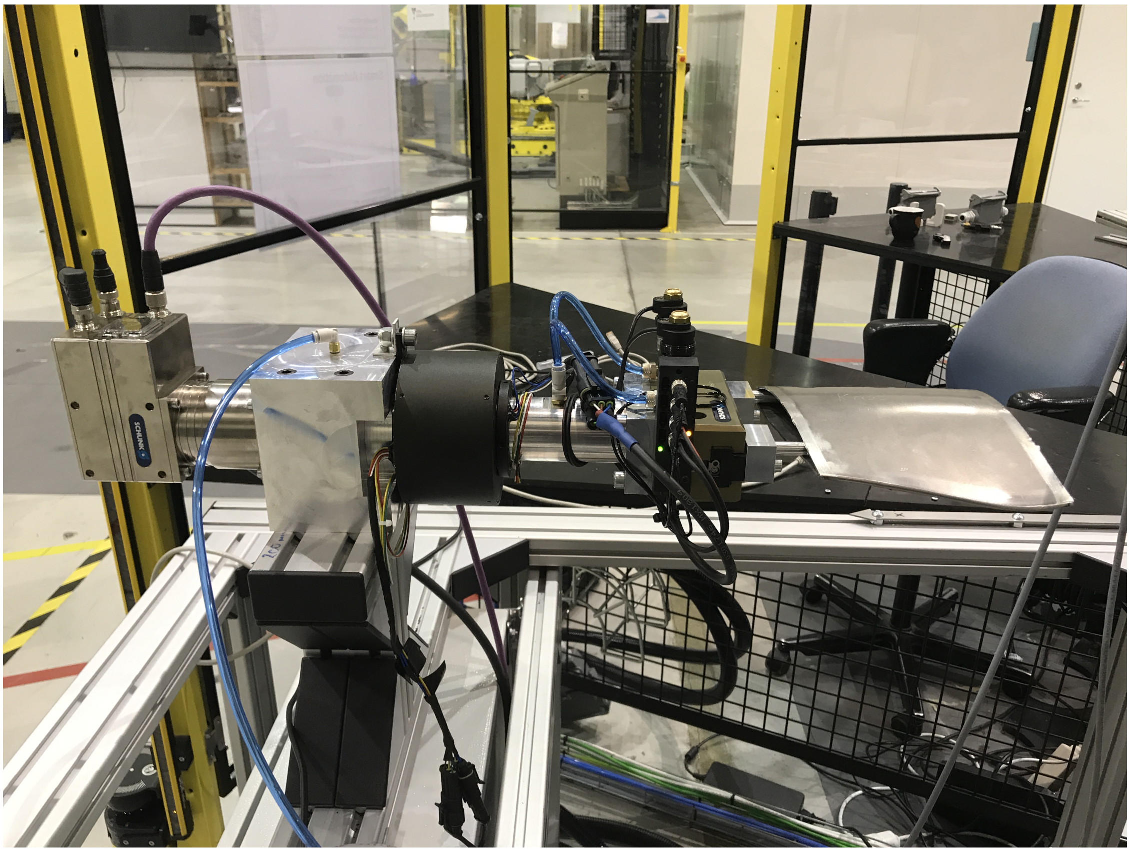

Development of Agent based optical measurement module in a multi-agent system

Master's thesis in Systems, Control and Mechatronics

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Gothenburg, Sweden 2020

Master's thesis 2020:EENX30

Development of Agent based optical measurement module in a multi-agent system

Evaluation of implemented Agent system and development of optical dimensional measurement module

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Gothenburg, Sweden 2020

The report will cover the steps from design phase to manufacturing and finally testing of a process module which handles optical dimensional measurements of aerospace components.
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Abstract

Multi-agent systems can increase the flexibility in today's production systems. However they operate quite differently from the traditional production which generates new challenges. This is probably due to the difficulty to design and implement the agents.

This report presents the design and implementation of a optical measuring agent that will be used as a module to measure an aerospace engine component. The report analyses the chosen measuring method as well as presenting the practical experience from these kinds of systems.

The module consists of both bought and manufactured components that together with a PLC to control the actuators makes for an integratable subsystem. However a full integration was not possible since the automation cell has limitations explained later in the report.

The measurement tool used is a 2D line laser and on these specific components covered in this thesis showed promising results. Though shiny surfaces was proved to be difficult to distinguish any geometrical features from.

Keywords: Agent, Multi-Agent systems, CNC manufacturing, Automation, Cyber-Physical-Production-Systems, CPS, CPPS, Optical dimensional measuring.

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First of all I would like to send my gratitude to the people at GKN for trusting me with their resources, especially Johan Ericsson and Stefan Forsman for their role as Supervisors where they both provided good feedback and help all throughout the projects different phases. I would also like to thank Anders Thorn and the whole of NYLI for providing the thesis with the measurement equipment used as well as suitable education to operate said equipment.

Special thanks should be given to my Supervisor and Examiner at Chalmers, Kristofer Bengtsson for his well formulated and precise feedback. I hope everyone involved has enjoyed this as much as I have.

Niklas Dahlstrand, Gothenburg, January 2020

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Nomenclature

CPPS	Cyber-Physical-Production System
CPS	Cyber-Physical System
MAS	Multi-Agent System
OPC-UA	Open Platform Communications Unified Architecture
PERFoRM	Production harmonizEd Reconfiguration of Flexible Robots and Machinery
PLC	Programmable Logic Controller
PTC	Production Technology Center

1

Introduction

The aviation traffic has doubled every fifteen year and is expected to keep increasing [1]. According to a study performed by Airbus [1], the amount of airplanes with more than 100 seats for passengers or used for freights at the beginning of 2016 was 19580. At 2035 the study shows that it is expected to be 39820 aircrafts in use, of which 33070 is new from 2016 and only 6750 can stay in service. This large increase of airplanes means that high demands is put on production where flexibility and smart production systems are key to meet the future demands. [1]

1.1 Background

At GKN Aerospace flexible automation is developed in order to support the large variation in part type and product flows. Flexible automation will enable adjustment of the shop to the current product demand as well as increasingly enable automation of manual work, since the same equipment can be used in manufacturing of several different parts and thereby lower the total expenditures. An automation cell is being commissioned at PTC to support the process development.

GKN Aerospace is serving a global customer base and operating in North America and Europe. With sales of £1.5 billion in 2011, the business is focused around three major product areas - aerostructures, engine products and transparencies (Aerospace windows), plus a number of specialist products - electro-thermal ice protection, fuel and flotation systems, and bullet resistant glass [1]. The business has significant participation on most major civil and military programs. GKN Aerospace is a major supplier of integrated composite structures, offers one of the most comprehensive capabilities in high performance metallic processing and is the world leading supplier of cockpit transparencies.

1.1.1 The PERFoRM station

The automation cell at GKN PTC is a demonstrator cell used for a larger EU project called PERFoRM with a target of meeting the increasing needs for multi-agent system based manufacturing domain. This need comes from higher demands where the production must be customizable in order to adapt to shorter and shorter product life cycles without compromising quality and price.

The flexible production cell that can be seen in figure 1.1 has been developed as a demonstrator to aid the development of the concept of an agent-based manufacturing system prior to installation in full-scale production. The station consists of an ABB industrial robot in the center and 10 slots available for modules, placed in a half circle around the robot. These modules are implemented as Agents and the station will demonstrate the potential of multi-agent based production systems. Previous work[2] has focused on the creation of a module for storing the part and one for grinding of oxides in preparation for welding. In this work the focus is on the user ergonomics, fixtures and tools for performing grinding of a part.

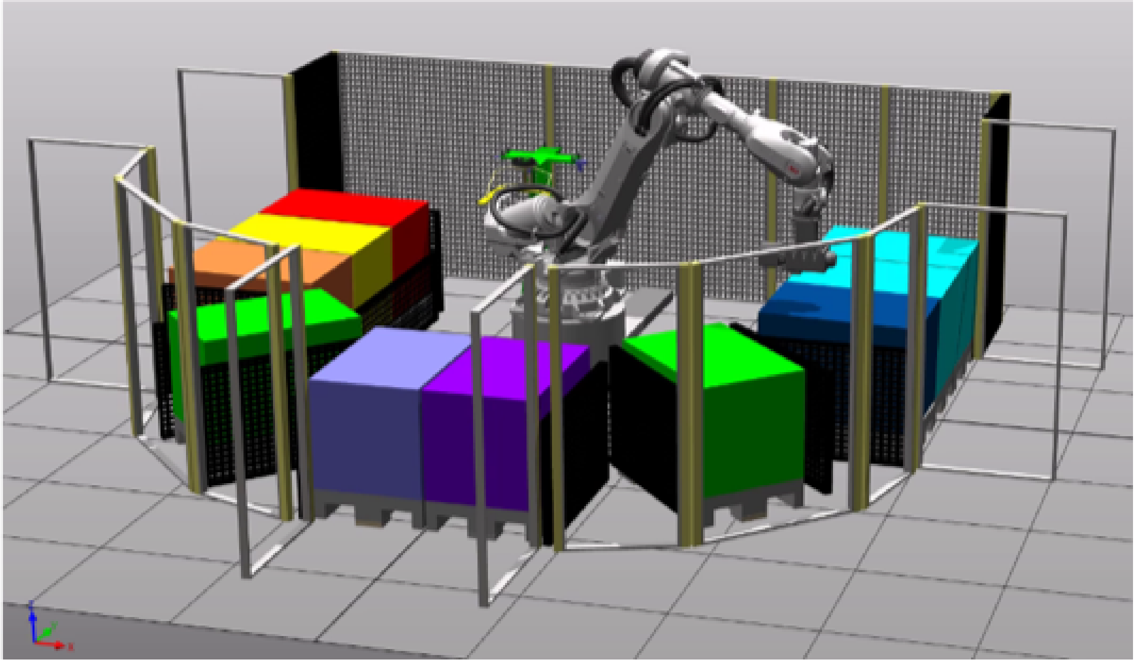


Figure 1.1: A 3D model of the flexible automation cell at PTC.

The cell consists of one ABB IRB 6700 industrial robot located in the centre with multiple modules visualised as colourful boxes surrounding the robot. As can be seen in figure 1.2 the modules are built up with aluminium profiles to create the skeleton. All modules have a PLC cabinet located with the varying internals depending on application. These fixates with the help of two dowel pins to ensure that they end up at the correct location and orientation every time as can be seen in figure 1.3 where the docking of a triple-slot is displayed.

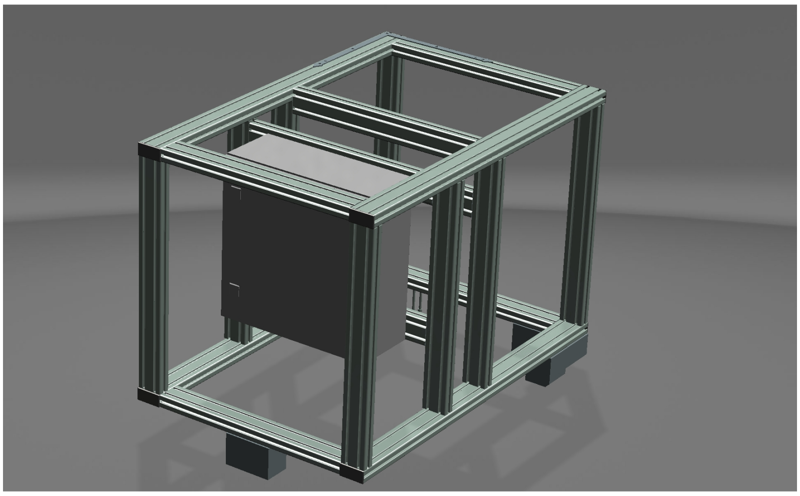


Figure 1.2: A 3D model of a module in the basic configuration.

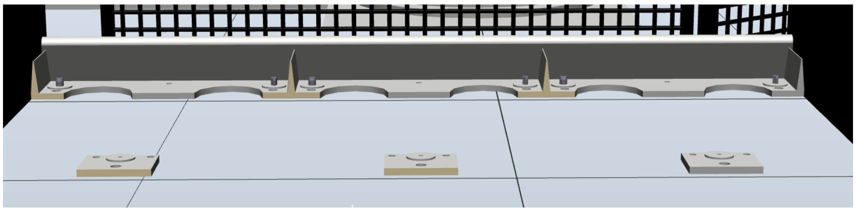


Figure 1.3: A 3D model of the docking solution[3].

The idea is that the modules are standardised as much as possible without limiting the needed processes such that any module can be put in another similar cell and work immediately. The modules should also be independent of placement, hence a module should be able to be placed at slot 1 or 8 and still work the same without any reprogramming required.

1.1.2 Part used for measuring

The module to be developed during the thesis is aimed at executing optical dimensional measurements of a turbine guide vane. The part shown in figure 1.4 is measured in this thesis and is an aerodynamically designed smaller component which is welded together to form a larger engine component that can be seen in figure 1.5. The part in question is a turbine structure Vane available in three different versions which are all used in the same larger component and with very similar characteristics. The overall differences between these versions is the thickness of the aerofoil as well as length. All versions have the same measurement points that is of interest, the leading- and trailing edge amongst others since it affects its aerodynamic performance. It is also of interest to inspect if the previous process that mills and grinds a weld seam has done it correctly such that the part is ready for the next step. A total of eleven areas of interest are defined in Chapter 5.1.

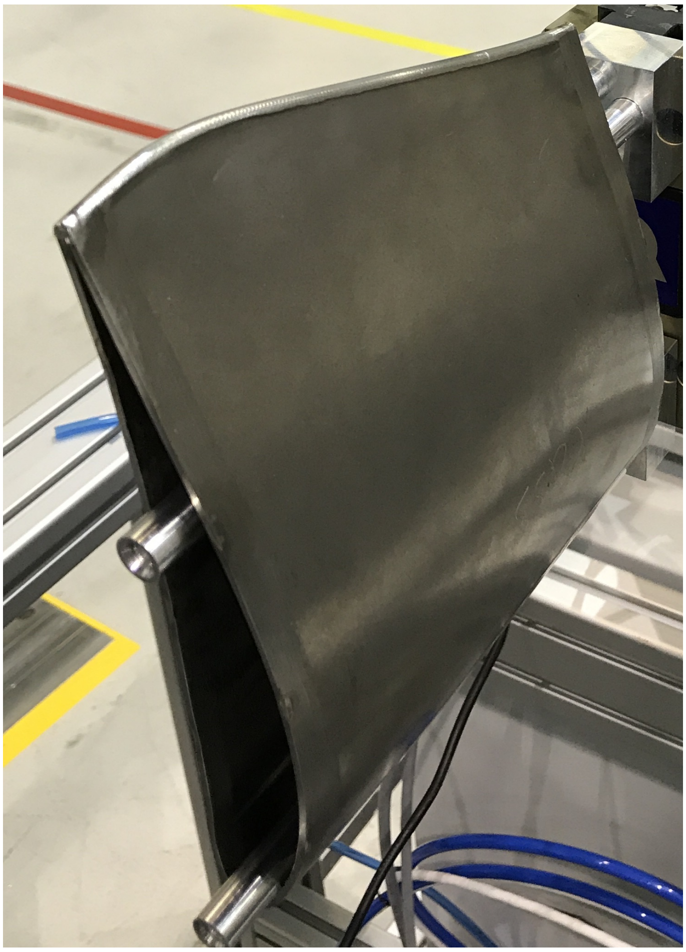


Figure 1.4: Picture of one version of the vane used in this project

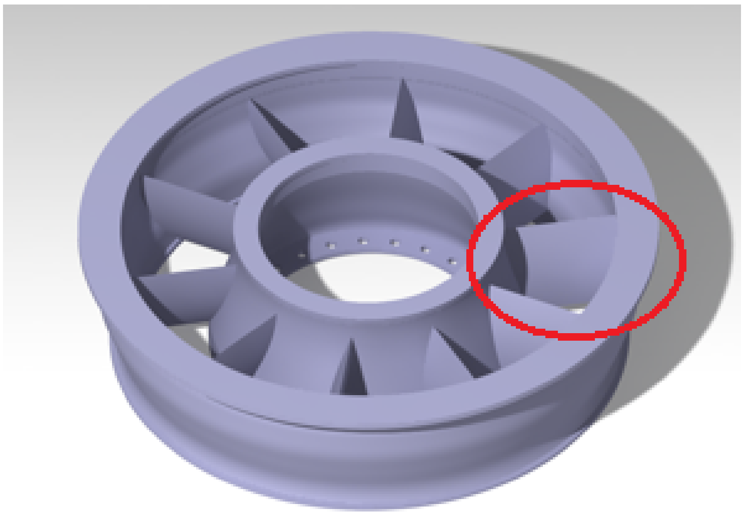


Figure 1.5: Engine frame with guide vanes

It is required to have a robust and precise solution for measuring the challenging geometric properties of the component. Due to the need to measure parts without physically touching them, optical methods are evaluated in this report with the use of a GapGun Vectro for the initial testing required prior to a potential introduction in the every day production. A GapGun is using a laser beam displayed as a line on the objects surface and together with a camera to capture this line.

1.2 Objective

As previously mentioned the automation cell at GKN is a part of a larger EU project called PERFoRM with the goal of creating a common standard for Agent based manufacturing processes. [1][4][5][6]. A multi-agent based system consists of multiple agents working together and using a middleware[5] for communication and system design[6] with respect to both hardware and software.

The goal of this thesis is to evaluate the development process of a complete agent in a multi-agent system. This is achieved by developing, manufacturing and implementing a measuring agent, to be used within the MAS station built at PTC. When implementing such an agent, the challenges of e.g. the mechanical design, PLC's programming in such an environment with regards to the interfaces set by the cell, both electrical as well as pneumatic, was evaluated during the development. The measurement method was also evaluated during the development of the agent.

1.2.1 Ethical aspects

The continued development of this demonstration cell will lead to an industry with less manual work and more autonomous production. This work could remove unhealthy and non ergonomic tasks currently performed by hand, which would improve the working conditions for the employees[7].

By introducing autonomous production systems there will be a lower chance of errors and therefore less scraped products. Overall production will be more efficient with less downtime when changing product design and processes since the modules are designed according to plug-and-produce[1].

1.2.2 Scope & Boundaries

This thesis focuses on understanding the difficulties and demands set by multi-agent based production systems with regards to smart and flexible automation cells. Focus will be on further understanding of Cyber-Physical systems and Multi-Agent systems and how it is implemented in the PERFoRM cell located at PTC. Once the challenges are clear, a process module for dimensional measuring will be developed and implemented into the cell.

The thesis will not cover the robot programming since the movements are quite simple and does not provide useful content. The developed module will not be a production ready solution, it will however show the concept previously described.

2

Theory

2.1 Multi-Agent systems

Multi-Agent systems contains several different Agents that could have different individual goals that interact with each other[8]. Imagine a production line of cars where the object for one Agent is to drill a hole at the correct location and correct depth while another agents objective is to attach a brake disc. This means that the two agents have different objective but together with all other agents in the production line have the same common goal of creating a fully functioning vehicle.

MAS can be immensely complex or very simple depending on how the agents are configured. For instance, each agent might have been developed independently by different developers. That way each agent have different motivations and goals [8][9] which would add complexity to the MAS system compared to if they were developed with a specific goal and common motivations. The actual task at hand will naturally affect the complexity as is the case with all automation systems.

Figure 2.1: Smart Factory with smart connected devices visualizing high level MAS

An example of a MAS could be the following: an agent sends a request to a production system that part A has to be welded for instance. This agent would then get different offers from other agents who can perform the said task. The requesting agent then chooses the most suitable agent to perform the job based on time and resource limitations. The chosen welding agent in this case might in turn might use other agents to aid with the task[10]. Let's imagine that there is a station like the PERFoRM station that has 3 different welding agents connected at the same time, one might be for small components and the two other for large components but one is occupied but fast and the other is available but slow. When the requesting agent from the example above gets the offers from the agents in the station it would get three possible solutions. Since they all have different properties an optimization problem must be solved wrt. time and resource utilization. With this said, agents are not limited to robots and machinery, it can also include people. [11]

2.2 Agents

According to Boissier et al.[12] Agents can be defined as a software or hardware that contains processing mechanics and data. Boissier also mentions that Agents can take control of their own actions and decisions affecting and reacting to the environment it is situated in with other Agents and norms. With this definition it is possible to split it up to three different types of Agents from an overall perspective, Situated, Social and Organization Aware Agents.[12] He writes that Situated Agents act on themselves and the environment while social Agents also act on other Agents where Organization Aware Agents also act on the norms of the organization. From his texts it can be concluded that the larger the scope is for an agent the more complex it becomes. The more simple of the three defined types of agents is the situated agent that only has to care about itself and the environment but the larger the scope is the potential for flexibility is increased.

2.3 Cyber-Physical Systems

Cyber-Physical systems(CPS)[13] is a term most frequently used when talking about how physical systems are linked/connected to the cyber environment. By implementing a robotic cell using CPS methods, sensors and data can be better utilised to analyse the processes for performance and quality[13]. CPS can also be implemented with features for showing the data in a descriptive way for a user to monitor. It can also provide a network for different subsystems of the cell to communicate which is essential for MAS [13].

2.3.1 Cyber-Physical-Production Systems

Cyber-Physical-Production Systems or CPPS for short is a subcategory of CPS where the ideas of CPS in implemented in a production environment[14]. Monostori et al.[14] states that this means combining mechanical and electrical components and connecting to other similar systems and the industrial network to create a connection to production and logistics networks. This means that a production system could be controlled from a superior system that handles the entire plant and has the complete picture of the component flow and an understanding of what actions are required. According to Monostori, CPPS gives an opportunity to have a simulated system running in parallel to the real system based on sensor data and component models to be able to analyse and compare equipment and machines. Further more, Lee et al.[13] states that this gives the factory a great overview of how the expected performance should be and could be used to make the factory self-configurable and self-maintainable. Component flow is possible to predict and changes made in the virtual twin of the factory would mirror the reality meaning less downtime and uncertainties when machines and other production equipment need changing[14]. For all machines and equipment to be able to connect to the industrial network there has to be a middleware that can take care of how every Agent in the system interacts and communicates.

2.4 Middleware

A Middleware from a computer science perspective is basically a software layer that "glues" different software applications, a general interface to handle many different standards of communication[15]. This also applies to networked systems where the applications are running on different hardware according to HSEL et al.[5].

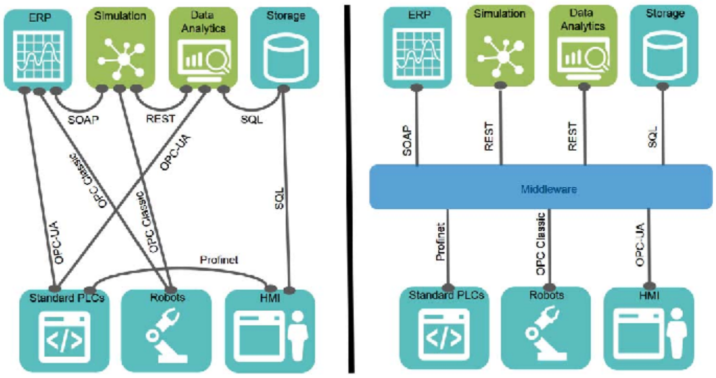


Figure 2.2: Difference between a system with and without middleware[5]

Using a Middleware makes the entire system more versatile and flexible since the Middleware will handle all standards that is required and have the possibility to store and manipulate data such that the data from one module can be transferred and used by all others connected to the same Middleware[5]. As can be seen in figure 2.2 Middleware make the system more structured and flexible.

2.4.1 OPC-UA

OPC-UA[16] is a kind of middleware which uses a machine – machine communication protocol for industrial automation and is developed by the OPC Foundation. OPC-UA is an industrial standard for communication where it is sending messages between clients and servers and is platform independent[17]. Borsych[15] writes that OPC-UA besides offering standardized communication protocols also provides data models for a set variation of data types but also states that the OPC Foundation welcomes additions of vendors and standardisation organisations to broaden the capabilities of OPC-UA.

3

The MAS in the PERFoRM cell

Since this project has been worked on quite extensively for a few years means that some parts of the concepts is already finished, for instance the physical layout of everything is finished as well as software for the Agent system. The design of the physical layout, safety system and docking system has already been developed by Julie Portal[3] as part of her Thesis. A standard module and docking system can be seen in figures 1.2 and 1.3. The Agent system was also part of a Thesis by Waldemar Borsych[15] as part of the PERFoRM project.

The cell currently has two different agent systems implemented, one developed in the PERFoRM project and one developed by University West where they function slightly different.

The idea used in the PERFoRM project utilises a more de-centralized approach where the supervising agent can present the system with a task and they ask for offers from the modules whether they can accomplish the task and at what cost, for instance energy and time. The supervising agent can then take a decision on who does what based on the resources at hand. Another opposite approach which has a more centralized thinking where the supervising agent has all the knowledge about the automation cell at hand and can therefore take all decisions without asking for "quotations". This is a fundamental difference between the PERFoRM project and the system developed by University West. This report uses the PERFoRM approach.

For the communication system in the automation cell, there is a middleware implemented which enables the cell to have a common communication infrastructure for every agent[5]. These agents are supposed to be able to communicate and take decisions by themselves, for instance: A part comes in and the agent where that part is stored tells the rest that a certain process is needed. The other agents can then give an offer if they can execute that process and also how much time it will take[4]. Then a decision is made and the process is executed accordingly and so forth [6].

Every module and agent of the automation cell is set up as a OPC-UA server and the main supervising Agent is set up as the client. The client in a network of OPC-UA servers is deciding everything from what data to be fetched from where and sent to whom. This means that the internal communication of the modules can be everything as long as the Agents OPC-UA server can send and receive what it requires for the complete system to operate. [18]

4

Agent design

The goal for the agent is to be able to grasp and orient the measurement object at hand such that all interesting geometries can be reached and measured by the GapGun held by the robot. This means that there is two main problems, orientation and gripping. Solving these will prove difficult and the sections below will go through the problems and solutions chosen. There are a few requirements for the module listed below.

1. Harmless gripping for the object
2. Exact orientation
3. Be able to grasp the three different versions of the vane
4. Must fit within the physical space available
5. Be able to communicate with the superior system
6. Safe to use e.g. fail-safe functions

Requirement 1 means that the vane must not be harmed in any way with regards to scratches and dents or similar. The actuation must be exact such that the position of the vane is repetitive and so that the same feature is measured the same way every time. Given that there are three different versions of this vane with slight variations in geometry means that it must be possible to grasp them all without having to re-configure anything on the hardware side. The overall concept of the demonstrator at PTC means that each module has a certain volume available where width and length are fixed but the height can vary. Since this module is a central part of the optical measurement process where it grips and orients the object there has to be communication between the module PLC and the superior system. One important aspect is safety, for component, operator and equipment.

4.1 Gripping

The gripping of the object can be done in various ways, however in order to be able to take measurements on the outer dimensions of the vane, the gripping would have to stay clear of every area of interest. The solution is to grip the object from the inside, this also solves another issue that occurs due to there being three different vanes of slightly different dimensions. The object is gripped with a Schunk JGP-125 equipped with two aluminium cylinders as can be seen in figure 4.1. [19]

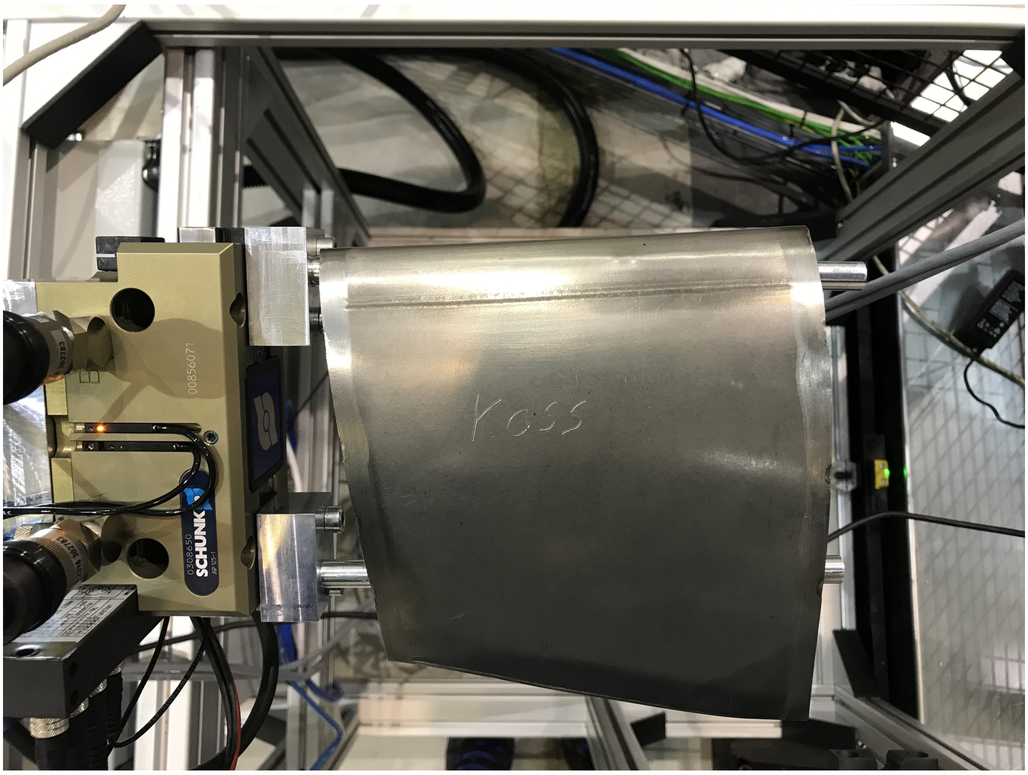


Figure 4.1: Gripper shown from above with a vane in place.

The Schunk gripper was chosen due to a good overall span and total jaw movement which was necessary due to the different dimensions among the vanes. By looking at the internals of the gripper, which can be seen in figure 4.2, the way it operates is clear. There is two air connections, one handling the opening of the gripper jaws and one handling the closing. There is no absolute position control available, only choosing open or close as control options.

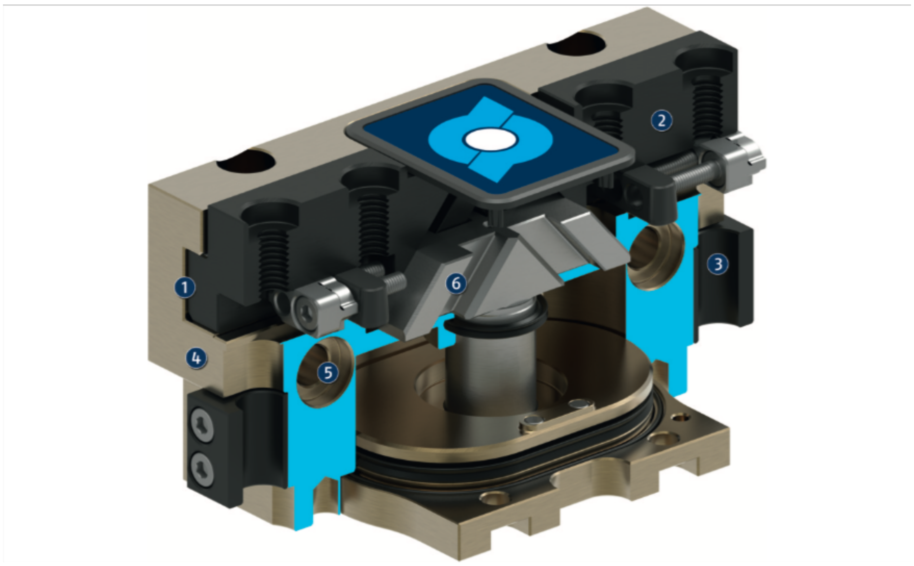


Figure 4.2: Gripper in cut section view showing the internals.

In a production facility it is sometimes dangerous to not have feedback on the system, especially on systems that move and rotate. Therefore two sensors was used as compliment. Two proximity sensors, Schunk MMS 22 magnetic sensor. This is used to detect if the jaws are open or closed and can then inhibit movement of the servo by PLC logic such that no accidents could occur. These sensors are placed on top of the gripper and marked in red can be seen in figure 4.3. The reason for having two sensors is to cover the long and varying travel.

Figure 4.3: Magnetic proximity sensors used to determine the state of the gripper

4.2 Orienting

The object has to be able to measured from different angles to reach all necessary areas and thereby it has to be able to be oriented in a controlled and accurate fashion. There can be different ways to orient an object with the two main ways of electric or pneumatic actuation. Conclusions from a market research showed that there was no viable option of pneumatic actuation with good accuracy and good freedom in the orientation.

There are several satisfying options on the market for electric actuation but few with a simple integration. Meaning that most options would require separate control electronics. The electric servo chosen and supplied by Schunk, a PDU2-70-51-PB which has integrated control- and power electronics with an integrated M12 ProfiBus connection. See Appendix A for full specification. This together with the Schunk drive protocol, makes for an easier integration with reduced amount of separate components and simpler control logic.

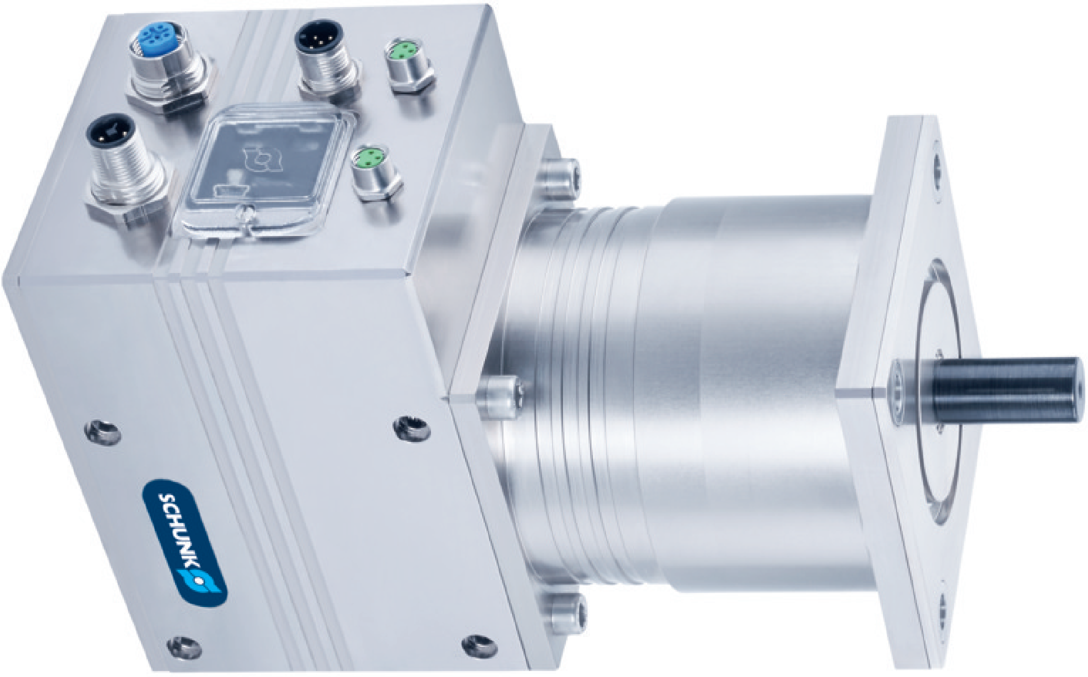


Figure 4.4: Schunk PDU2-70-51-PB servo

As can be seen in figure 4.4 the left and square half is where the control electronics and brake is located and the cylindrical half is where the electric motor and gears are located. The gears have a ratio of 51:1 meaning that the motor must rotate 51 complete turns for the output shaft to rotate one turn. This increases the absolute rotational accuracy as well as giving the unit a high output torque but slightly lower maximum rotational speed. The above mentioned characteristics are wanted for this kind of application since absolute position of the measured object is important and high rotational speed is not necessary.

Due to the fact that the control electronics are integrated makes the rest if the system a bit easier and the servo can be treated as a complete unit. The control electronics communicates with either ProfiBus or CanBus, but since the available PLC components use PB this was the chosen variant. More about the commands sent to the unit under Chapter 5.

4.3 Rotating media solution

In order for this solution to be viable certain criteria was set, where free orientation was one of them. This means that the object must be able to reach any degree in the axis chosen and that there can be no problems with wires or pneumatic hoses winding up under continuous rotation. The first of the two criteria mentioned above is solved by using an electric servo with great accuracy, the second requires several sub-solutions. These sub-solutions is covered in the following sub-chapters.

4.3.1 Pneumatic valves

Normally a Schunk gripper requires two pneumatic connections for operation, one for opening and one for closing. However Schunk offers a component which would solve this issue. This component is called ABV-MV15 and it is a valve that is electronically controlled and by putting one on the opening and one on the closing connection of the gripper means that they can be supplied from the same source of pressurised air.[20]

The two valves sit on the upper side of the gripper and contains a solenoid each for actuation, their placement can be seen in figure 4.5. This means that there is still a need to transfer compressed air to the gripper and it also brings up one more problem which is the transfer of electrical power and signals, this is covered in chapter 4.3.3.

Figure 4.5: Schunk ABV-MV valve clearly showing that one source of compressed air is needed

4.3.2 Pneumatic transfer

Since it still requires a pneumatic connection, there had to be a special design to solve this which can be seen in figure 4.6. As can be seen in the figure marked by the green line, the air comes from above at the green circle, into the housing which is mounted stationary on the module. The air then goes into an air pocket inside where there are holes around the surface of the shaft to let air into the centre channel and then onwards to the exit close to the gripper and its valves.

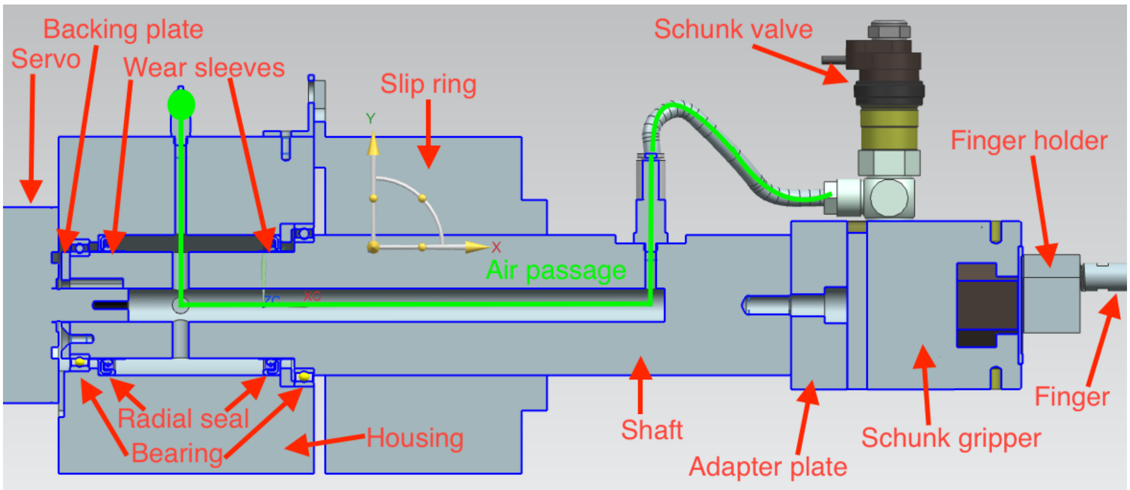


Figure 4.6: Cut section to show components and internal design

The air pocket is sealed by two BABSL 38 50 6 Seals which are sealing against SKF speedi-sleeves. The pressurised air will affect the service life of the seals and can be seen in figure 4.7. It shows that with higher pressure there is a higher force pressing the seal against the mating material. The system pressure in the automation cell is 6 bar and given that the shaft material is aluminium there is an absolute need to have speedi-sleeves which makes the mating surface hard and smooth to ensure a good and lasting seal. Figure 4.8 shows how a speedi-sleeve looks and it is basically a very thin walled tube that is pressed on the a shaft to ensure that the surface is hard and smooth to prolong the life of the seal and shaft. A list of all components can be found in Appendix B.

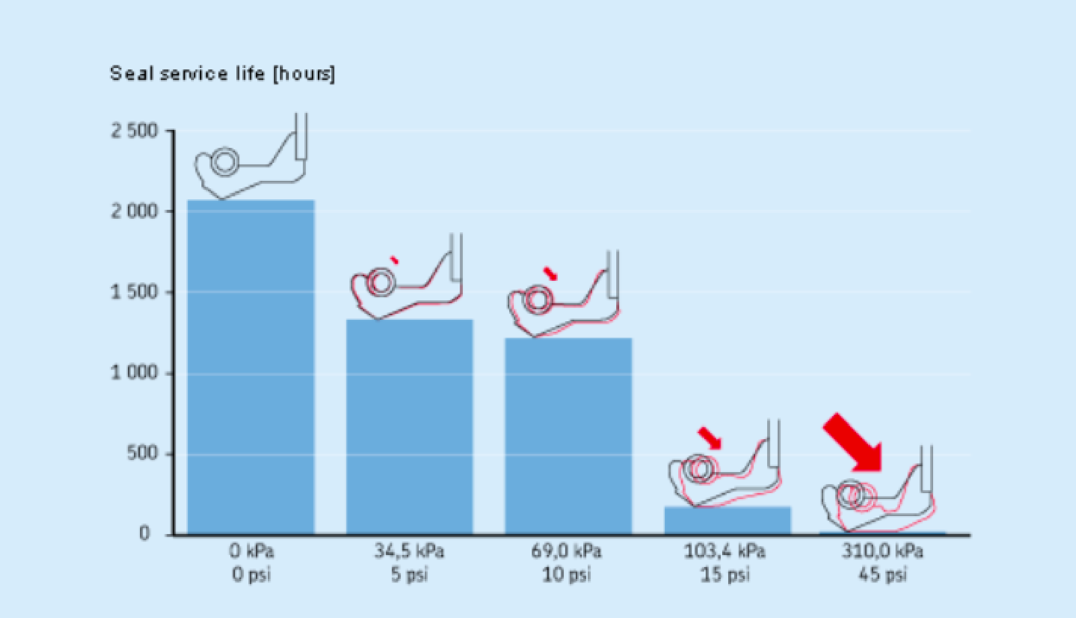


Figure 4.7: SKF seal service life at different operating pressure difference. Click here.

Figure 4.8: SKF Speedi-sleeve. Click here.

4.3.3 Electrical power and signals

Electrical power and signals still has to be transmitted without winding up any cables around the shaft and gripper and a slip ring was used for that.A slip ring has a certain amount of cables each representing a channel which can be seen in fig 4.9, A slip ring has one stationary part and one rotating and the electrical connection is usually through a brush in contact with a ring. Slip rings in general can't handle high rpm which in this project is no concern since there is no need for high rpm.

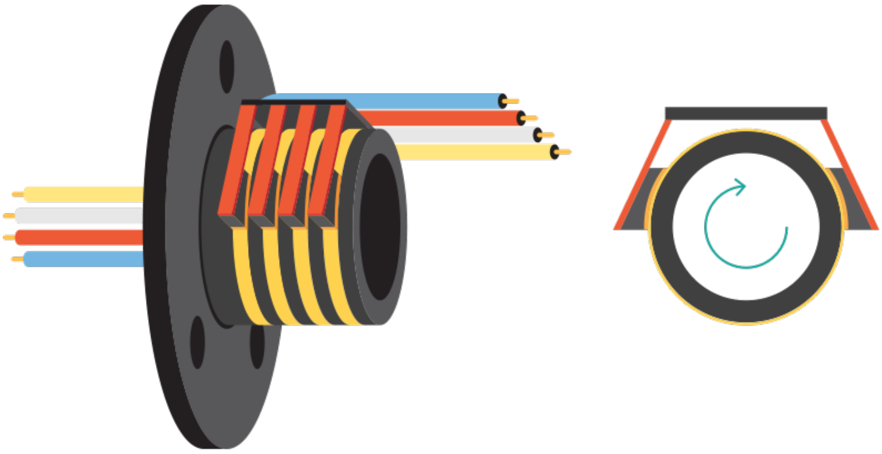


Figure 4.9: General concept of a slip ring.

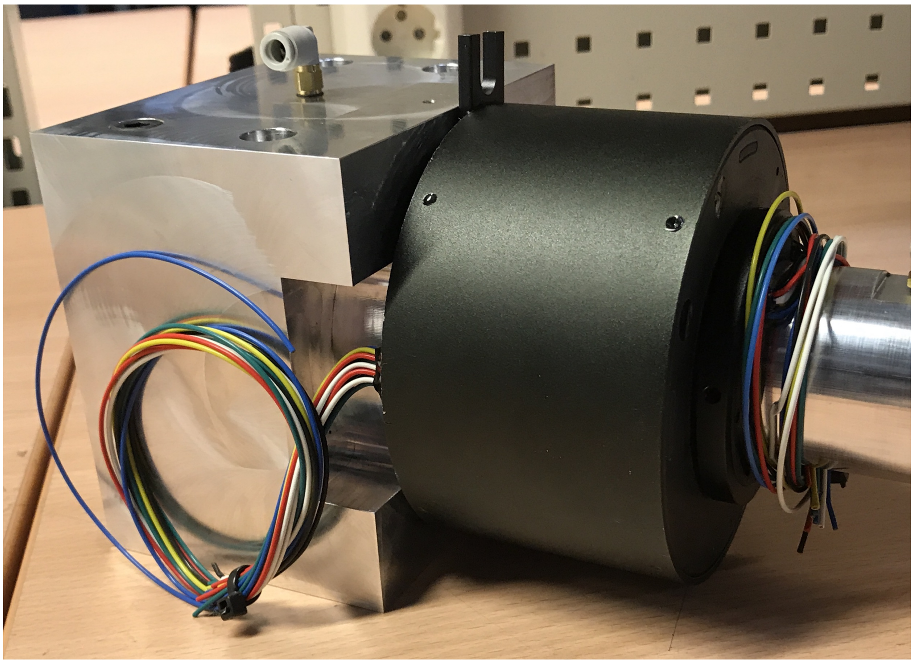


Figure 4.10: Slip ring used in this project

The slip ring used in this project is a SETH-50-120 supplied by Servotronic and can be seen in 4.10. This servo has a length of 70mm and has a total of 12 5A channels to be handle both signals for the proximity sensors, control signals to valves as well as power to operate the valves.

4.4 Final solution

The final solution is tool that can both grip the three vanes with good angular repeatability. The final mechanism, as can be seen in figure 4.11, is compact fits well within the pre-defined restricted module dimensions.

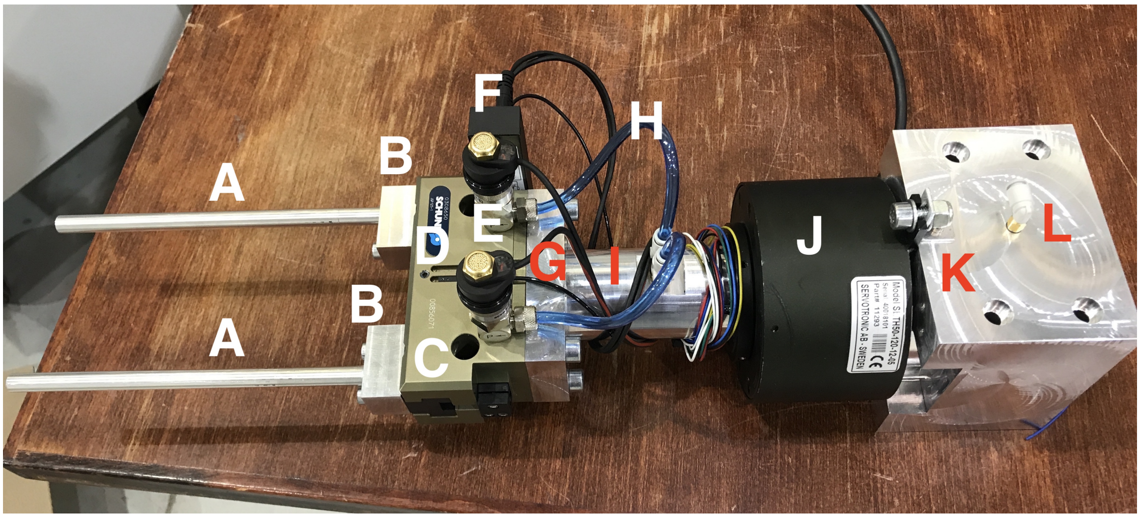


Figure 4.11: Mechanism constructed to handle the movement and media transfer

Figure 4.11 shows the main assembly which is the central part of the thesis. It consists of the following visible components from the left:

A) 2 x Finger
B) 2 x Finger holder
C) Schunk JGP-125 gripper
D) 2 x Schunk MMS-22 sensor
E) 2 x Schunk ABV-MV valve
F) Schunk Connection block
G) Adapter block
H) 2 x Pneumatic hose
I) Shaft
J) Slip ring
K) Housing
L) Pneumatic connection

4.5 Safety

Safety is an important aspect in general but for GKN especially. To avoid the risk of an object flying away from the gripper due to lack of pressure or broken components a sensor is used to monitor if the gripper has opened or not. This signal is also transferred through the slip ring and into the I/O module connected to the PLC.

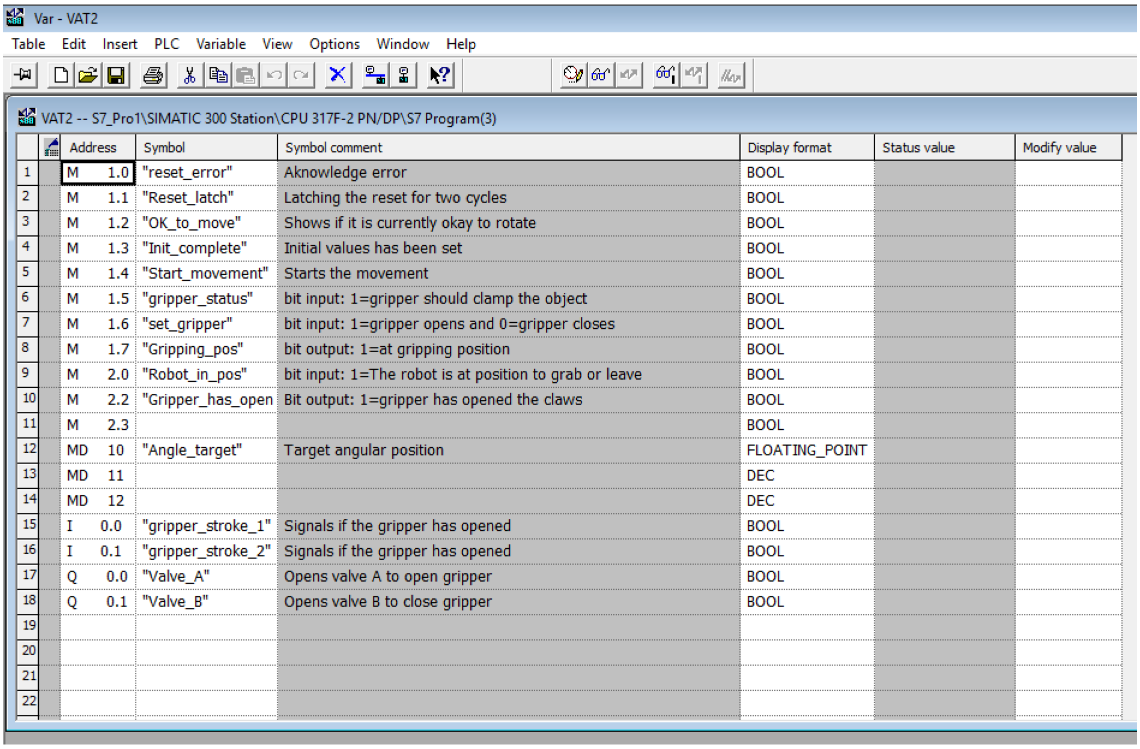
5

PLC and accessories

The complete PLC setup consists of a PLC, network card, power supply and I/O module as can be seen in figure 5.1. The PLC is a Siemens S7 317f-2 PN/DP which is connected to a network card Siemens CP 343-1 Lean. The reason for this older spec PLC is due to a drive protocol included with the servo which only operates for this spec. The PLC communicates with an I/O module that takes care of controlling the gripper valves and reads sensors, the module is a Siemens ET 200S paired with one power module, one digital output module with eight outputs as well as one digital input module with eight inputs. The power supply is a Siemens SITOP PSU100L which supplies the PLC setup as well as the servo which runs on 24V. A more detailed specification can be found in Appendix C.

Figure 5.1: Zoomed picture of the components installed in the PLC cabinet

The software was first tested on a bench setup to easier debug both physical connections as well as the logic without having to work in the cabinet itself. Complete code can be found in Appendix D. The Schunk Servo was delivered with a software module which is used to control the servo together with setup specific logic such as making sure that the servo is allowed to move if it has gripped an object or not.



VAT2 -- S7_Pro1\SIMATIC 300 Station\CPU 317F-2 PN/DP\S7 Program(3)

	Address	Symbol	Symbol comment	Display format	Status value	Modify value
1	M 1.0	"reset_error"	Aknowledge error	BOOL		
2	M 1.1	"Reset_latch"	Latching the reset for two cycles	BOOL		
3	M 1.2	"OK_to_move"	Shows if it is currently okay to rotate	BOOL		
4	M 1.3	"Init_complete"	Initial values has been set	BOOL		
5	M 1.4	"Start_movement"	Starts the movement	BOOL		
6	M 1.5	"gripper_status"	bit input: 1=gripper should clamp the object	BOOL		
7	M 1.6	"set_gripper"	bit input: 1=gripper opens and 0=gripper closes	BOOL		
8	M 1.7	"Gripping_pos"	bit output: 1=at gripping position	BOOL		
9	M 2.0	"Robot_in_pos"	bit input: 1=The robot is at position to grab or leave	BOOL		
10	M 2.2	"Gripper_has_open	Bit output: 1=gripper has opened the claws	BOOL		
11	M 2.3			BOOL		
12	MD 10	"Angle_target"	Target angular position	FLOATING_POINT		
13	MD 11			DEC		
14	MD 12			DEC		
15	I 0.0	"gripper_stroke_1"	Signals if the gripper has opened	BOOL		
16	I 0.1	"gripper_stroke_2"	Signals if the gripper has opened	BOOL		
17	Q 0.0	"Valve_A"	Opens valve A to open gripper	BOOL		
18	Q 0.1	"Valve_B"	Opens valve B to close gripper	BOOL		
19						
20						
21						
22						

Figure 5.2: Variables that are used to handle the module

Figure 5.2 shows the main global variables used to be able to control the module. It checks that the initialization has been done correctly and the zero position is correct, otherwise it won't move and it would be forwarded to the superior Agent. The safety logic also checks if the gripper should have gripped an object and if it has done so and thereby can determine if the servo is allowed to rotate or not to prevent possible damage and flying objects. It can also determine if the servo has reached its home position to be able to leave and take objects without possible unwanted contact between gripper and robot that could cause damage. Before releasing an object it also checks that the robot is in position to grip the object and has gripped. Basically handles all possible scenarios that could occur and only allows movement when it is absolutely safe to do so.

To make the servo move a numeric value is set to "Angle_target" in degrees and then set TRUE to "Start_movement". To grip simply put TRUE to "set_gripper" and FALSE would do the opposite. Please see figure 5.1 which is the finite state automata clearly showing the possible states and conditions that applies to the module. The states and initial values are given in equation 5.1 below.

$$\Theta = \begin{bmatrix} Error \\ OK\_to\_move \\ Init\_complete \\ Start\_movement \\ gripper\_status \\ Gripping\_pos \\ Robot\_in\_pos \\ Gripper\_has\_open \\ Movement\_OK \end{bmatrix}, \Theta_0 = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{5.1}$$

Figure 5.3: Finite state machine

5.1 Measurement device

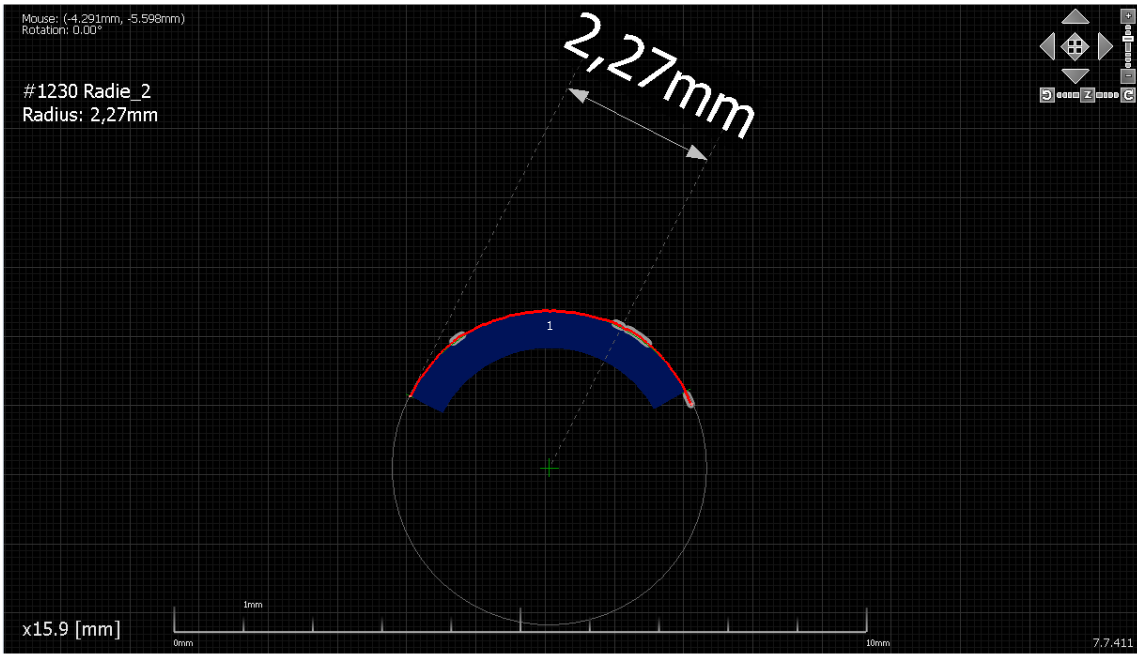
A GapGun Vectro is used for measuring the vanes and it is a robot held 2D line laser with different tools and toolboxes available to suit every kind of measurement. The main focus was to measure milled welds seams and overall radius of the vane. The important part is not if the object itself is within tolerance but if this is a viable method considering repeatability and accuracy.

Figure 5.4: GapGun Vectro setup. Click here.

As mentioned before the sensor is mounted to the end effector of the robot and the control electronics is placed somewhere else, which can be seen in figure 5.4. The control electronics handles the control of the sensor and also communication to an external system which can send commands to fetch data and to make measurements.

As mentioned earlier the Vectro measures a 2D-line where the toolboxes available can help calculate radii and distances automatically. An example measurement can be seen in figure 5.5 where a simple radii is measured and calculates the radii. The GapGun system takes multiple measurements and compares them to each other to determine if it was an accurate and correct measurement. Typically a first measurement is taken to build the algorithms that evaluates the geometry. A profile can also be generated from CAD but since the manufactured part might be slightly different an actual measurement would be better in terms of developing an accurate algorithm.

GapGun originates from the automotive industry where is has been used to measure the gaps between the body panels in terms of width and height. It was also used to measure radii and sharp edges and angles but the tool has since developed to handle more and more features. It does struggle with reflective surfaces which is typically the case with aerospace engine components.



Mouse: (-4.291mm, -5.598mm)
Rotation: 0.00°

#1230 Radie_2
Radius: 2,27mm

Figure 5.5: Example of a GapGun Vectro measurement

6

Results

6.1 Measurement results

There are certain areas of interest on this particular component where measurements has taken place which will be described below. Given that this is an aerodynamic component the trailing edge and trailing edge radii is of high importance for its performance and for this thesis three measurements along the edge was deemed enough and can be seen in figure 6.1. The leading edge is also important for performance and for testing purposes two points would be enough to test as can be seen in figure 6.2.

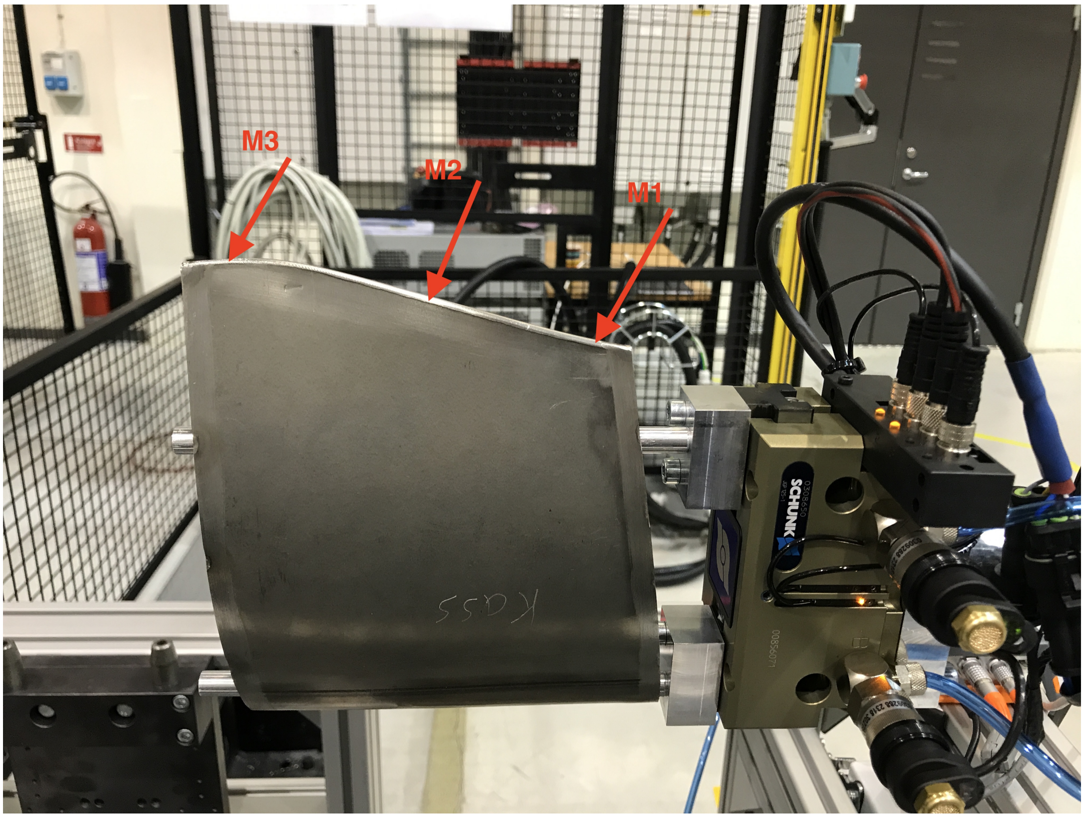


Figure 6.1: Measurement points M1, M2 and M3

Figure 6.2: Measurement points M4 and M5

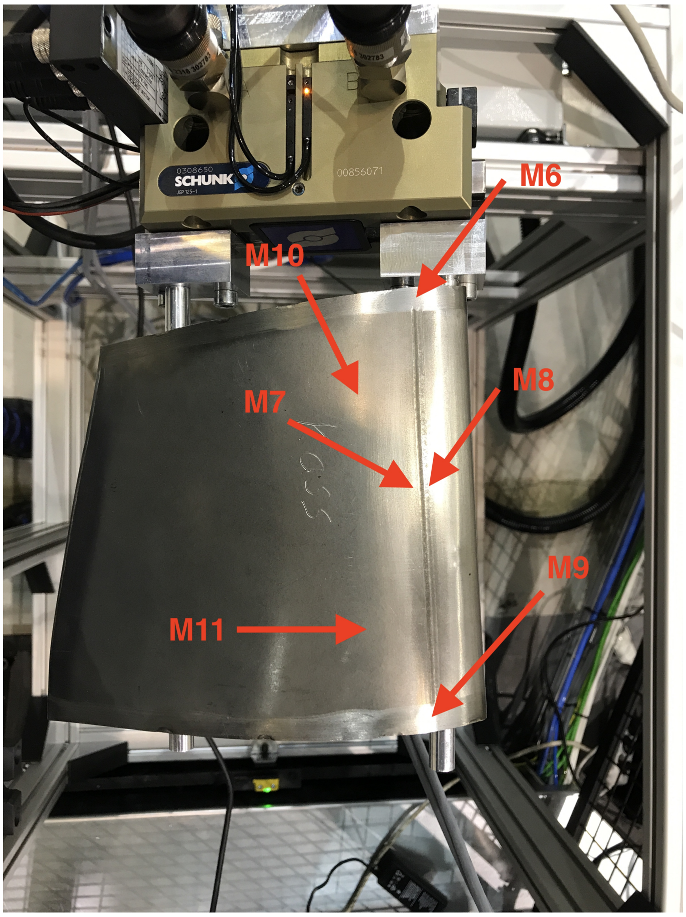


Figure 6.3: Measurement points M6 to M11

The top surface has several points of interests highlighted by figure 6.3, to test the limits of the GapGun Vectro system. This component is welded which can be seen above by the grey vertical line between the red arrows. To prepare for the next step in the production line the weld seam must be machined to flat surface at the flat ends to be able to weld it into the final engine frame. Thereby M6 and M9 are necessary to measure. M7 and M8 are measured to be able to evaluate how well the vane has been welded together. M10 and M11 are a test to see if the Vectro can measure such large and possibly changing curved surface.

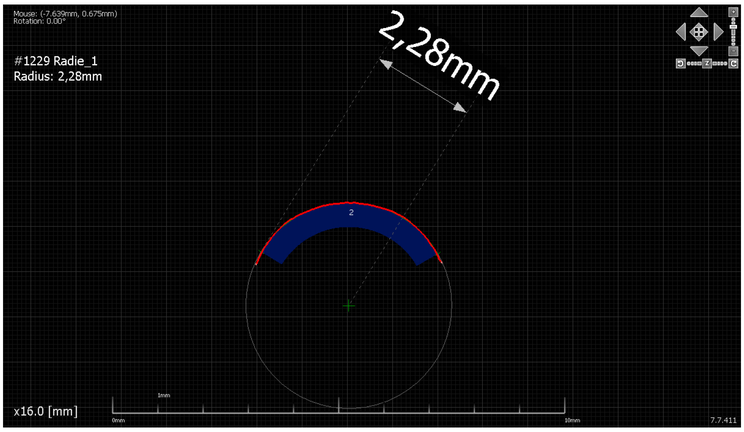


Figure 6.4: Measurement of the trailing edge

Given the restricted width of a single measurement a trailing edge should in theory be simple to capture and the result of which can be seen in figure 6.4. The measurements of trailing edges can be done with good results and repetitiveness. As previously mentioned the GapGun uses different algorithms to capture different geometries and all can be adjusted to fit basically every need. This measurement however is simple since it consists of one continuous radii and nothing else and can therefore use the standard radii calculation tool available in the GapGun software without any modification.

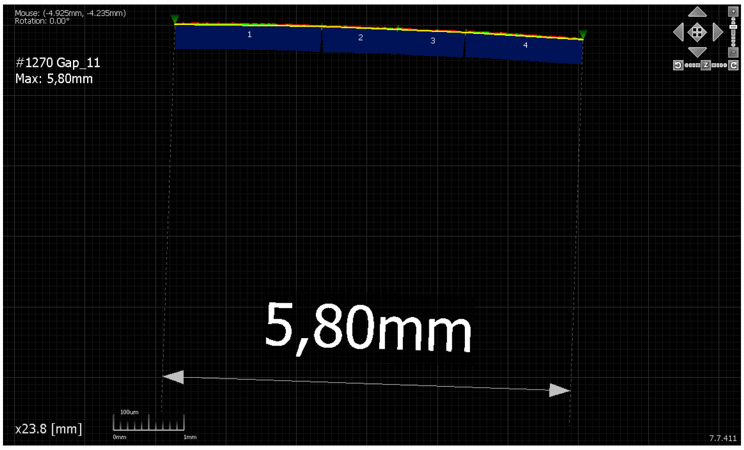


Figure 6.5: Measurement of a machined weld seam

Measuring the machined weld seam is difficult since it can look quite different from time to time and there might not be a single algorithm from the usual tools to cover all possibilities. There is another tool available which is described later in the chapter which would be suitable for this kind of varying geometry that can take many different but okay forms. This area might for instance be machined flush with the curvature of the vane which can be seen in figure 6.5.

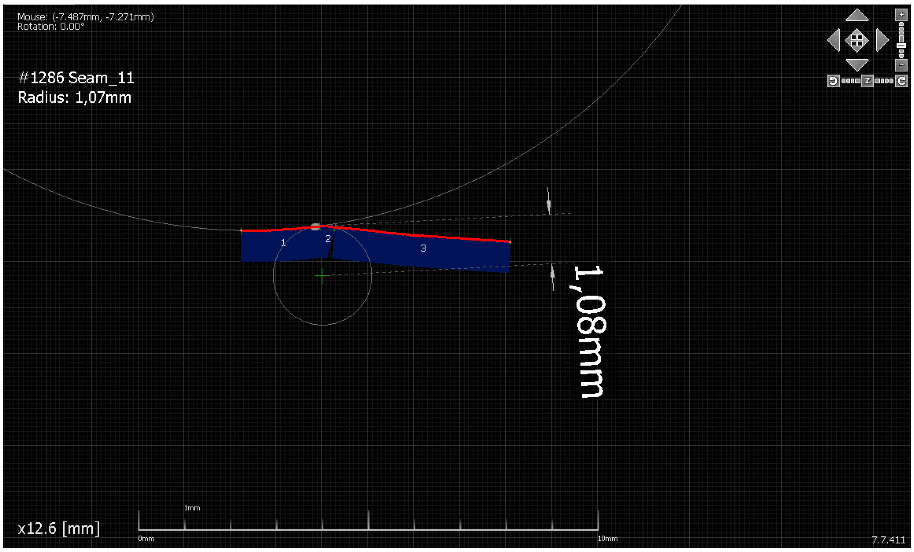


Figure 6.6: Measurement of a weld seam

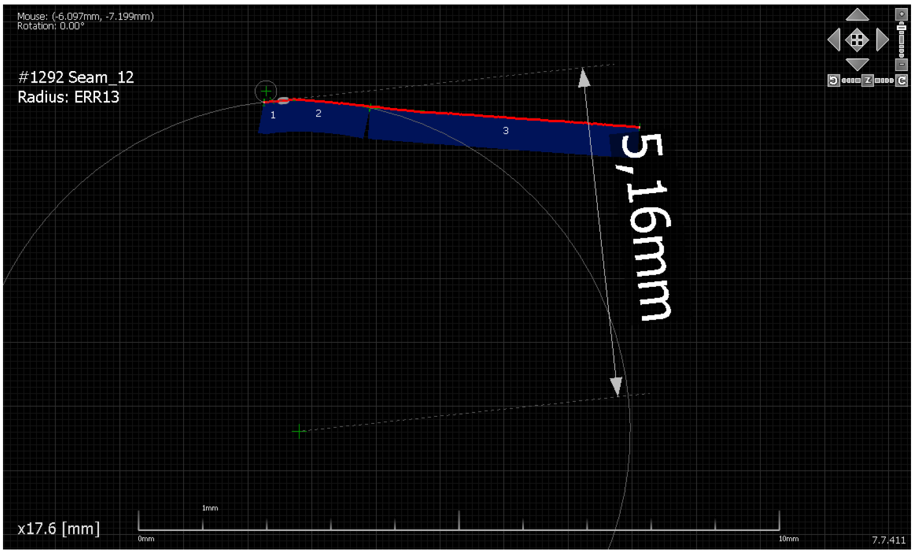


Figure 6.7: Measurement of a weld seam

Due to a wider seam than the actual span of the sensor the measurement of a weld seam has to be split into two measurements(M7 and M8) to be able cover the entire width of the weld as can be seen in figures 6.6 and 6.7. Since it is difficult to make assumptions based on two different measurements of the same geometrical feature in this case. It can be captured in one go but it would require a sensor which covers a greater distance, however that comes at a cost where the resolution and thereby the accuracy is compromised and might not be deemed enough to capture all features. It is currently not possible to take two measurements and merge those with the help of the robots coordinates to analyse the entire geometry in one take.

GapGun are working on an updated sensor which would make wider measurements possible with maintained accuracy which could solve half of this problem. The second issue is that these tools used to get the dimensions rely on the geometry to remain rather similar. This means that for instance a gap should have a clear gap to be able to get the dimension. Welds have a tendency to have slightly different form especially if done by hand. This could be a problem if the algorithm would for instance require a certain form.

Figure 6.8: Example of a weld seam

Figure 6.9: Example two of a weld seam

A weld can have varying attributes but still be deemed OK, in figure 6.8 and 6.9 two examples are shown where the same standard algorithm can't be used. In the GapGun software the user specifies from left to right which type of geometry to expect, for instance "l" for straight line, "r" for radius and so on. For the first of the two figures mentioned the tool would have to be specified with "lrrrl" to capture the entire width. The second however would require a slightly longer list to cover the feet of the weld, "lrrrrrl" would cover this and is clearly different from the one needed for the first example.

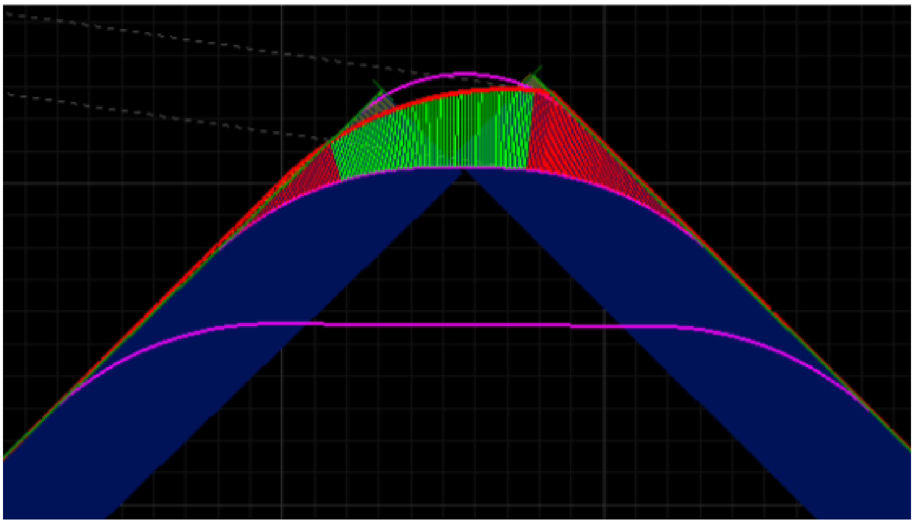


Figure 6.10: Example of how a different algorithm could be used

As mentioned before there is another tool in the GapGun toolbox that could cover the slight deviance in geometry with some restrictions. This tool compares the measured profile with three other, a minimum, maximum and nominal profile. These profiles can be made manually but to cover more advanced profiles they can be generated from various CAD software. When this tool is used the measured profile is compared to the maximum and minimum line and if it is within these the result will be green and otherwise red. The biggest drawback is that it will not be able to calculate any radii, length, angle or gap from this so it will only work for geometries without such demands but in this work alone two areas for this component has been identified to be able to utilise this tool. This tool has not been evaluated in this project since it would require a deep-dive into the arts of welding.

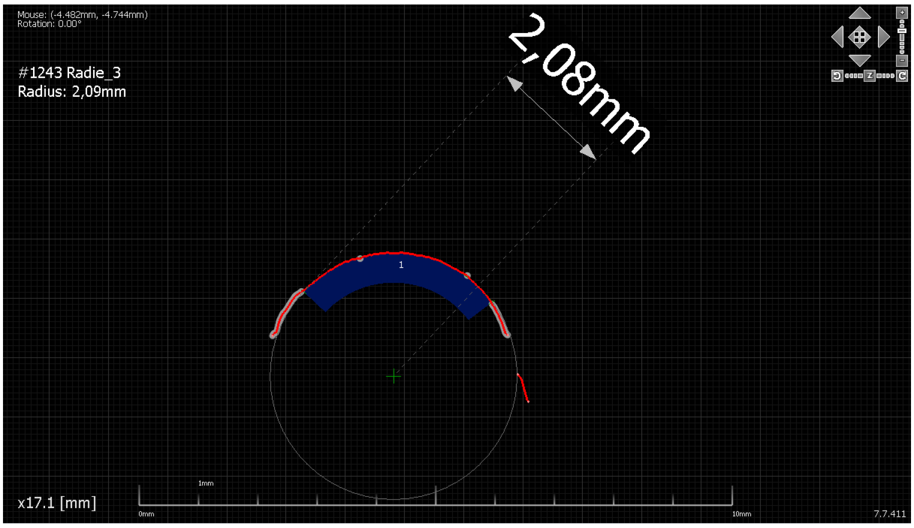


Figure 6.11: Measurement with noise

Optical measuring systems are typically sensitive to reflective surfaces as can be seen in figure 6.11. Here it is affected on the surfaces on the sides where it reflects the laser too much and it is clear by looking at the marked bits in grey which on the left hand side it is not very accurate and on the right hand side there is actually a bit missing. This issue is worse if there is an internal radii which then reflects the laser inwards and creates a very bright area and nothing can be extracted from that measurement. This can sometimes be solved by spraying or painting the material to reduce the amount of reflection but not all components are allowed such process.

There are a few more question marks to straighten. How will the system adapt for the different vanes given slight changes in dimensions and how will it handle different components? All components that will be used in this kind of setup will have a QR code that is read every time it is picked from the components stand module and thereby it is known what to measure and how. For the three different vanes used there will be a slight change in robot coordinates but the amount of measurements will still be the same and the modules hardware can handle all three variants.

The data generated from the measurements is another question mark since there is nothing setup to handle it so far at PTC. Given that the majority of aerospace components are safety critical traceability is incredibly important therefore a remote server would be ideal to store all the data related to every component such that the data can get fetched at any time for any components. Since they already have individual partnumbers aids in storing every detail possible for every component in their way through the processes.

6.2 Agent operation

In Chapter 4 six criteria for the module was listed, as can be seen below. These criteria can be used to evaluate if the implementation and module design was successful or not.

1. Harmless gripping for the object
2. Exact orientation
3. Be able to grasp the three different versions of the vane
4. Must fit within the physical space available
5. Be able to communicate with the superior system
6. Safe to use e.g. fail-safe functions

Harmless gripping of the object, the aluminium rods used in this project are harmless for the object at hand but it could be improved to steel rods with Teflon coating if this would be implemented in the factory, this would reduce flex, friction and improve stiffness of the rods.

Exact orientation, the repeatable accuracy is defined to 0.03° which is accurate enough for the measurement method used.

Be able to grasp the three different version of the vane, yes there is no problem grabbing the three vanes without having to swap out the fingers or the gripper since the total throw and movement of the Schunk gripper is enough to cover all three.

Must fit within the physical space available, it was successfully designed to stay within the space of the standard module space.

Be able to communicate with the superior system, communication is possible, however as will be explained not perfectly.
Safe to use e.g. fail-safe functions, the safety of the module has been tested and there where no immediate problems found.

So to conclude, the agent operates well by itself and all the logic work well and according to figure 5.3. It has been tested separately from the rest of the automation cell due to the current setups incapability to send numerical values such as the target angle for the servo. The reason for not being able to send numerical values Agent-Agent is due to the fact that Plain Old Java Objects(POJO) are used as messages and these are a type of string[15]. The current OPC-UA server setup is only capable to send strings which would require a comprehensive amount of re-work on the programming to evaluate the strings and convert to a numerical value and check for plausibility. Given this incapability of the current MAS setup it was deemed not needed to adapt the modules code for this.

The PLC of the module is connected to the OPC-UA network of the automation system and commands could be written and signals read which means that the communication works as intended albeit without the possibility to set target angle of the servo. The safety critical logic for feedback for gripping and allowance to movement when robot is near could be tested with the help of a laptop manipulating the signals. There was no issue found with the safety of the module.

7

Conclusion

One of the objectives with this project was to investigate if this process could be implemented in such an environment as the PERFoRM cell, and yes it clearly is possible to do so but there are certain things that needs to be addressed first. Firstly the current setup can't send numeric values which would be necessary to be able to send the target angle to the servo. Other than that the module works by itself with all of its own logic. The general concept of what to measure with can also be changed, especially if the system would be carried over to real production since it would be advised to have the main robot in the cell work on something else while measurements are being taken. Hence it would be possible to have a second module mounted on the slot to the side which could carry a second smaller robot which then handles the GapGun while for instance the big robot grinds and prepares the next component. This would better utilise the resources provided by this concept. Given that this is in fact a cell to demonstrate the technology it was not deemed necessary to have a second robot in use for this matter.

The method of measuring is also an area where improvements can be done where for instance a 3D scanner could be used which captures the entire object and creates a three dimensional virtual copy that can be compared to the intended CAD design. These are in general more expensive and the accuracy can sometimes be too poor given the tight tolerances in the aerospace industry. The chosen GapGun Vectro unit has as preciously shown poor performance with shiny surfaces, this is however something GapGun claims that they are working on which could improve the issue or completely remove it.

To conclude, with this design, measuring object and measuring tools it was a successful implementation of this process even though a complete installation could not performed due to lacking features in the current Agent system.

Another interesting topic to discuss is what components are needed to have a functioning MAS automation station, not only hardware and software but also various surrounding systems. There are certain aspects that needs to be taken in consideration when setting up this kind of environment so let's use this particular cell to discuss around.

First of there need to be well specified processes and demands set such as how many slots should there be available at one time, not how many processes that should be usable since that can easily be solved by changing module. What kind of technical equipment should there be available? Meaning that there could be several robots working in the specified area or even zero robots. Should the cell be able to cooperate with humans or should it be completely stand alone to work by itself? This would set hard constraints on the safety of the cell and surrounding systems. Then there is the side of the cell which can't be seen with the eyes, electricity and software. This could be the most important thing in an Agent-based industrial environment.

Having a pre-defined interface between the modules really helps with reducing the complexity and the amount of potential problems with the system. By having that also improves the ability to develop new modules/agents to add to the system which creates the MAS. If the inter-module inter-agent communication is standardised then the agents themselves can have whichever way of communicating internally as deemed best. The module developed in this project is a clear example of just that, the inter-agent communication is through ProfiNet using UPC-UA client and servers while internally communicating with the servo is with ProfiBus. That opens up more possible solutions for the same problem at hand.

The software is an important piece of this puzzle and without it there would simply be no usable Multi-Agent automation cell without it. There are tools available to develop such software and JADE is an example of that which is a toolbox based on the JAVA programming language and is in fact used in the PERFoRM project.

What tasks and decisions should be taken by the module agents and what tasks and decisions should the overall control take?

When it comes to decision making and who to perform certain tasks it gets a bit difficult and there is a need to make thorough investigations on the system design based on the requirements. For every case and every automation station that will use MAS there will be different optimum configurations. Sometimes it would be advised to have one agent controlling many agents. Let's make two different examples from the same process.

1) Imagine the measurement module described earlier. The superior Agent can read from the factory work order that a measurement of Vane A must be performed. It has knowledge about the other agents in the system and can then demand the Optical dimension measurement module to make X amount of measurements on defined locations on the vane. The process is executed and proceeds to tell the superior agent and then the work is done.

2) Imagine the same module. This time the Superior agent don't have as much control over the rest of the systems which means that it now asks the other agents if any of them can perform this measurement stated by the factory work order. It may get several replies of what services can be provided and also the amount of time required and if they are busy at the moment with other tasks. Suppose now that this Optical dimensional measurement module has the best offer and then receives the object in question. Now the module can fetch the work order from factory servers and proceed the process without getting all commands from the superior agent.

Example one is a case of a more centralised control of the automation cell and its processes while example 2 is acting more of a system with distributed control. Which of these suits best will always depend on the application and both have their pros and cons. By having several less complex smaller systems to work together can make the complete cell simpler. More over, having a system of distributed computational power and control can also drastically reduce cost and downtime for repairs and service.

For this module my understanding is that the best solution would be a mix of the two examples where the superior agent would supply the system with data of what part and which coordinates to measure and then await a reply with results from the automation cell which is then uploaded to a factory server to store all manufacturing data related to every component. I think this is a good way to do it since there are several different vanes with slightly different dimensions and thereafter also coordinates to measure. This kind of system should be easily adjustable to new and different components and should handle as much as possible without the need to be re-programmed, therefore by having the components process data stored and communicated through the superior agent would reduce the component specific programming to make it more versatile.

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A

Servo specification

Technical data PDU 2-070-051-PB-I

ID	0360550
Torque [Nm]	4.3
Max. torque [Nm]	16.8
Standstill torque [Nm]	5.3
Nominal speed [1/min]	45
Max. RPM [1/min]	78
Repeat accuracy [°]	0.03
Transmission	51:1
Moment My max. [Nm]	6
Force Fx max. [N]	50
Force Fz max. [N]	0
Brake	yes
Weight [kg]	1.9
Min. ambient temperature [°C]	5
Max. ambient temperature [°C]	50
Protection class IP	40
Length X [mm]	113
Width Y [mm]	70
Height Z [mm]	148.6
Nominal voltage [V]	24
Nominal current [A]	5
Max. current [A]	16
Control electronics	integrated
Power supply [V]	24
Encoder system	Encoder (incremental)
PROFIBUS interface [Mbit/s]	12
USB interface	Host/device
Number of digital inputs	2

General notes about the series

Swiveling times
are purely the times of the module to rotate from rest position to rest position. Relay switching times or PLC reaction times are not included in the above times and must be taken into consideration when determining cycle times. Load-dependent rest periods may have to be included in the cycle time.

Repeat accuracy
Is defined as the spread of the target position after 100 consecutive positioning cycles.

Nominal currents
can be permanently actuated. With regard to all the currents which are ranging above the nominal current up to the maximum current, the notes of the individual product documentation has to be respected.

Electrical brake
The installed, electric holding brake serves to fix and hold the position in case of power failure up to the rated torque. It cannot cover any complete safety functions.

Peak torque
The peak torques serve as short-term drive reserves when accelerating and delaying.

Housing material
Aluminum alloy, coated

Actuation
servo-electric, via brushless DC servomotor and incremental encoder for controlling position and velocity.

Operating principle
Harmonic drive® gear driven directly via brushless DC servomotor

Scope of delivery
DVD with SCHUNK software and commissioning assistant, includes assembly and operating manual, declaration of incorporation, functional module for control via Siemens S7.

Warranty
24 months

B

BOM

Part	Partnumber	ID	Place of purchase	Number	Price [SEK/st]	Price [SEK]
Pneumatic hose	TU0604BU-20	154-23-871	elfa.se	1	196	196
Pneumatic connection	KQ2U06-M5A	101-30-276	elfa.se	1	35,9	35,9
Pneumatic connection	KQ2L06-M5A	101-30-163	elfa.se	1	40,9	40,9
Transformer	Siemens 6EP13341LB00	169-88-817	elfa.se	1	978	978
					Total sum:	1250,8

Part	Partnumber	ID	Place of purchase	Number	Price [SEK/st]	Price [SEK]
Loctite	243	L.24310ML	Kullagret.com	1	103,2	103,2
Loctite	638	L.63810	Kullagret.com	1	143,2	143,2
Bearing front	SKF 61809-2RS	SPK.618092RS	Kullagret.com*	1	316	316
Bearing rear	SKF 61807-2RS	SPK.618072RS	Kullagret.com*	1	228	228
					Total sum:	790,4

Part	Partnumber	ID	Place of purchase	Number	Price [SEK/st]	Price [SEK]
Seal	BABSL 38 50 6	5007-3205	Momentum Industrial AB	2	111	222
					Total sum:	222

Part	Partnumber	ID	Place of purchase	Number	Price [SEK/st]	Price [SEK]
Servo	PDU 2-070-051-PB-I	360550	Schunk	1	47000	47000
Power cable	KA WLN12T0150-LK-00500-A	310263	Schunk	1	574	574
Communication cable	KA GGN1204-PB-00150-A	349750	Schunk	1	311	311
Communication termination	ST SG1204-PB-A-A	349650	Schunk	1	139	139
Gripper	JGP 125-1	308650	Schunk	1	6304	6304
Valves	ABV-MV30-G1/8-V4-M8	303366	Schunk	1	3103	3103
Magnetic sensor	MMS 22-S-M8-PNP	301032	Schunk	2	495	990
					Total sum:	58421

Part	Partnumber	ID	Place of purchase	Number	Price [SEK/st]	Price [SEK]
Slipring	SETH50-120-12-05	-	Servotronic AB	1	7800	7800
					Total sum:	7800

Part	Partnumber	ID	Place of purchase	Number	Price [SEK/st]	Price [SEK]
Wear-Sleeve	SKF CR99147	-	Sverull*	2	0	0
					Total sum:	0

Place of purchase	Contact person	Individual sum
Elfa.se	None	1250,8
Kullagret.com	None	790,4
Momentum Industrial AB	Håkan Welander	222
Schunk	Daniel Lutzov	58421
Servotronic AB	Leif Lindberg	7800
Sverull	Filiz Sandén	0
	Total sum:	68484,2

* Can be bought directly from SKF if necessary

NOTE: When price=0, price is unknown

C

PLC components

SIEMENS SITOP PSU100L
SIEMENS SIMATIC S7-300 CPU317F-2 PN/DP
SIEMENS SIMATIC NET CP 343-1 Lean (343-1CX10-0XE0)
SIEMENS ET 200S (6ES7 151-3BA23-0AB0)
SIEMENS 6ES7 193-4CB30-0AA0
SIEMENS 6ES7 193-4CB30-0AA0
SIEMENS 6ES7 193-4CD30-0AA0
SIEMENS 6ES7 138-4CB11-0AB0
SIEMENS 6ES7 131-4BD01-0AA0
SIEMENS 6ES7 132-4BD02-0AA0
SIEMENS SCALANCE X208 (208-0BA10-2AA3)

D

PLC logics

OB1 - <offline>

"SYS: G.Sig./Dat. Verz."   GP: Grundsignale-/daten & Sprungverzeigung
Name: sys   **Family:** cpu/gp.a
Author: gersch   **Version:** 8.0
Block version: 2
Time stamp Code: 11/28/2018 10:08:43 AM
Interface: 02/15/1996 04:51:12 PM
Lengths (block/logic/data): 00736 00532 00026

Name	Data Type	Address	Comment
TEMP		0.0	
OB1_EV_CLASS	Byte	0.0	Bits 0-3 = 1 (Coming event), Bits 4-7 = 1 (Event class 1)
OB1_SCAN_1	Byte	1.0	1 (Cold restart scan 1 of OB 1), 3 (Scan 2-n of OB 1)
OB1_PRIORITY	Byte	2.0	Priority of OB Execution
OB1_OB_NUMBR	Byte	3.0	1 (Organization block 1, OB1)
OB1_RESERVED_1	Byte	4.0	Reserved for system
OB1_RESERVED_2	Byte	5.0	Reserved for system
OB1_PREV_CYCLE	Int	6.0	Cycle time of previous OB1 scan (milliseconds)
OB1_MIN_CYCLE	Int	8.0	Minimum cycle time of OB1 (milliseconds)
OB1_MAX_CYCLE	Int	10.0	Maximum cycle time of OB1 (milliseconds)
OB1_DATE_TIME	Date_And_Time	12.0	Date and time OB1 started

Block: OB1   php=sym;pb.s;:>

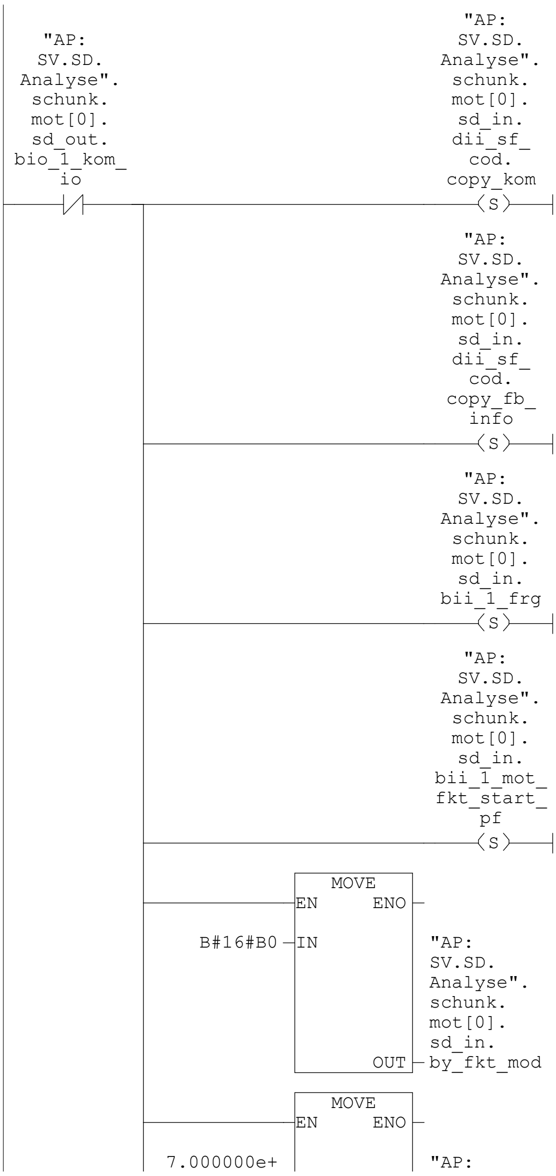
```
php=sym;pb.s;:>Symbol    :
php=sym;pb.a;:>Adresse   :
php=sym;pb.t;:>Datentyp  :
php=sym;pb.k;:>Kommentar:
```

Network: 1   sps-zykluszeiten erstellen

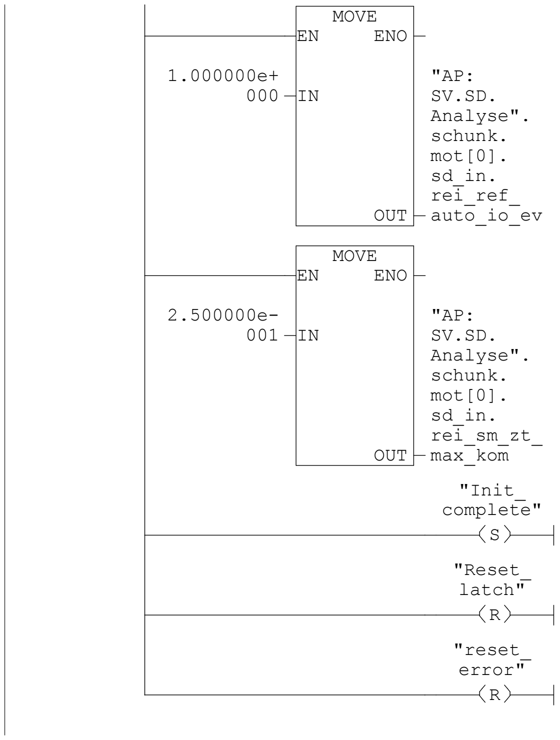
php=nw;>=;31200

```
      L     #OB1_PREV_CYCLE
      ITD
      T     "sps_zkyl_zt"     // sps-zykluszeit
```

Network: 2	Init com
This Network sets the initial values for communication and controller.	

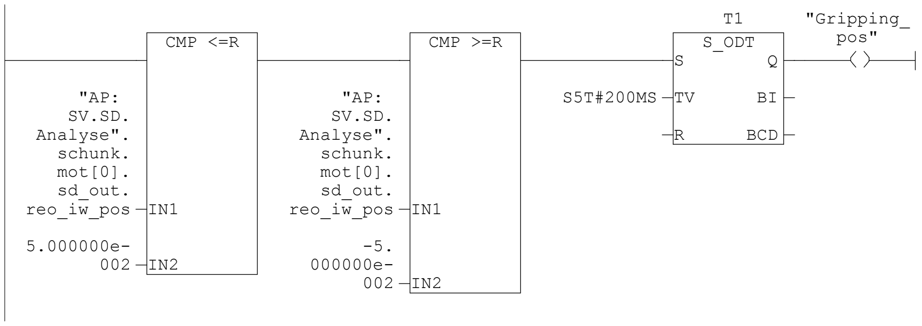


```
          001 -|IN         |  SV.SD.
               |           |  Analyse".
               |           |  schunk.
               |           |  mot[0].
               |           |  sd_in.
               |           |  rei_sw_v_
               |        OUT|- tip
               +-----------+

               +-----------+
               |   MOVE    |
      ---------|EN     ENO |-
               |           |
   7.000000e+  |           |  "AP:
          001 -|IN         |  SV.SD.
               |           |  Analyse".
               |           |  schunk.
               |           |  mot[0].
               |           |  sd_in.
               |           |  rei_sw_v_
               |        OUT|- reg
               +-----------+

               +-----------+
               |   MOVE    |
      ---------|EN     ENO |-
               |           |
   3.000000e+  |           |  "AP:
          002 -|IN         |  SV.SD.
               |           |  Analyse".
               |           |  schunk.
               |           |  mot[0].
               |           |  sd_in.
               |        OUT|- rei_sw_vr
               +-----------+

               +-----------+
               |   MOVE    |
      ---------|EN     ENO |-
               |           |
   4.000000e+  |           |  "AP:
          000 -|IN         |  SV.SD.
               |           |  Analyse".
               |           |  schunk.
               |           |  mot[0].
               |           |  sd_in.
               |        OUT|- rei_sw_i
               +-----------+

               +-----------+
               |   MOVE    |
      ---------|EN     ENO |-
               |           |
   0.000000e+  |           |  "AP:
          000 -|IN         |  SV.SD.
               |           |  Analyse".
               |           |  schunk.
               |           |  mot[0].
               |           |  sd_in.
               |        OUT|- rei_sw_pos
               +-----------+

               +-----------+
               |   MOVE    |
      ---------|EN     ENO |-
               |           |
   1.000000e+  |           |  "AP:
          006 -|IN         |  SV.SD.
               |           |  Analyse".
               |           |  schunk.
               |           |  mot[0].
               |           |  sd_in.
               |           |  rei_sw_
               |        OUT|- ruck
               +-----------+
```



Network: 3 Check that current position is the picking position

This Network checks if the current position is within tolerance of the servos home position which is 0 degrees. The tolerance is currently +/- 0.005 degrees. The Timer is there simply because the output position from the servo sometimes changes to 0 degrees for very short periods of time even if the servo is at another angle.

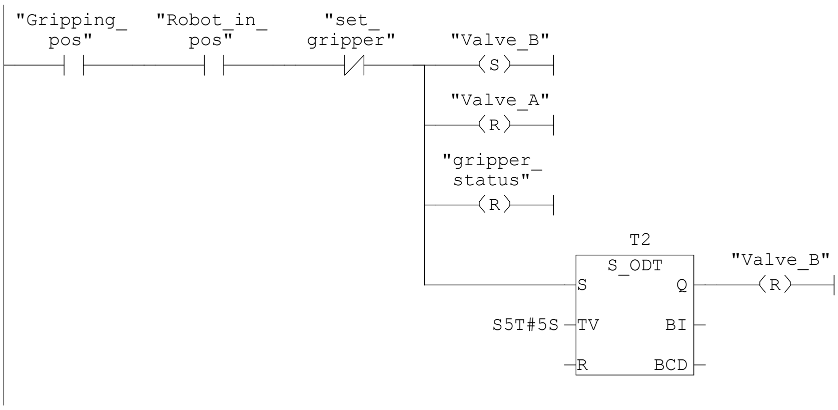


Network: 4 Check gripper status

This Network checks the two sensors that monitors the jaws movement and if any
of these are True, the gripper is opened.

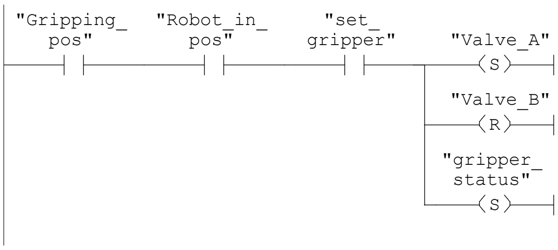
Network: 5 Release an object

This Network releases an object, closing the gripper. After five seconds
Valve_B
that was previously set to True will be set to False, leaving the gripper in
"sleep" mode.



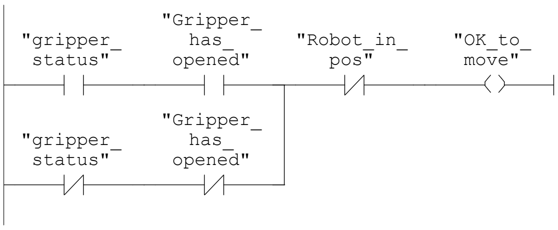
Network: 6 Grip an object

This Network opens the gripper if the prerequisites are met.



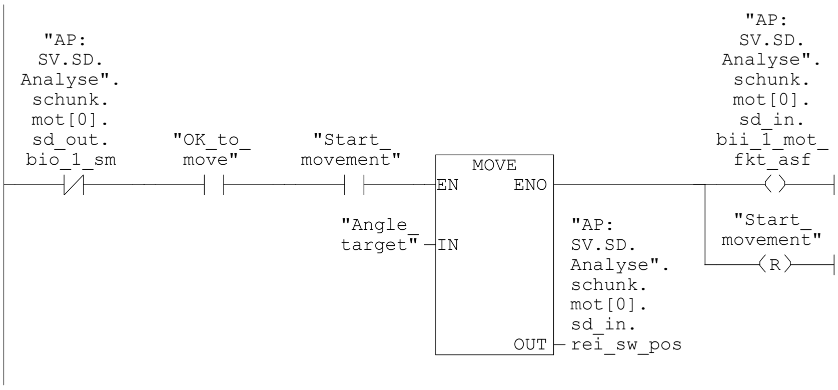
Network: 7 Check that it is okay to move

This Network checks if it is okay to move. It is okay if the gripper is opened if it should be opened and vice versa. It is also not okay to move if the "Robot_in_pos" is set.



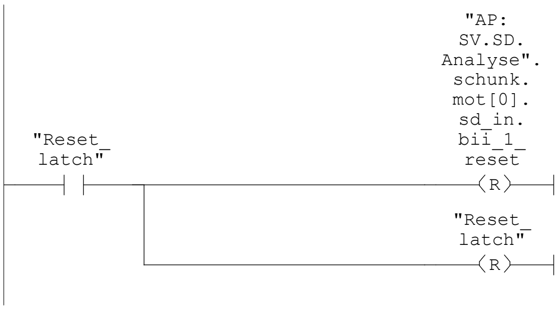
Network: 8 Run

This Network makes the servo move by first checking some prerequisites and then setting the "Angle_target" to the correct Schunk address and then starts the movement.



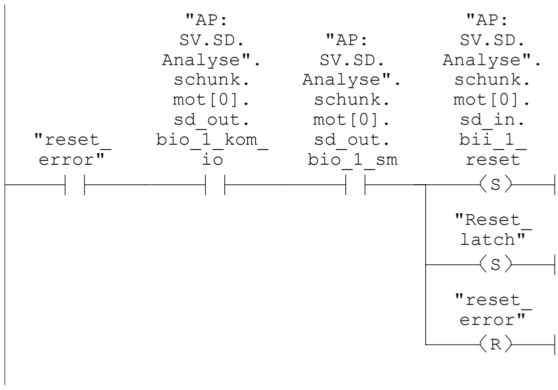
Network: 9 Reset cycle 2

This is the second Reset cycle since it requires two cycles to reset an error.



Network: 10 Reset cycle 1

This is the first Reset cycle which is possible to do if the communication is okay and there is some error. Then it sets the variables needed.

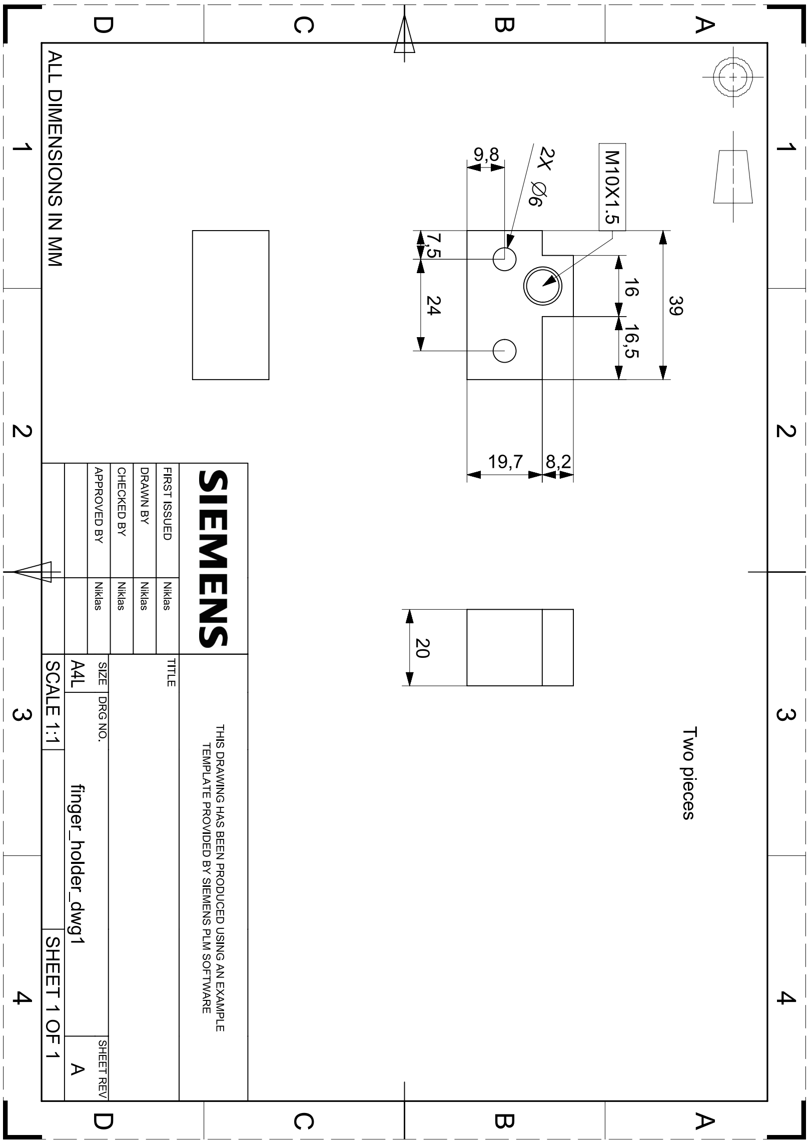


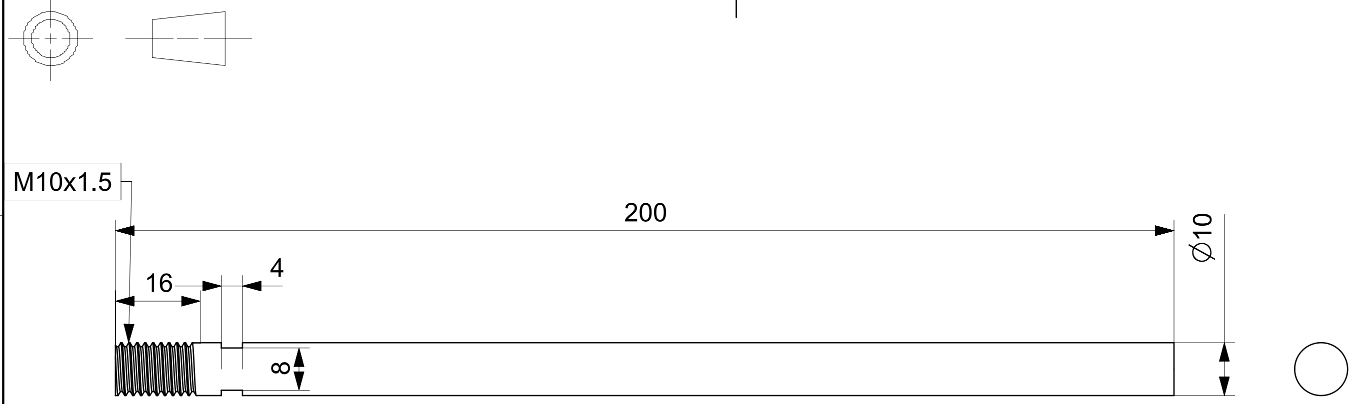
Network: 11 sprungverzeigungen anwenderprogramm

```
      CALL  "GPA: Spezif. Verzw." , "fb1_dbi"  // sprungverzeigung ausführen
```

E

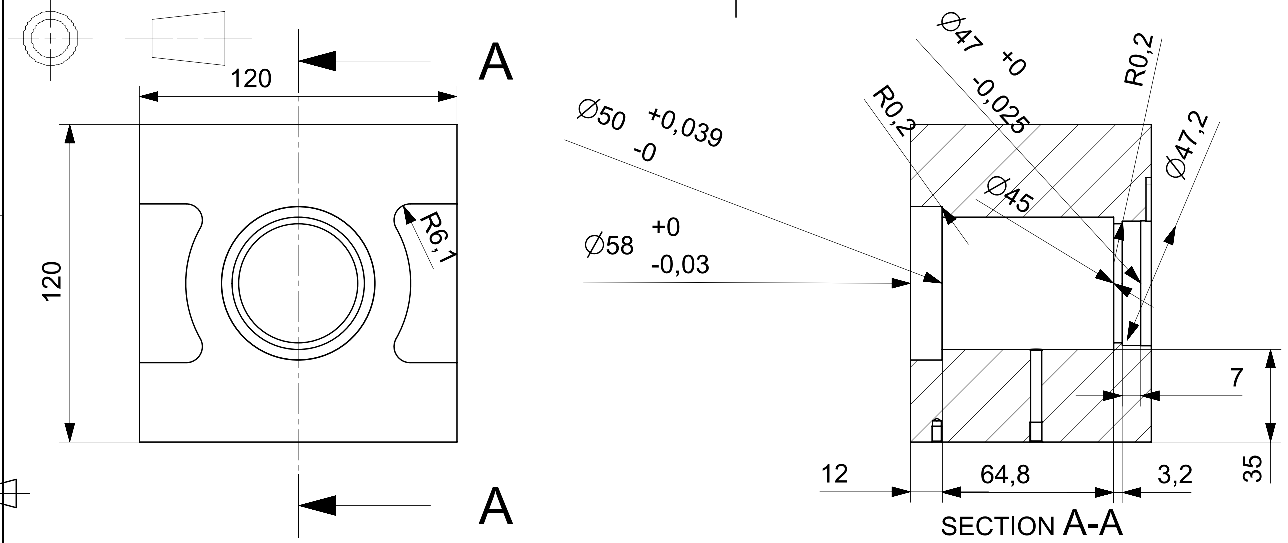
Drawings


A
B
C
D
1
2
3
4
ALL DIMENSIONS IN MM
9,8
2X ⌀6
M10X1.5
7,5
24
16
39
16,5
19,7
8,2
20
Two pieces
SIEMENS
FIRST ISSUED Niklas
DRAWN BY Niklas
CHECKED BY Niklas
APPROVED BY Niklas
TITLE
THIS DRAWING HAS BEEN PRODUCED USING AN EXAMPLE TEMPLATE PROVIDED BY SIEMENS PLM SOFTWARE
SIZE A4L
DRG NO. finger_holder_dwg1
SHEET REV A
SCALE 1:1
SHEET 1 OF 1

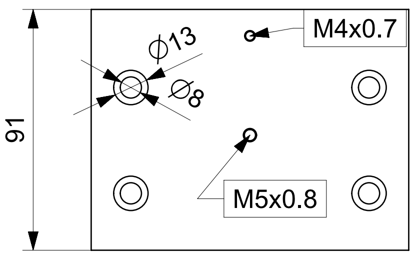


ALL DIMENSIONS IN MM

SIEMENS		THIS DRAWING HAS BEEN PRODUCED USING AN EXAMPLE TEMPLATE PROVIDED BY SIEMENS PLM SOFTWARE
FIRST ISSUED	Niklas	TITLE
DRAWN BY	Niklas	
CHECKED BY	Niklas	
APPROVED BY	Niklas	SIZE A4L DRG NO. finger_dwg1 SHEET REV A
		SCALE 1:1 SHEET 1 OF 1



SECTION A-A



SIEMENS

THIS DRAWING HAS BEEN PRODUCED USING AN EXAMPLE TEMPLATE PROVIDED BY SIEMENS PLM SOFTWARE

FIRST ISSUED	Niklas
DRAWN BY	Niklas
CHECKED BY	Niklas
APPROVED BY	Niklas

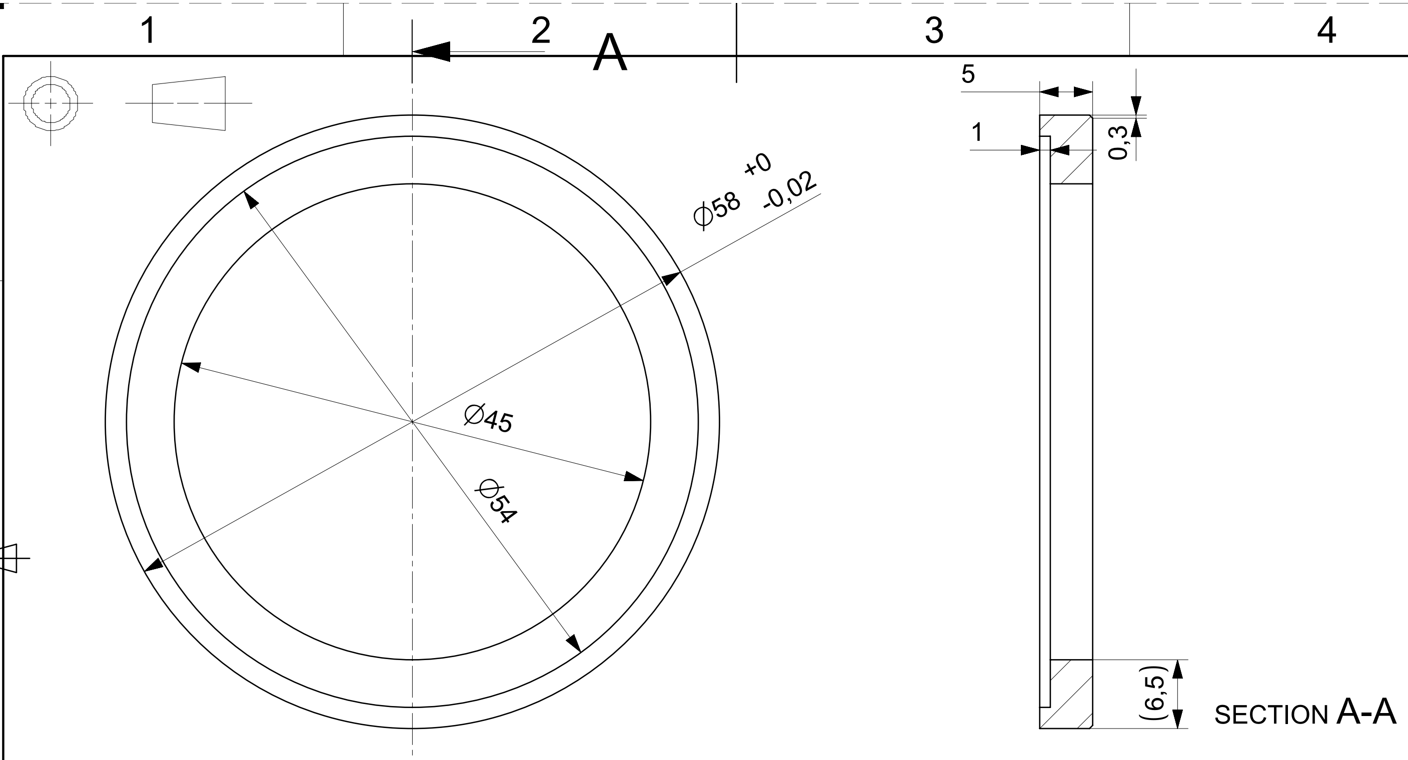
TITLE

SIZE	DRG NO.	SHEET REV
A4L	housing_dwg1	A

SCALE 1:1

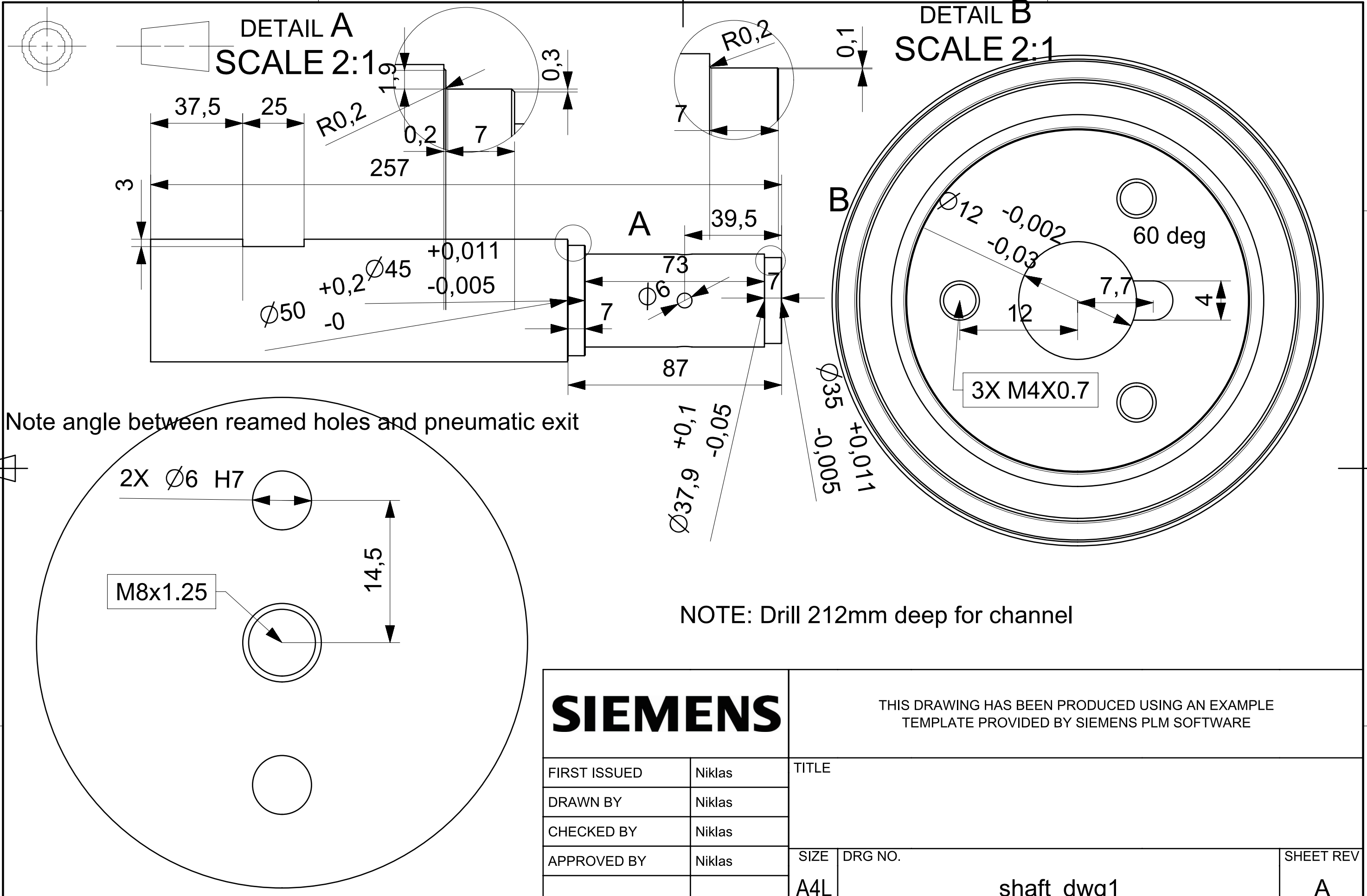
SHEET 1 OF 1

ALL DIMENSIONS IN MM



SIEMENS		THIS DRAWING HAS BEEN PRODUCED USING AN EXAMPLE TEMPLATE PROVIDED BY SIEMENS PLM SOFTWARE	
FIRST ISSUED	Niklas	TITLE	
DRAWN BY	Niklas		
CHECKED BY	Niklas		
APPROVED BY	Niklas	SIZE A4L	DRG NO. seal_ring_dwg1	SHEET REV A
		SCALE 1:1	SHEET 1 OF 1

ALL DIMENSIONS IN MM



Note angle between reamed holes and pneumatic exit

NOTE: Drill 212mm deep for channel

ALL DIMENSIONS IN MM

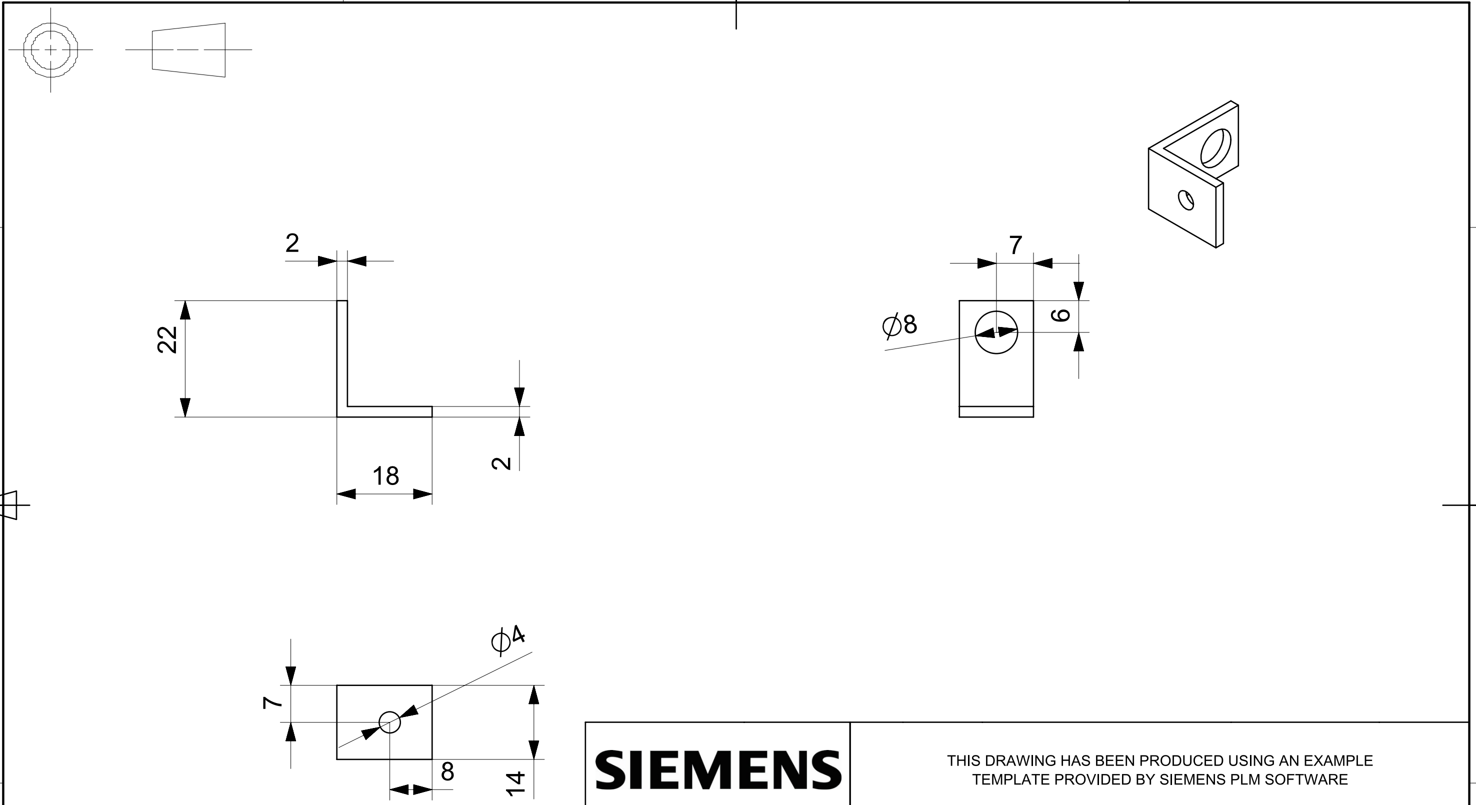
SIEMENS

THIS DRAWING HAS BEEN PRODUCED USING AN EXAMPLE
TEMPLATE PROVIDED BY SIEMENS PLM SOFTWARE

FIRST ISSUED	Niklas
DRAWN BY	Niklas
CHECKED BY	Niklas
APPROVED BY	Niklas

TITLE

SIZE	DRG NO.	SHEET REV
A4L	shaft_dwg1	A
SCALE 1:1		SHEET 1 OF 1



ALL DIMENSIONS IN MM

SIEMENS

THIS DRAWING HAS BEEN PRODUCED USING AN EXAMPLE
TEMPLATE PROVIDED BY SIEMENS PLM SOFTWARE

FIRST ISSUED	Niklas
DRAWN BY	Niklas
CHECKED BY	Niklas
APPROVED BY	Niklas

TITLE

SIZE	DRG NO.	SHEET REV
A4L	slip_ring_retainer_dwg1	A

SCALE 1:1

SHEET 1 OF 1