{min}	$B_{min} = \frac{60B_{cart}}{t_{cart}}$
Beads per hour	B_{hour}	$B_{hour} = 60B_{min}$
Buffer-break time loss [s]	$t_{buf\text{-}loss}$	$t_{buf-loss} = S_{day}(3600 - t_{cart}C_{buf})$
Additional losses [s]	$t_{add\text{-}loss}$	$t_{add-loss} = t_{main} + t_{breakdown} + t_{setup}$
Total time lost [s]	$t_{tot\text{-}loss}$	$t_{tot-loss} = t_{buf-loss} + t_{add-loss}$
Potential beads per day	$B_{pot\text{-}day}$	$B_{pot-day} = 24B_{hour}$
Net beads per day	$B_{net\text{-}day}$	$B_{net-day} = B_{pot-day} - t_{tot-loss}\frac{B_{min}}{60}$

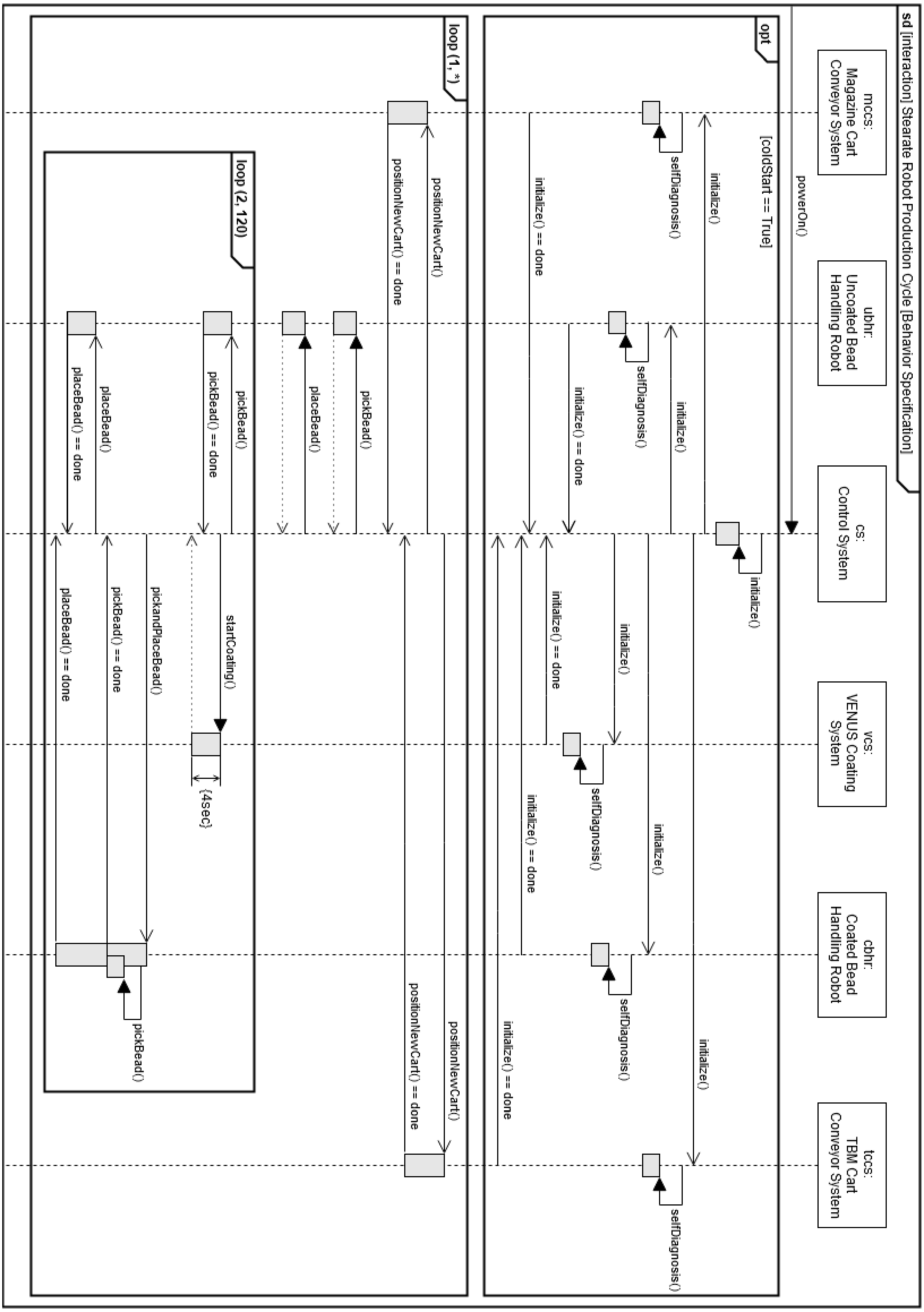
Appendix G: SysML – Block definition diagram

An overview of the physical parts of the stearate coating production cell.



Appendix H: SysML – Sequence diagram

An overview of the normal behavior of the system.

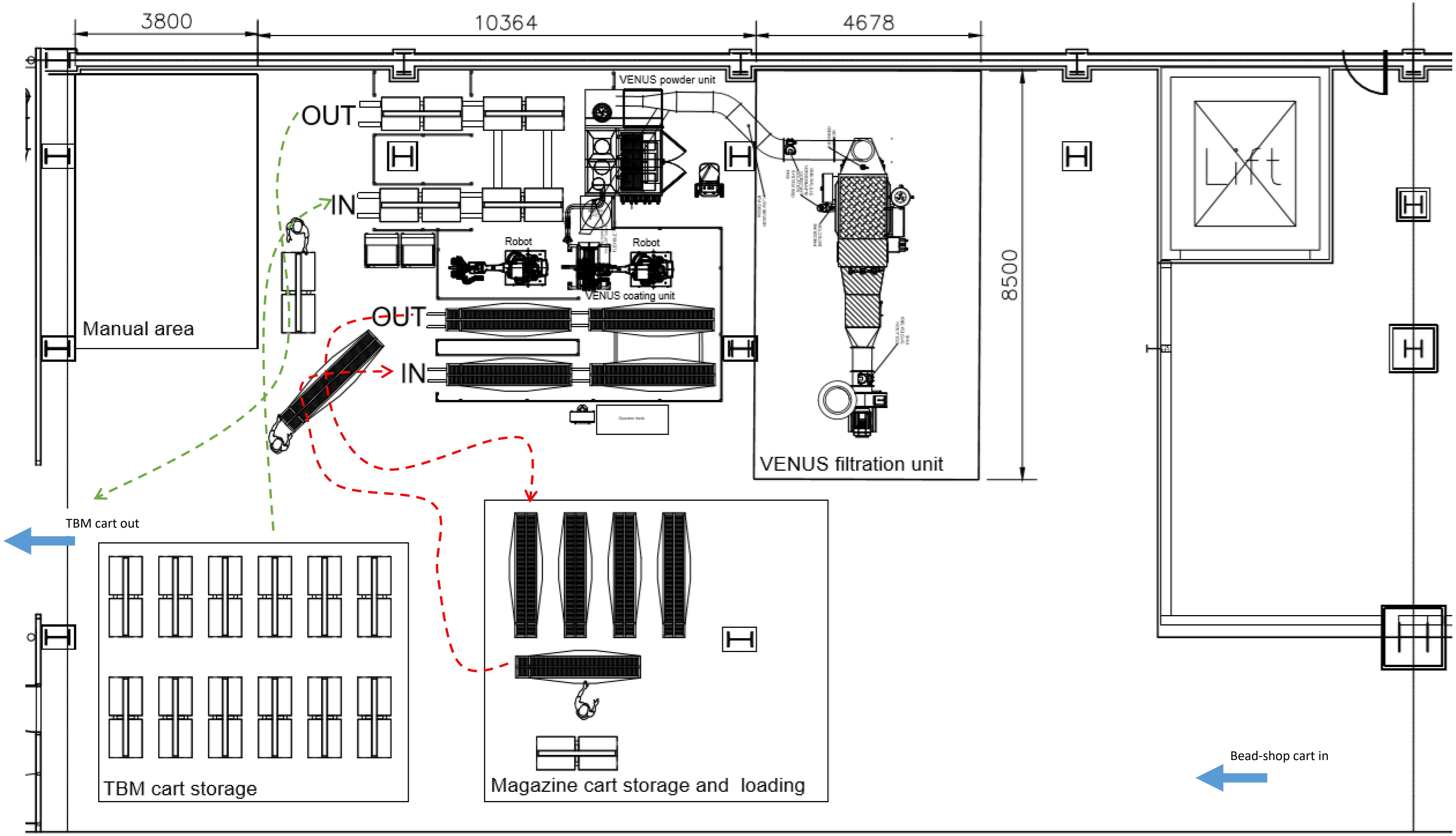


Appendix I: Layout concepts

The layout concepts that have been considered by the client can be found here. The manual area will only be used during the construction phase of the project. After the system is installed and operational the manual area will be changed to a TBM cart holding area. Building columns are displayed as H beams. Dimensions on the layout drawings are in millimeters and plotted on scale 1:75.

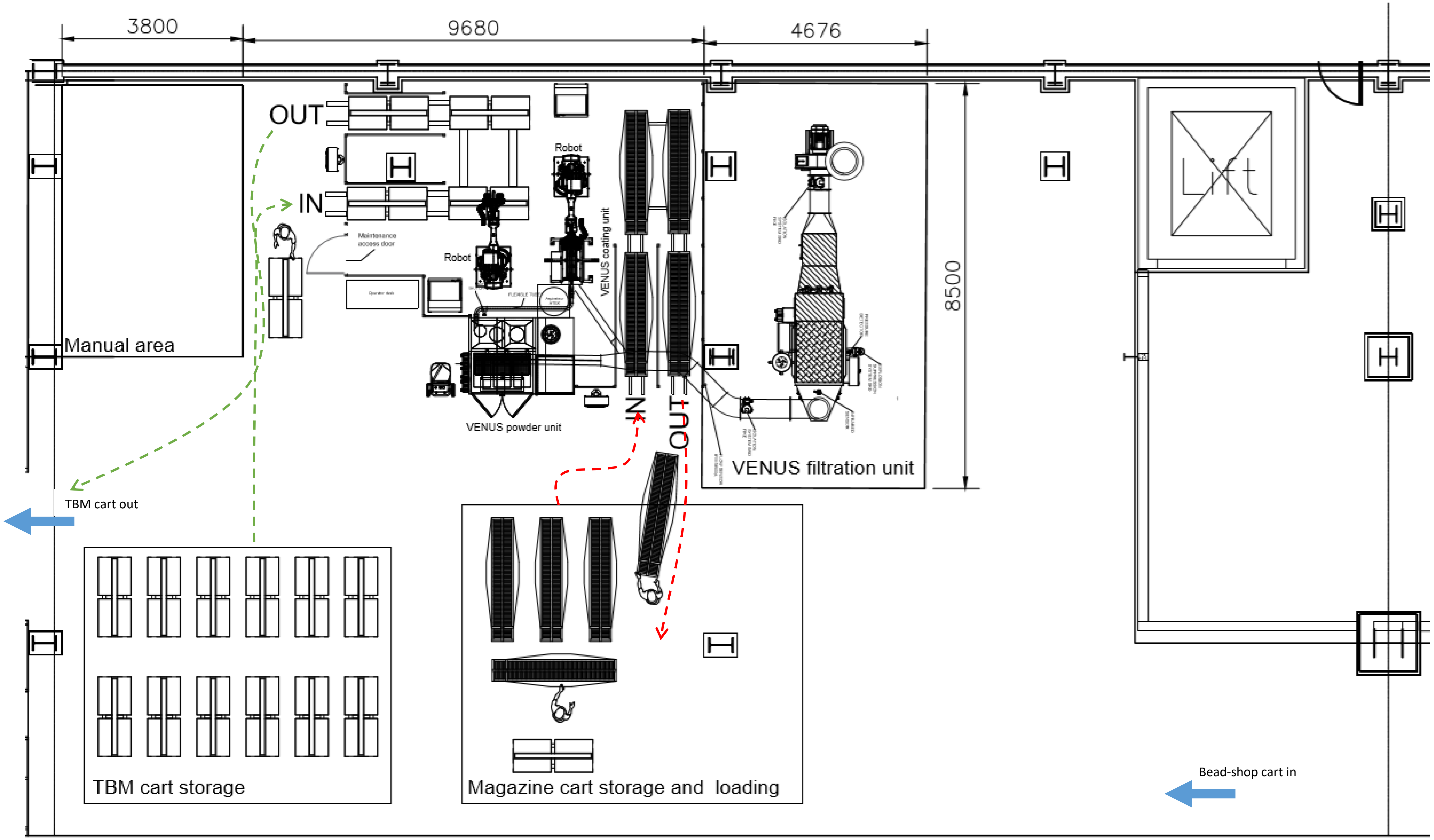
Layout concept 1

The aim of this concept is to have the loading and unloading of the carts on one side of the system. The VENUS powder can be accessed at the back of the machine. The operator desk and HMI are in front of the production cell. The problem of this layout is that the magazine cart is difficult to steer (especially when fully loaded).



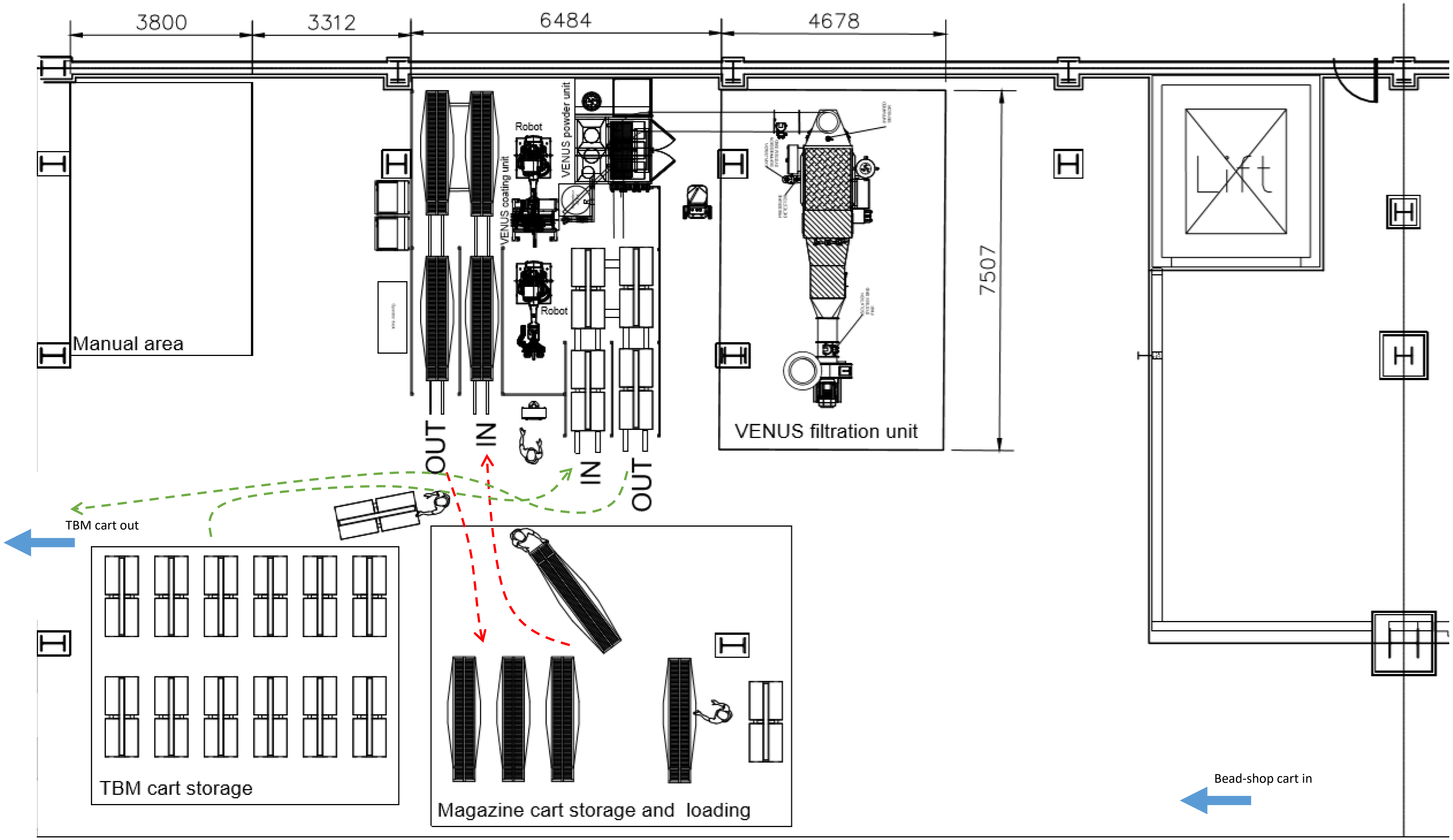
Layout concept 2

This concept separates the loading of the TBM and magazine carts (see the colored zones). The magazine carts can be loaded into the machine without having to steer. The powder unit can be loaded at the front of the machine. The blower motor of the filtration unit is faced to the back of the machine to reduce operator noise exposure.



Layout concept 3

For this concept the magazine and TBM carts can be driven straight inside the machine. The problem of this layout is that the path of the carts crosses each other. Mirroring the two conveyor systems is not possible because the building columns will obstruct the VENUS powder unit.



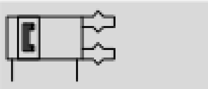
Appendix J: Festo HGPD-63-A specifications

Parallel grippers HGPD, sealed

Technical data

FESTO

Function
Double-acting
HGPD-...-A



Size
16 ... 80 mm

Total stroke
6 ... 40 mm

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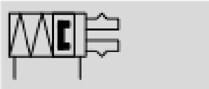
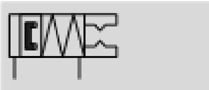
Function – Variants
Single-acting or
with gripping force retention ...
... opening HGPD-...-G1



... closing HGPD-...-G2



General technical data									
Size		16	20	25	35	40	50	63	80
Design		Wedge-shaped actuator							
		Forced motion sequence							
Mode of operation		Double-acting							
Gripper function		Parallel							
Number of gripper jaws		2							
Max. load per external gripper finger[1]	[g]	25	57	138	278	445	813	1340	2170
Stroke per gripper jaw	[mm]	3	4	6	8	10	12	16	20
Pneumatic connection		M5	M5	M5	M5	M5	G1/8	G1/8	G1/4
Pneumatic connection for sealing air		M3	M3	M5	M5	M5	M5	M5	M5
Pneumatic connection for lubrication nipple		M3	M3	M5	M5	M5	M5	M5	M5
Repetition accuracy[2]	[mm]	≤ 0.03	≤ 0.04		≤ 0.05				
Max. interchangeability	[mm]	≤ ±0.2							
Max. operating frequency	[Hz]	≤ 3				≤ 2			
Rotational symmetry	[mm]	< ∅ 0.2							
Position sensing		Via proximity sensor, position transmitter							
Type of mounting		Via through-hole and dowel pin/centring sleeve							
		Via female thread and dowel pin/centring sleeve							
Mounting position		Any							

1) Valid for unthrottled operation
2) End-position drift under constant conditions of use with 100 consecutive strokes in the direction of movement of the gripper jaws

Operating and environmental conditions		
Min. operating pressure		
HGPD-...-A	[bar]	3
HGPD-...-A-G	[bar]	4
Max. operating pressure	[bar]	8
Operating pressure for sealing air	[bar]	0 ... 0.5
Operating medium		Compressed air in accordance with ISO 8573-1:2010 [7:4:4]
Note on operating/pilot medium		Operation with lubricated medium possible (in which case lubricated operation will always be required)
Ambient temperature[1]	[°C]	+5 ... +60
Degree of protection		IP65
Corrosion resistance class CRC[2]		2

1) Note operating range of proximity sensors
2) Corrosion resistance class CRC 2 to Festo standard FN 940070
Moderate corrosion stress. Indoor applications in which condensation may occur. External visible parts with primarily decorative requirements for the surface and which are in direct contact with the ambient atmosphere typical for industrial applications.

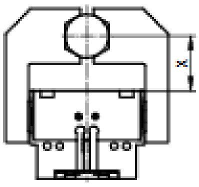
Parallel grippers HGPD, sealed

FESTO

Technical data

Gripping force F_H per gripper jaw as a function of operating pressure and lever arm x

The gripping forces as a function of operating pressure and lever arm can be determined from the following graphs.



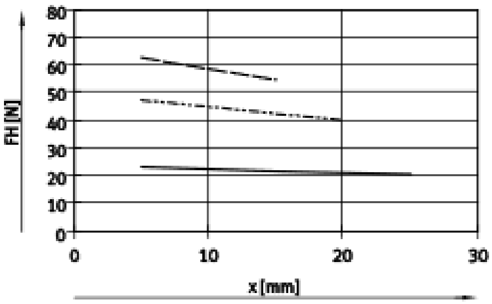
—— 3 bar
-·-·- 6 bar
— — 8 bar

Note

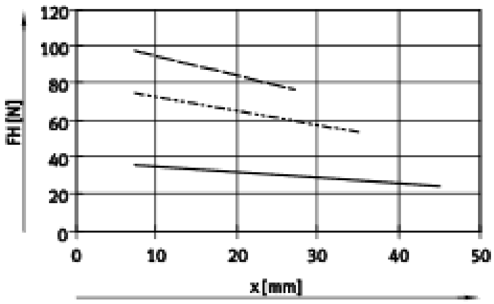
Gripper selection sizing software
→ www.festo.com

External gripping (closing)

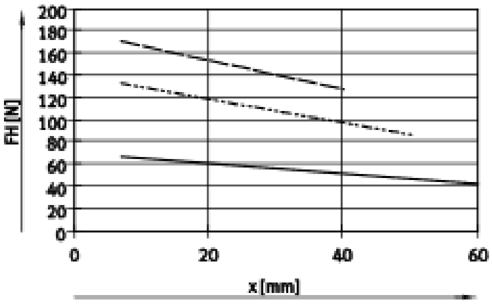
HGPD-16-A



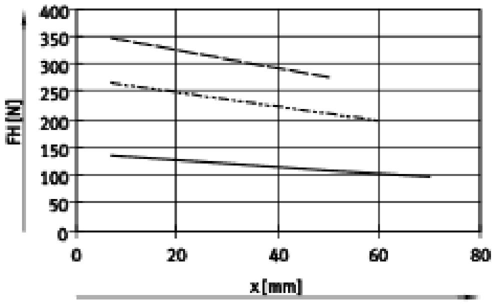
HGPD-20-A



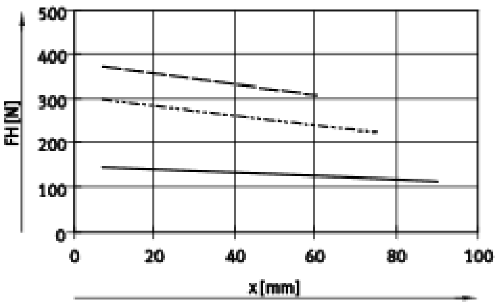
HGPD-25-A



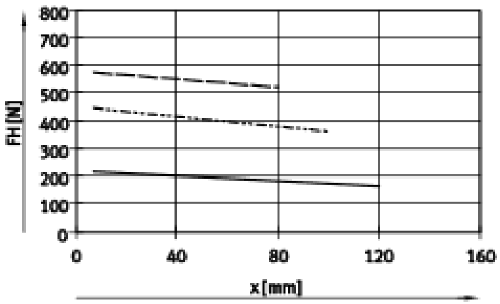
HGPD-35-A



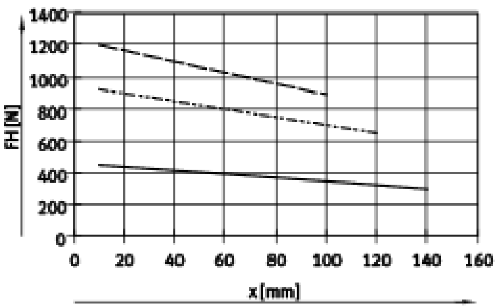
HGPD-40-A



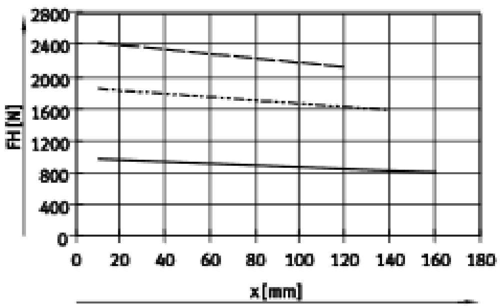
HGPD-50-A



HGPD-63-A



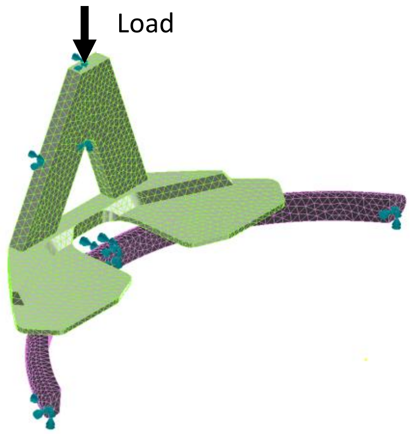
HGPD-80-A



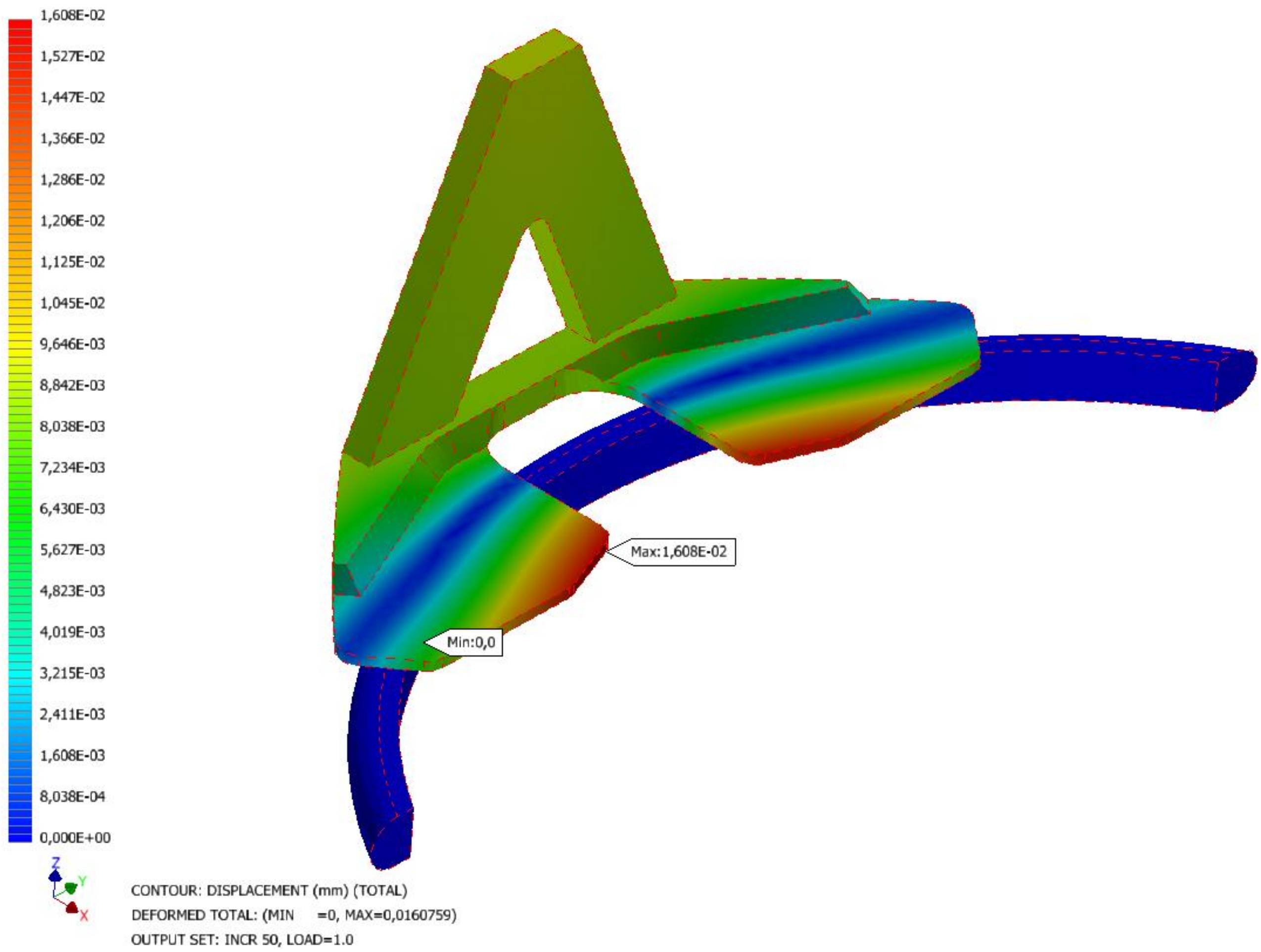
Appendix K: FEA gripper jaws

The gripper jaws are analyzed using a nonlinear static simulations. The resulting Von Mises stresses and displacement are shown in this appendix. The material of the bead is set to steel for the simulation to focus on the stress and displacement of the gripper jaw. A surface contact between bead and gripper jaw is set with a stiffness factor of 1. Autodesk Nastran is used for the FEA simulation and the following settings were used:

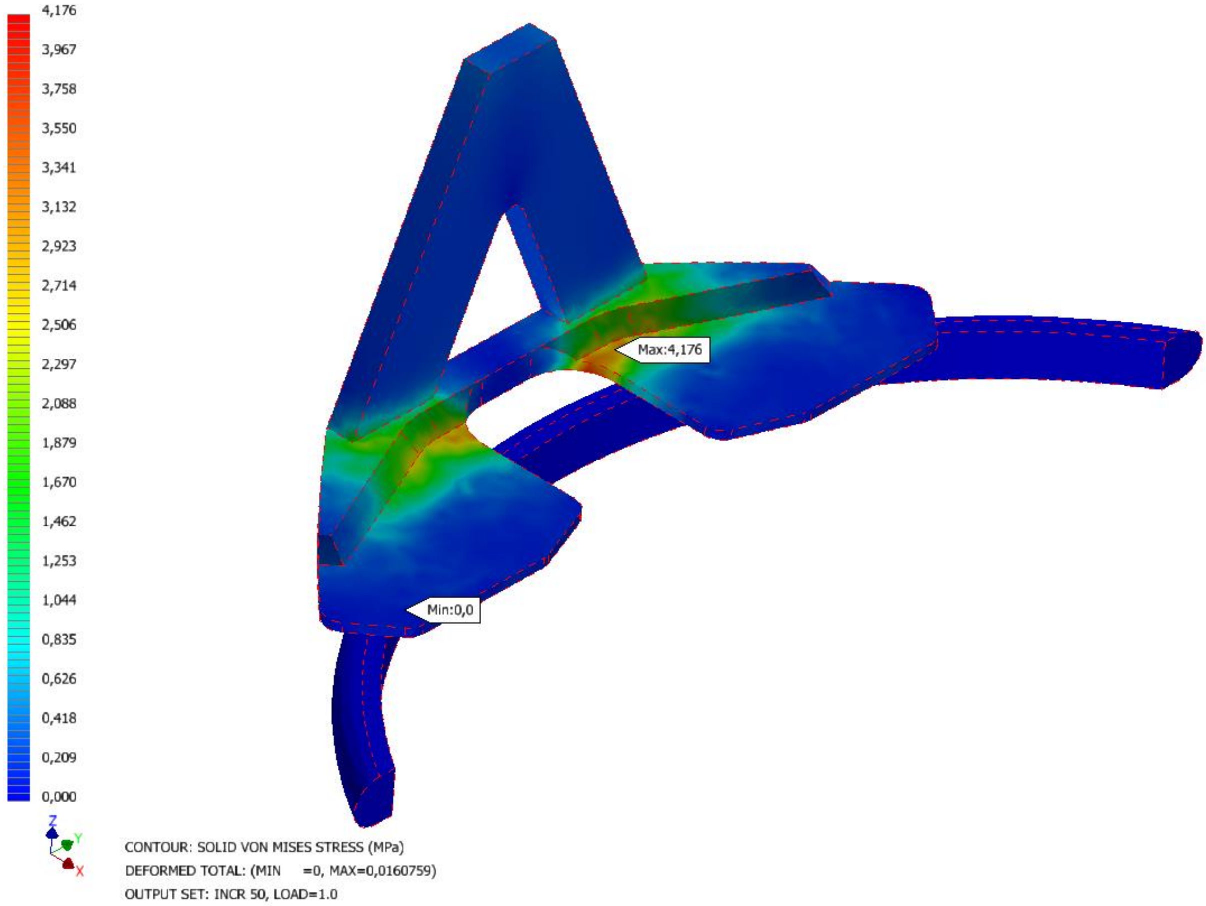
Element size [mm]	6
Element order	Linear
Number of increments	50
Load used [N]	400



Displacement



Von Mises stresses

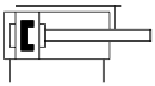


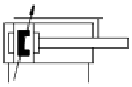
Appendix L: Festo DFM-B specifications

Guided drives DFM-B

Data sheet

Function





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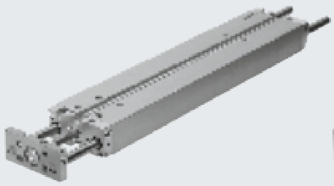
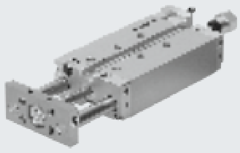
Diameter
12 ... 63 mm

Stroke length
10 ... 400 mm

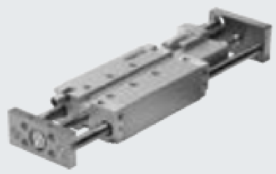


DFM-B-...-P (stroke 400 mm)

DFM-B-...-PPV



DFM-B-...-AJ-EJ



DFM-B-...-YSRW

General technical data								
Piston diameter	12	16	20	25	32	40	50	63
Pneumatic connection	M5	M5	M5	G1/8	G1/8	G1/8	G1/4	G1/4
Design	Piston							
	Piston rod							
	Guide rods with yoke							
Cushioning								
DFM-...-P	Elastic cushioning rings/plates at both ends							
DFM-...-PPV	–	Pneumatic cushioning, adjustable at both ends						
DFM-...-YSRW	–		Self-adjusting at both ends					
Cushioning length								
DFM-...-PPV [mm]	–	12	15	15	16	17	19	19
Position sensing	Via proximity switch							
Type of mounting	With through-hole							
	With female thread							
Mounting position	Any							
Protection against torsion/guide	Guide rod with yoke/plain-bearing or recirculating ball bearing guide							
Variant AJ								
Setting range [mm]	0 ... 10							
Variant EJ and YSRW								
Setting range [mm]	–	–	0 ... 10					
Variant YSRW with shock absorber								
Repetition accuracy [mm]	–	–	max. 0.05					

Note: This product conforms to ISO 1179-1 and ISO 228-1.

Appendix M: Sick WTB4-3P2261 photoelectric sensor

Specifications of the Sick photoelectric sensor WTB4-3P2261.

WTB4-3P2261 | W4-3

MINIATURE PHOTOELECTRIC SENSORS

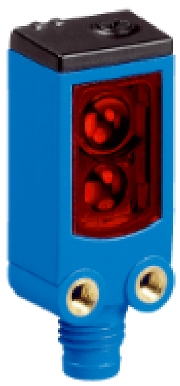


Illustration may differ

Ordering information

Type	Part no.
WTB4-3P2261	1028100

Other models and accessories → www.sick.com/W4-3

Detailed technical data

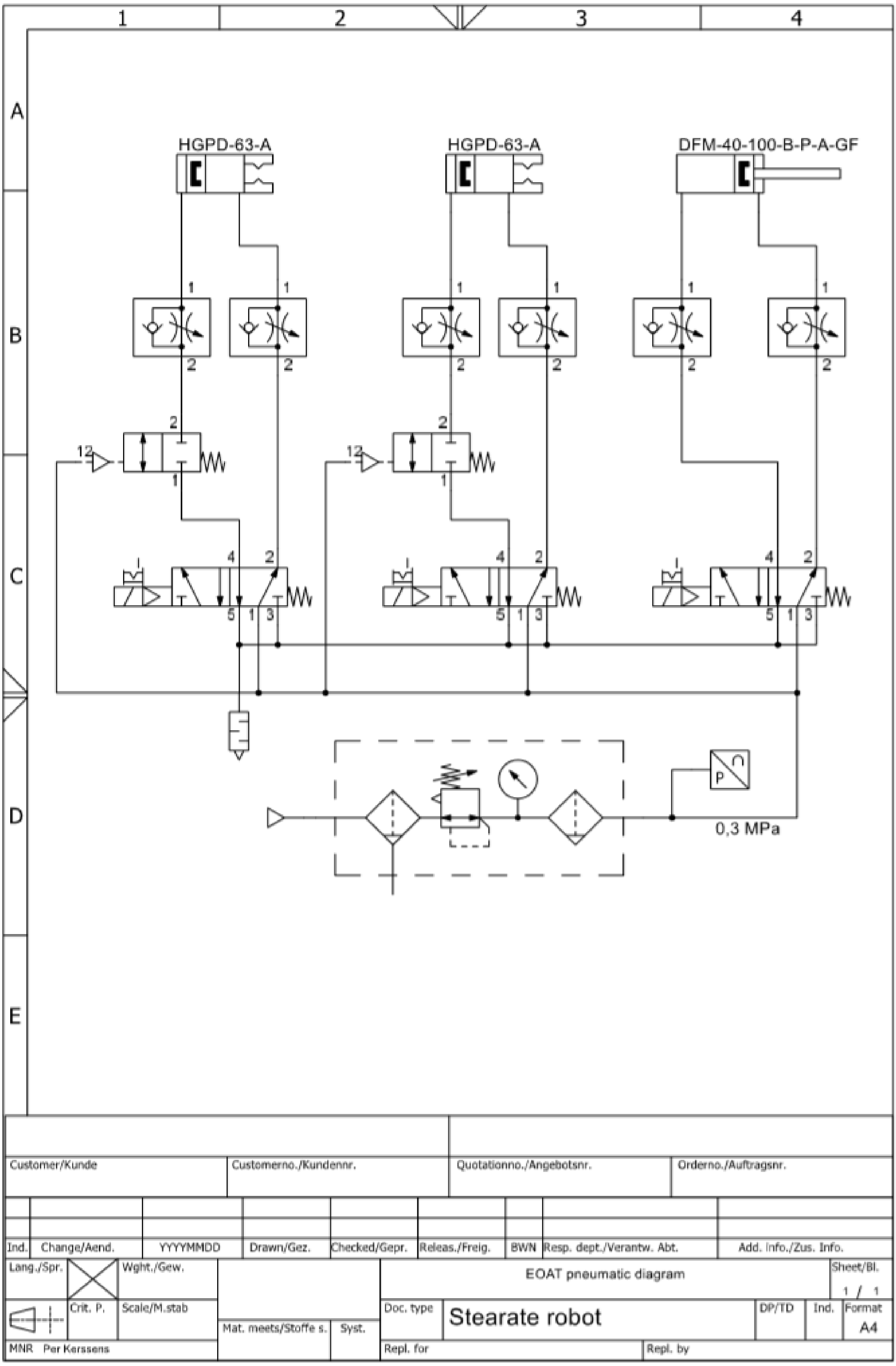
Features

Sensor/ detection principle	Photoelectric proximity sensor, Background suppression
Dimensions (W x H x D)	16 mm x 39.5 mm x 12 mm
Housing design (light emission)	Rectangular
Sensing range max.	4 mm ... 150 mm [1)]
Sensing range	15 mm ... 150 mm [1)]
Type of light	Visible red light
Light source	PinPoint LED [2)]
Light spot size (distance)	Ø 7 mm (50 mm)
Wave length	650 nm
Adjustment	Potentiometer, 5 turns
Special applications	Detecting small objects

[1)] Object with 90 % reflectance (referred to standard white, DIN 5033).

[2)] Average service life: 100,000 h at T_U = +25 °C.

Appendix N: EOAT pneumatic diagram



Appendix O: Fanuc M-710iC/45M specifications

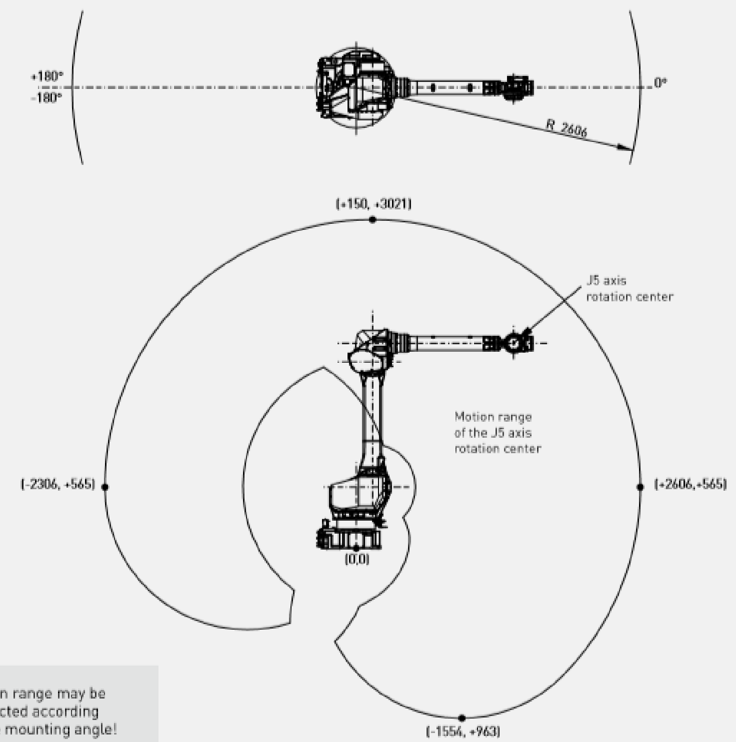
M-710*i*C/45M (High inertia version)

Max. load capacity at wrist: **45 kg**

Max. reach: **2606 mm**

Controlled axes	Repeatability (mm)	Mechanical weight (kg)	Motion range (°)						Maximum speed (°/s)						J4 Moment/ Inertia (Nm/kgm^2)	J5 Moment/ Inertia (Nm/kgm^2)	J6 Moment/ Inertia (Nm/kgm^2)
			J1	J2	J3	J4	J5	J6	J1	J2	J3	J4	J5	J6			
6	± 0.06*	570	360	225	440	800	250	800	180	180	180	250	250	360	206/28	206/28	127/20

Working range



Motion range may be restricted according to the mounting angle!

Robot	**M-710*i*C/45M**
Robot footprint [mm]	535 x 550
Mounting position Floor	•
Mounting position Upside down	•
Mounting position Angle	•
Controller	**R-30*i*B Plus**
Open air cabinet	-
Mate cabinet	o
A-cabinet	•
B-cabinet	o
*i*Pendant Touch	•
Electrical connections	
Voltage 50/60Hz 3phase [V]	380-575
Voltage 50/60Hz 1phase [V]	-
Average power consumption [kW]	2.5
Integrated services	
Integrated signals on upper arm In/Out	8/8
Integrated air supply	1
Environment	
Acoustic noise level [dB]	71.3
Ambient temperature [° C]	0-45
Protection	
Body standard/optional	IP54/IP67
Wrist & J3 arm standard/optional	IP67

• standard o on request - not available ( ) with hardware and/or software option *Based on ISO9283

Appendix P: Acceptance test

Assessment of the design whether the requirements have been met.

Requirements		**Satisfied**
M	- Design is compliant with Michelin safety standards (refer to Michelin wikiME).	X
	- Design is compliant with Michelin design standards (refer to Michelin WikiME).	X
	- Time study is based on preventive maintenance downtime that does not exceed 2%.	X
	- Time study is based on a machine breakdown of 4%.	X
	- Daily capacity is at least 11.224 beads.	X
	- Cycle time is at least ten beads per minute.	X
	- VENUS stearate coating unit, dust collector, and exhaust system is used.	X
	- The coating production process from magazine cart to TBM cart is automated.	X
	- All 12 bead types are supported by the system (see appendix A).	X
	- A maximum of two industrial robots are used in the design.	X
S	- Industrial robot is limited to the brands Yaskawa or Fanuc.	X
	- Daily setup time is not more than 1 hour.	X
	- Loading station supports existing magazine cart.	X
	- Coated beads are automatically placed on existing TBM cart.	X
	- Production cell can run 23 hours at seven days a week (excluding maintenance).	X
	- Total cost of production cell does not exceed 18.500.000 THB (≈550.000 EUR).	X
	- Final production cell fits within allocated factory space.	X
	- EOAT detects whether a bead is present after picking it up.	X
	- The EOAT can grip all 12 bead types without the need for a tool change or manual readjustment.	X
	- The bead is securely hold in the event of a power failure.	X
	- Production cell process state is indicated by a light tower.	-
C	- Product identification using existing barcode tags.	X
	- Computer vision system to counter variability in output cart height.	-
	- Direct unloading from bead-shop cart.	-
W	- System is implemented and tested.	X
	- System can detect bead indicator arrow and adjust orientation accordingly.	X