



TALLINN UNIVERSITY OF TECHNOLOGY

SCHOOL OF ENGINEERING

Department of Electrical Power Engineering and Mechatronics

**ASSEMBLY STATION FOR INSPECTING THE QUALITY OF IGBT ASSEMBLY
PROCESS**

IGBT KOOSTAMISPROTSESSI KONTROLLIMISE TÖÖJAAM

Student: Siim-Joosep Saulep

Student code: 192598MAHM

Supervisor: Mart Tamre

Tallinn, 2021

AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

"....." 202... .

Author:

/signature /

Thesis is in accordance with terms and requirements

"....." 202... .

Supervisor:

/signature/

Accepted for defence

".....".....202... .

Chairman of theses defence commission:

/name and signature/

Non-exclusive Licence for Publication and Reproduction of Graduation Thesis¹

I, Siim-Joosep Saulep (name of the author) (date of birth: 23.04.1996) hereby

1. grant Tallinn University of Technology (TalTech) a non-exclusive license for my thesis

Assembly station for inspecting the quality of IGBT assembly process,
(*title of the graduation thesis*)

supervised by Mart Tamre.

(*Supervisor's name*)

1.1 reproduced for the purposes of preservation and electronic publication, incl. to be entered in the digital collection of TalTech library until expiry of the term of copyright;

1.2 published via the web of TalTech, incl. to be entered in the digital collection of TalTech library until expiry of the term of copyright.

1.3 I am aware that the author also retains the rights specified in clause 1 of this license.

2. I confirm that granting the non-exclusive license does not infringe third persons' intellectual property rights, the rights arising from the Personal Data Protection Act or rights arising from other legislation.

¹ *Non-exclusive Licence for Publication and Reproduction of Graduation Thesis is not valid during the validity period of restriction on access, except the university's right to reproduce the thesis only for preservation purposes.*

_____ (*signature*)

_____ (*date*)

THESIS TASK

Student: Siim-Joosep Saulep 192598MAHM

Study programme, MAHM02/18

main speciality: Industrial Automation

Supervisor(s): Head of Department, Prof. Dr. Mart Tamre, +372 620 3202

Consultants: Priit Raid, Business Development, Hoob OÜ, +372 501 2419, hoob@hoob.ee

Thesis topic:

Assembly station for inspecting the quality of IGBT assembly process

IGBT koostamisprotsessi kontrollimise tööjaam

Thesis main objectives:

1. Design of a low-height jig with product locking features
2. Establishing communication between PLC, Atlas Copco devices and a vision system
3. Software development for controlling the process of the assembly

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Understanding the problem	30.09.2020
2.	Design of the jig	30.10.2020
3.	Technical drawings for manufacturing	06.11.2020
4.	Material ordering	10.11.2020
5.	Drawing of electric/pneumatic schematics	13.11.2020
6.	Programming and testing the assembly station	11.12.2020
7.	Factory Acceptance Test (FAT)	18.12.2020
8.	Finishing the manuals	08.01.2021
9.	Thesis writing	17.05.2021

Language: English **Deadline for submission of thesis:** "18" May 2021 .a

Student: Siim-Joosep Saulep ".....".....2021 .a
/signature/

Supervisor: Mart Tamre ".....".....2021 .a
/signature/

Consultant: Priit Raid

.....

".....".....2021.a

/signature/

Head of study programme: Mart Tamre

".....".....2021.a

/signature/

Contents

- PREFACE 8
- List of abbreviations and symbols 9
- 1 INTRODUCTION10
- 2 LITERATURE REVIEW AND BACKGROUND12
 - 2.1 Overview of the Atlas Copco setup.....12
 - 2.2 Communication.....13
 - 2.3 Machine vision.....14
 - 2.4 Product locking.....15
- 3 PROPOSED SOLUTION17
 - 3.1 Process flow17
 - 3.2 Vision system19
 - 3.3 Communication between devices20
 - 3.4 Jig design20
- 4 DESIGN OF THE ASSEMBLY STATION22
 - 4.1 Product detection24
 - 4.2 Vacuum clamping.....25
 - 4.3 Linear motion between different positions28
 - 4.4 Cables and pneumatic tubing29
- 5 ELECTRONICS.....30
 - 5.1 System architecture30
 - 5.2 PLC system31
 - 5.3 Power supply.....31
 - 5.4 Relays.....33
 - 5.5 Circuit breaker and fuses.....33
 - 5.6 Switch.....35
 - 5.7 Button box.....35
 - 5.8 Electrical cabinet.....36
- 6 VISION SENSOR.....38
 - 6.1 Configuration38
 - 6.2 Detection of graphite sheets and springs.....39
 - 6.3 Additional light and polarized cover.....42
 - 6.4 Assigning a name for the image43

6.5 Saving the images	43
7 PLC PROGRAMMING	45
7.1 Hardware configuration	45
7.2 Network configuration.....	46
7.3 Structure of the program.....	47
7.4 Important sections of the program.....	47
7.4.1 Communication with the vision sensor through ModbusTCP	47
7.4.2 Reading the barcode	48
7.4.3 Sending the product code to vision sensor	49
8 HMI.....	51
8.1 Main page.....	51
9 Power Focus 4000	53
9.1 Configuring the internal I/O	53
9.2 Activation of the job	54
9.3 Testing the system.....	55
10 SAFETY AND COST OF THE SYSTEM.....	56
10.1 Mechanical safety requirements	56
10.2 Electrical safety requirements.....	56
10.3 Cost of the system	57
SUMMARY	58
KOKKUVÕTE.....	59
LIST OF REFERENCES	60

PREFACE

The thesis topic is based on a hands-on project from Hoob OÜ. The client has an existing workstation with Atlas Copco devices which needs to be upgraded with a vision sensor and a fixture to control the quality of IGBT assembly process.

The project involves the integration of mechanics, electronics, control theory and computer science which is why it was chosen as the mechatronics thesis topic. The project was managed by the author and the system was built from scratch. Throughout the process, the requirements of the client were always met.

I would like to express my gratitude to Priit Raid, who guided and supported me through the duration of the project.

Finally, I would like to thank Prof. Mart Tamre for thesis-related suggestions and help with the structure of the paper.

Keywords: Master Thesis; Industrial Automation; Power Focus, ToolsTalk, In-Sight Explorer; Automation Studio; Low-height jig.

List of abbreviations and symbols

IGBT – Insulated-gate bipolar transistor

NOK – Not okay

PCB – Printed circuit board

PF4000 – Power Focus 4000 controller

TPS – Tool positioning system

PLC – Programmable logic controller

ESD - Electrostatic discharge

POM – Polyoxymethylene thermoplastic

HMI – Human-machine interface

PC – Personal computer

CPU – Central processing unit

IO – Inputs/outputs

DO – Digital output

DI – Digital input

FTP - SSH file transfer protocol

SVG – Scalable vector graphics

ROI – Region of interest

IP – Internet protocol

IIS – Internet Information Services

W – Watt

N – Newton

mm – Millimeter

A – Ampere

V – Voltage

kPA – Kilopascal

LVD – Low Voltage Directive (2014/35/EU)

1 INTRODUCTION

Due to the technological advances, the human error in manufacturing has become more transparent. It is said that human error is the cause of nearly 80 percent of failures and defects [1]. It is known that faulty and not reliable products can have a huge negative impact on the company's reputation and finances. Therefore it is important to reduce the risk of human error in manufacturing processes where it is possible. One of the possibilities is to use machine vision for quality control inspections.

Machine vision can be used in a diverse range of tasks, the most significant area of use is although in part of production processes. These systems can acquire images of products and are immediately analyzed by the system. This provides instant results, which speeds up the manufacturing process [2].

The purpose of this thesis is to upgrade the IGBT assembly station to control the quality of the assembly process. The current workstation consists of Atlas Copco Power Focus 4000 controller, Atlas Copco Tensor Tool, Atlas Copco Tool Positioning System and a barcode scanner, all communicating with the Power Focus 4000 controller [3, 4]. The IGBT modules are scanned using a barcode scanner and all the screwing operations are done using Atlas Copco Tensor tool to provide the right torques for the bolts.

During the assembly, the presence of graphite sheets and 21 contact springs on 3 IGBT modules must be verified. The IGBT modules are based on pressure-contact strategy and they are solder-free. The springs act as contacts to the driver plate which is mounted on the module. To minimize the risk of human-made mistakes, a vision system is implemented to the workstation, as it improves accuracy, speed and precision of the inspection process. A low-height jig needs to be designed with 3 different positions, where the vision sensor acquires the image. The operation with the electric screwdriver following the vision sensor control is then disabled or enabled regarding of the job result. For more convenient overview of the assembly process, a visual feedback should be involved at the station as well. The results of the acquired images ought to be stored with corresponding product codes for further analysis.

The developed system needs to communicate with Atlas Copco tools. As all the I/O ports

of Atlas Copco Power Focus 4000 controller are already full, a PLC must be added to the station to control and communicate with the vision sensor, the jig and Atlas Copco devices.

This work aims to

1. Research on different technologies and communication methods
2. Developing a prototype
3. Choosing the optimal design for the jig
4. Choosing appropriate vision sensor
5. Electrical and pneumatical wiring
6. Writing software code for PLC
7. Testing and verifying the system
8. Installing the system on site

2 LITERATURE REVIEW AND BACKGROUND

2.1 Overview of the Atlas Copco setup

Atlas Copco is a company which offers a lot of solutions and products regarding industrial assembly. One of these is a manual tightening system which is used to control and monitor the tightening sequences of various screwing operations.

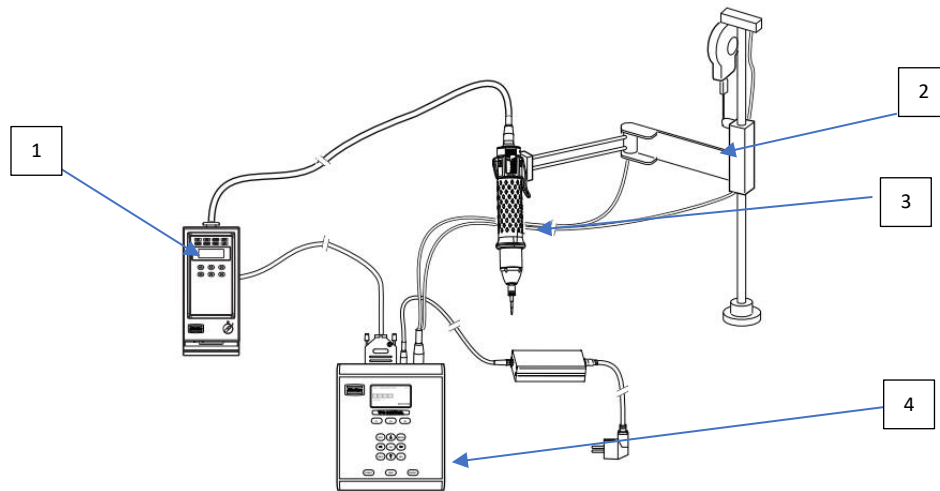


Figure 2.1 Setup of a typical Atlas Copco manual tightening system [4]

Labels

- 1 – Power Focus controller
- 2 – Smart Arm
- 3 – Tensor tool
- 4 – TPS controller

The Power Focus controller enables to create different kinds of tightening processes, some of the parameters which can be set are the torque, angle, speed and ramp, batch count etc. It also monitors and collects statistical data which can be later analyzed. The smart arm is responsible for the detection of the tool and allows the tool to be used only in predefined positions. The tensor tool is the tool that is used for the screwing operations. The TPS controller monitors the sequence of screws and the tightening program [3, 4].

2.2 Communication

As the exchange of information needs to be established between the PLC, which acts as a main control unit, and other devices, a communication protocol must be chosen. For that purpose, a family of computer network protocols called Fieldbus have been standardized. The motivation to use a Fieldbus is to reduce the system's cost and increase the process availability and reliability. There are many buses used in the automation and manufacturing industries, the most common are [5]:

1. Modbus
2. Profibus
3. Interbus
4. Can
5. DeviceNet
6. CanOpen

To communicate with Power Focus 4000, there are multiple options. One of them is by Fieldbus. Power Focus 4000 has an option to use different Fieldbus standards, but it acquires a specific card for the preferred type of Fieldbus. Another one is to use digital inputs/outputs to monitor and control the state of the smart arm and the process flow [3].

The vision systems have self-contained platforms for acquiring and analyzing the image, which reduces the volume of data needed to be transmitted. Vision systems usually communicate with the main control unit to provide whether the acquired image has passed or failed. Therefor the network interface networks can be accommodated by production networks such as Ethernet/IP, PROFINET, Modbus-TCP and so on [6].

In order to get the product code data from the barcode scanner there are various ways. One of them is RS232 interface, which is commonly referred to as serial communication and has almost certainly a 9-pin male connector. Another option is to use a keyboard wedge interface, which refers to the physical connection and communication protocol. Third option is to use USB interface which has multiple communication protocol options [7]. The current barcode scanner is connected directly to Power Focus 4000 through RS232 interface.

2.3 Machine vision

Machine vision is used for a lot of different applications, one of the most important of them is product verification. These applications range from checking the object presence to checking that the seals of the packages are correctly placed [2].

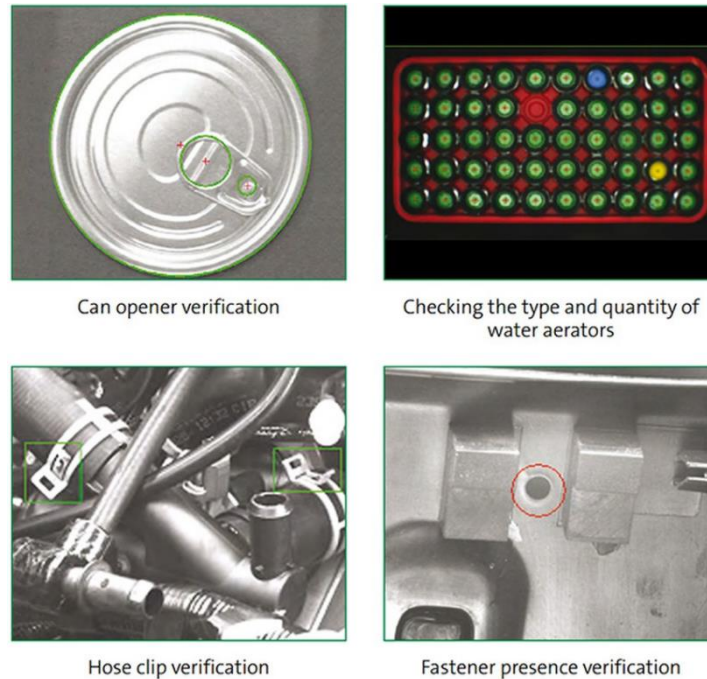


Figure 2.2 Product verification with vision systems [2]

As the main problem point regarding this work revolves around the detection of graphite sheets and 21 contact springs, some parameters must be kept in mind before choosing an appropriate machine vision system. These parameters include [8]:

1. Resolution – Dimension of smallest object that can be detected
2. Field of View – The area that the camera can see
3. Work distance – distance from the objective to the object
4. Focal Length – defines the lens's angular field of view/magnification
5. Feature detection tools – predefined algorithms to detect objects/features

All cameras need a lens to form an image of an object by collecting scattered light from the surface of the object. The chosen lens has to be able to resolve the pixel size. The better the optical resolution of the lens, the better detailed structures can be seen from the image. To ensure a definite edge detection of an object, the detail should be reproduced across about 4 pixels, therefore the magnification is dependent on the object's resolution and the

respective pixel size [2]. To acquire accurate and repeatable images, the workplace lightning and background must also be considered. To avoid shading and vignetting the lens also has to be able to illuminate the complete sensor area. Illumination plays a big role in vision systems, so it is important to look out for lightning effects, reflectance and the appearance of shadows and highlights [9].

2.4 Product locking

To make the process as reliable as possible, the client wants to have the product locked during the whole assembly process. For that purpose, the product needs to be fixed and not released until every step of the process is done. The workplace where the system is installed, is operated at seated positions. When it comes to sitting and working, the height of the workplace has a significant importance. The higher the arms are, the faster the shoulder and arm fatigue increases [10]. For this reason, the jig needs to be as low profiled as possible. To design a low height jig, with product locking purpose, a similar technique to vacuum clamping can be used [11]. The use of this technique makes the process reliable and efficient.

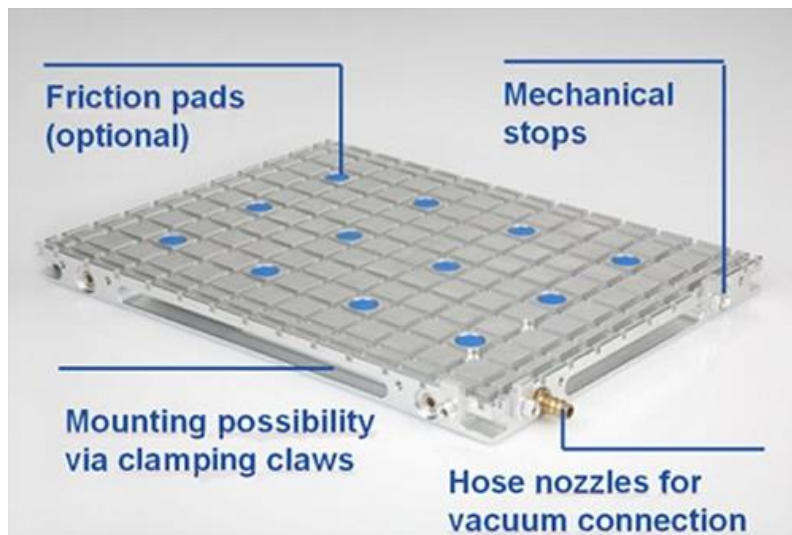


Figure 2.3 Vacuum plate with friction pads [11].

Another option would be pneumatic clamping to fix the product. The clamps usually consist of a double acting cylinder, clamping arm, linkages and a base for mounting. Air pressure is applied to the cylinder which moves the clamping arm for holding the work piece [12]. The same method can be also replicated by choosing an electromechanical system by using a linear motor or actuator for fixing the product.

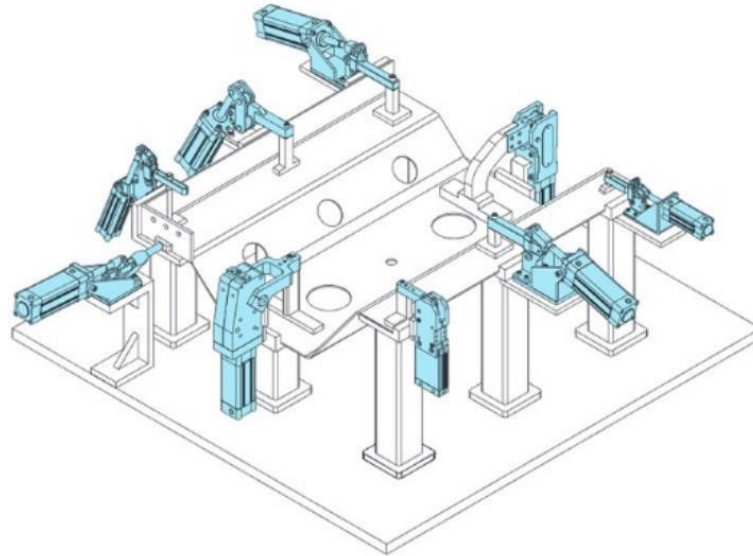


Figure 2.4 Pneumatic clamping mechanism [12]

Product fixing can also be done with swing clamps, which eliminates the bulky two-cylinder concept, giving more space with less parts [13]. This method can also be reproduced by using electromechanical components like stepper or servo motors.

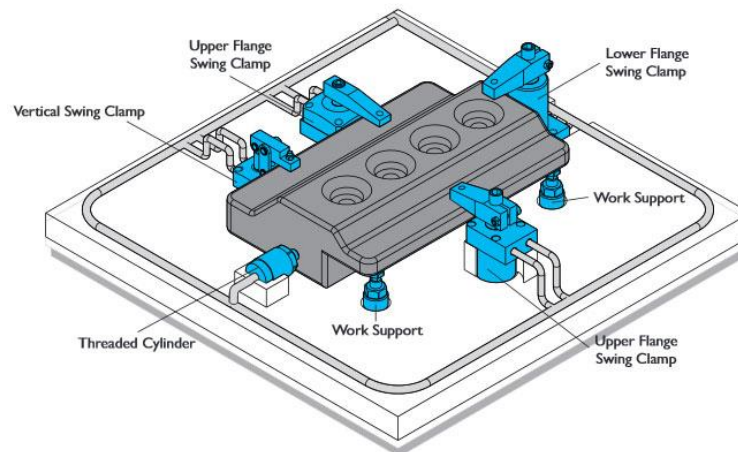


Figure 2.5 Swing clamping mechanism [13].

3 PROPOSED SOLUTION

3.1 Process flow

Before designing the system, the process of the workflow needs to be clearly defined and the proposed solution is the following:

1. Operator places heat sink on fixture, locks product in fixture:
 - a. Sensor detects product.
 - b. The product is locked in the fixture.
2. Graphite sheet will be placed on the heat sink and checked by Vision Sensor.
3. Operator places the 1st IGBT on the heat sink on top of the graphite sheet.
4. The product code is scanned by the barcode reader.
5. Vision Sensor acquires an image of IGBT top side with springs visible:
 - a. If result is FAIL, then system informs operator on PC screen that result is NOK. Missing springs must be placed.
 - b. If result is PASS, then camera output connected to screwdriver input is set high (1 of 3 outputs). Screwing operation can start.
6. After screwing is done, product fixture is shifted to next position (2nd IGBT position).
7. Operator assembles 2nd IGBT
8. ... (same sequence is repeated for 3rd and final IGBT)
9. If all 3 IGBTs have been successfully screwed, a label is printed with timestamp, job results and product codes. If all results are PASS, product can be released from fixture.

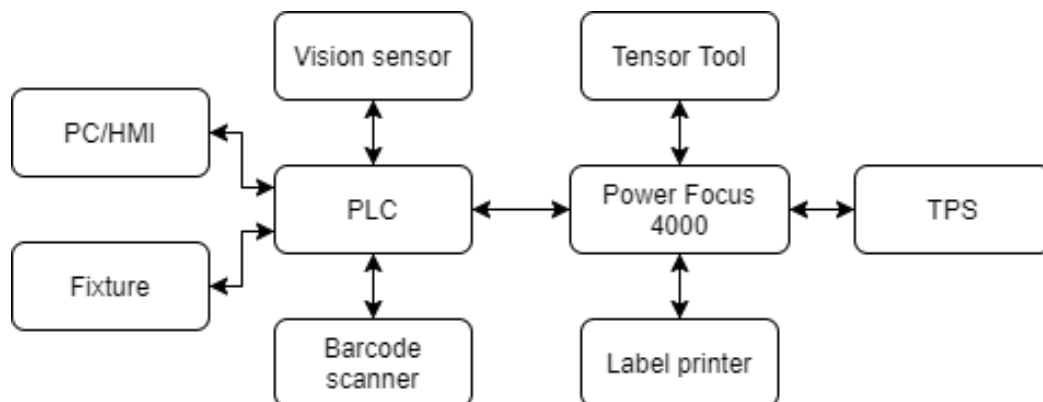


Figure 3.1 Block diagram of system components

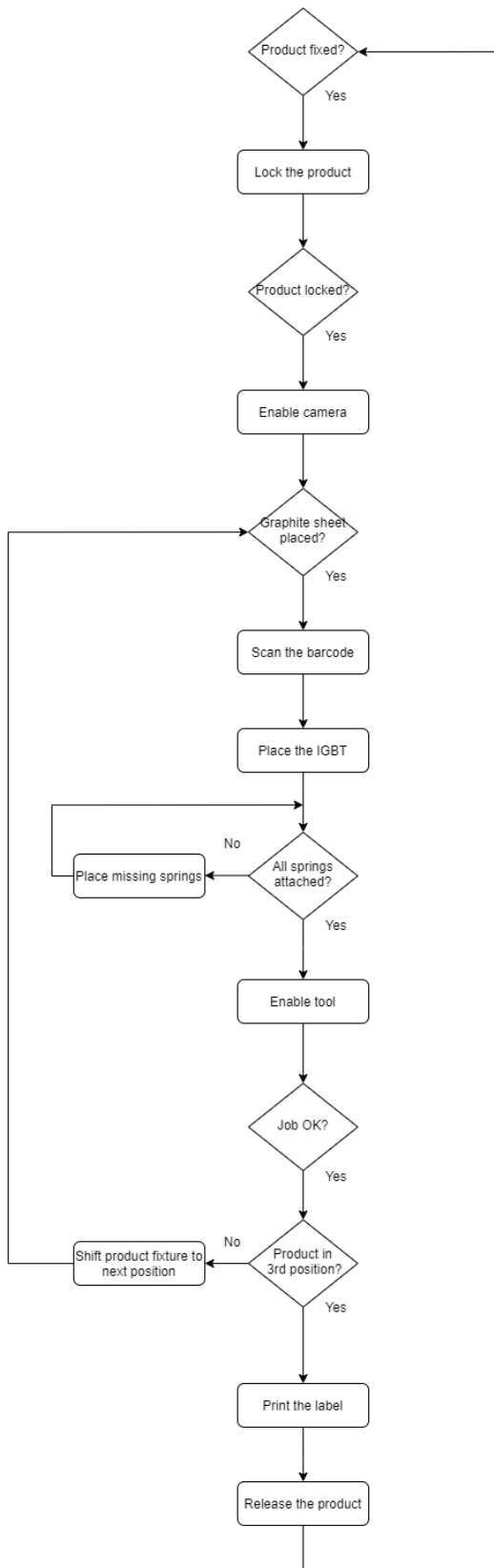


Figure 3.2 Process flowchart

3.2 Vision system

The proposed solution is to use Cognex In-Sight 2000-130 Vision Sensor(800x600px) together with 16m lens and standard lightning for the given task [14].



Figure 3.3 Cognex In-Sight 2000-130 [14]

This camera allows communications in commonly used Fieldbus protocols and has a wide enough variety of feature detection tools. As the camera needs to be above the smart arm, which is used for fastening the IGBTs, the work distance is chosen to be 660 mm. This translates to approximately 200x150 mm Field of View. The spring, which is needed to be detected, has a diameter of 2,4mm, approximately 9,6 pixels, which is more than enough for the vision sensor to detect the spring. The vision sensor is looking at slightly larger area than IGBT and by detecting features at the sides, it can be determined at which position the fixture currently is and which IGBT is being assembled.

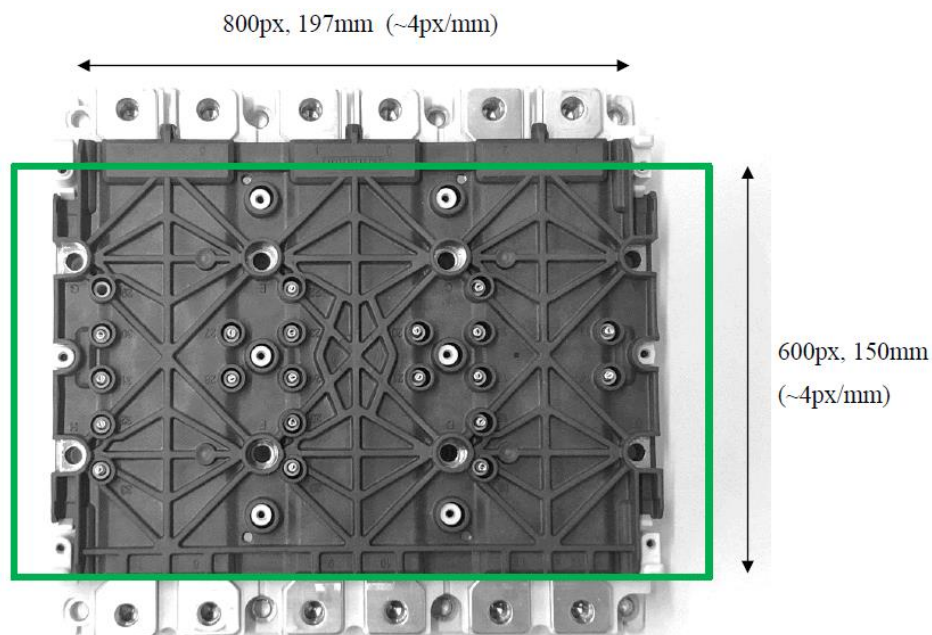


Figure 3.4 Field of View vs resolution.

3.3 Communication between devices

The system is going to have a B&R PLC [15] as the main control unit as it is cost-efficient and belongs to ABB group. It is one of the requirements of the client to use ABB or B&R PLC.



Figure 3.5 B&R X20CP0410 [15]

For the communication protocol, Modbus-TCP is going to be used because the author wants to familiarize with it and it is one of the most used industrial protocols out there which has been a de facto standard for 30 years [5]. As the Power Focus 4000 does not have a Fieldbus card installed, and the client refuses to acquire it, some rewiring must be done with the help of relays to communicate with Atlas Copco devices. In order to save the images with corresponding product codes to the PC, the product codes must reach the main control unit. Due to this some additional rewiring must be done to read the scanned product codes to PLC and to send the codes to Power Focus 4000 for label printing. As the current system has an existing barcode with RS232 interface, the final solution is based on serial communication.

3.4 Jig design

A manual jig needs to be designed, which has the following functions:

- I. Product detection
- II. Can hold different variants of heat sinks
- III. Locks the heat sink by vacuum or clamping
- IV. Linear motion between 3 positions, position locking is mechanical

The jig is going to be designed using vacuum clamping technique. The heatsink size and design can change with upcoming product revisions, thus making it difficult to use swing clamp as the height may vary. The workstation has an air supply nearby, which makes the use of pneumatic solution convenient. As the pneumatic clamping method requires more space than the vacuum clamping, the latter option suits the best for product locking. A simple proximity sensor is sufficient for the purpose of product detection and linear motion between 3 positions can be assured by using linear guides and a plunger.

4 DESIGN OF THE ASSEMBLY STATION

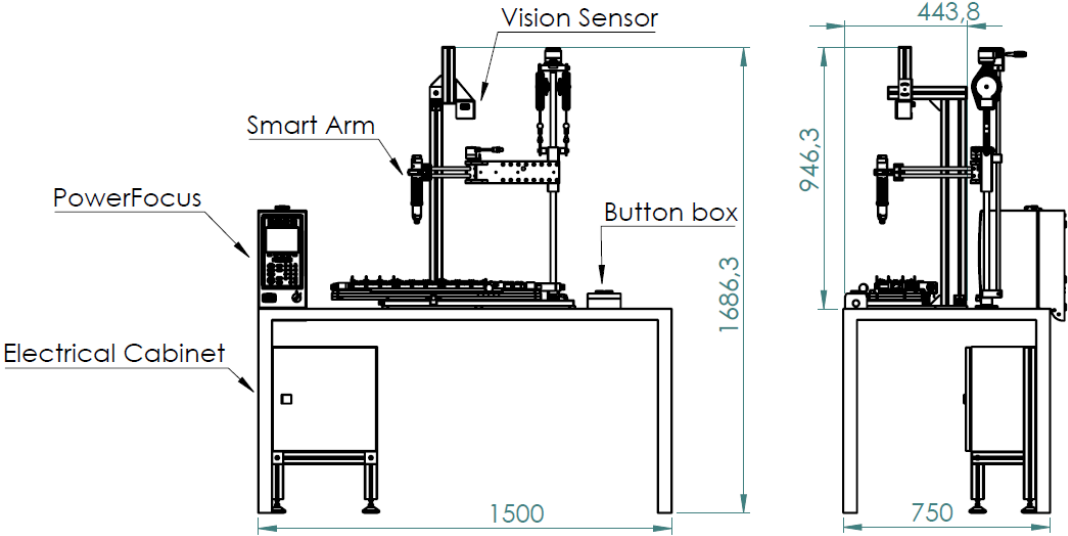


Figure 4.1 Overview of the assembly station

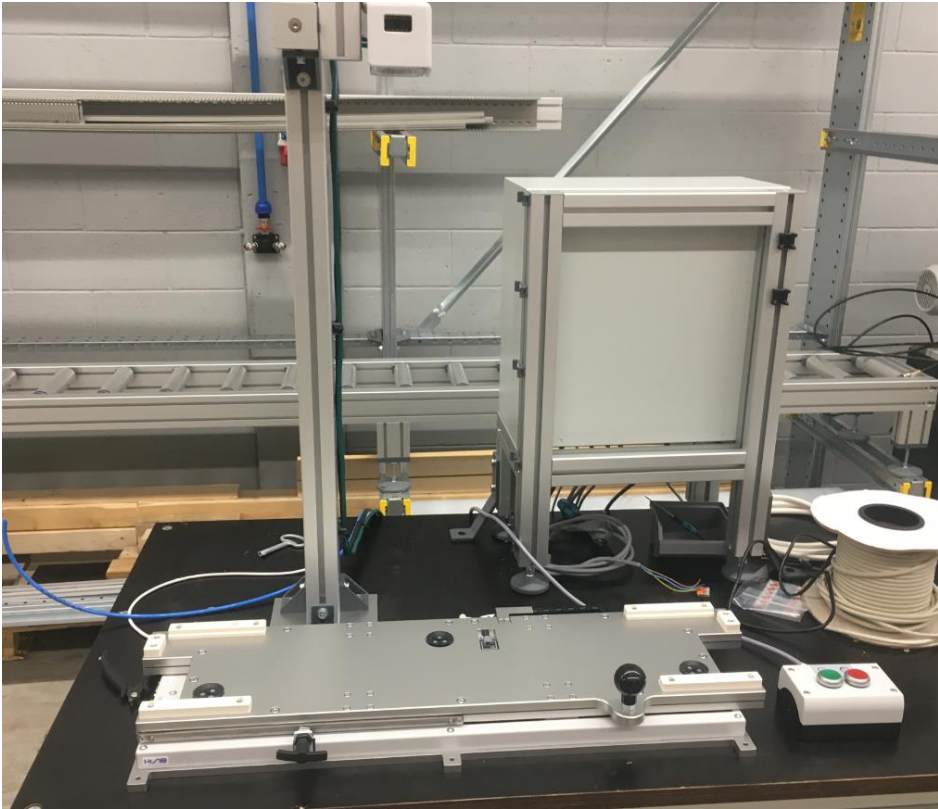


Figure 4.2 Assembled IGBT assembly station

The purpose of this section is to explain the general requirements and the main aspects regarding the design of the jig. As the workstation is also in the ESD Protected Area, the guidelines from keeping the electrostatic discharge from damaging the components, need to be followed. To prevent that all the components in contact with the product need to be made out of ESD materials [16]. As the fully assembled product has mass around 19 kg and the jig is essentially a fixture, no complex strength/torque calculations and stress analyses were done.

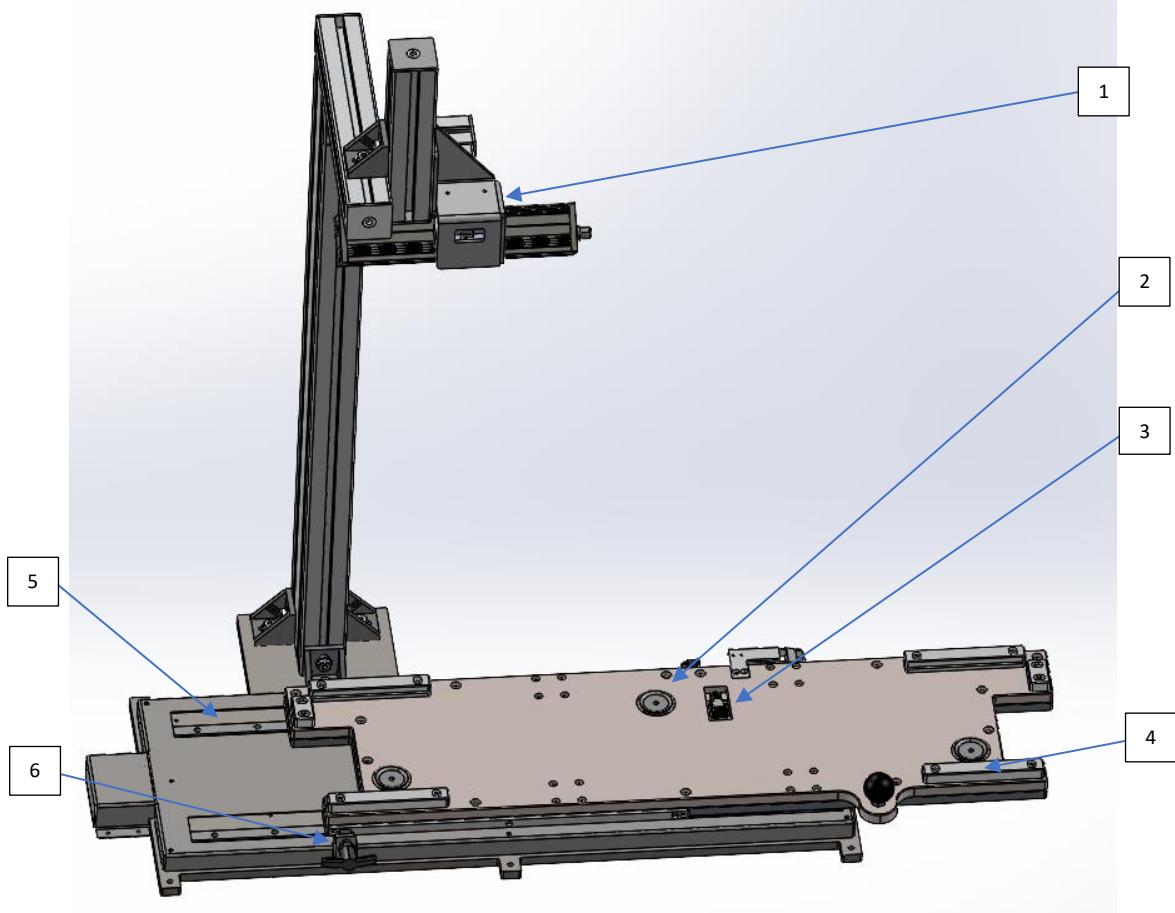


Figure 4.3 Overview of the design

Labels

- 1- Vision sensor
- 2- Vacuum pad
- 3- Proximity sensor
- 4- Linear guides
- 5- Index plunger
- 6- ESD POM guides

4.1 Product detection

For product detection purposes an inductive proximity sensor is used. The proximity sensor needs to be low height as it should fit inside the top plate of the fixture where the heatsink will be placed. One proximity sensor is sufficient for this task. If the sensor detects the heatsink, it means the product is installed correctly, because the heatsink is flat and even. The company that the author is working at has favorable prices with SICK distributor partner. Therefore the chosen proximity sensor will be from SICK. SICK IQ20-07BPSDU2S is a rectangular sensor with a height of 8 mm. It is normally open (NO), the switching output is PNP and the supply voltage is 10 V DC to 30 V DC [17].



Figure 4.4 Sick inductive proximity sensor IQ20-07BPSDU2S [17]

The heatsink which needs to be detected is made of aluminum and it has approximately 0,3 reduction factor related to the sensing range of the sensor. The sensing range of the selected sick proximity sensor is 7 mm and for aluminum the reduction factor is 0,3 For this case the sensing range for the heatsink is $7 \times 0,3 = 2,1 \text{ mm}$, which is enough for object detection purpose.

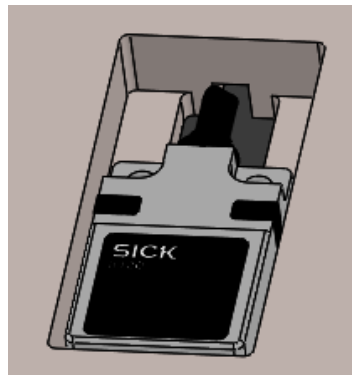


Figure 4.6 Milled pocket for the proximity sensor

4.2 Vacuum clamping

Vacuum clamping method is used to hold the product in place during the assembly process. The vacuum clamping method is chosen primarily due to the fact that other clamping methods require more space. As the working area is limited a vacuum ejector is going to be used. The vacuum ejector chosen for this purpose is from SMC ZK2-A series. It is high efficiency and very compact, making it easy to mount into small spaces. The assembly station has no other pneumatic equipment than the vacuum ejector. Therefore the author decided to place the ejector on the base plate of the jig below the fixture [18].

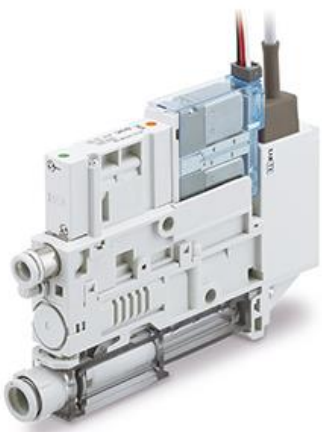


Figure 4.7 SMC vacuum ejector ZK2A07K5RWA-06 [18]

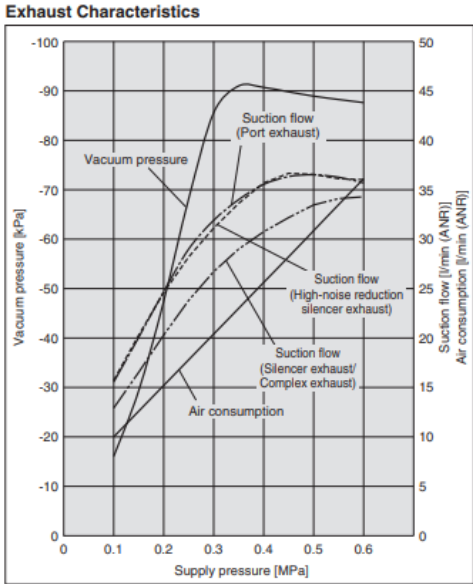


Figure 4.8 Exhaust characteristic of ZK2A07K5RWA-06 vacuum ejector [18]

The supply pressure for the vacuum ejector comes from another nearby workstation. The supply pressure near the workstation is set at 6 bar, so the selected vacuum ejector has a vacuum pressure of around -70 kPa.

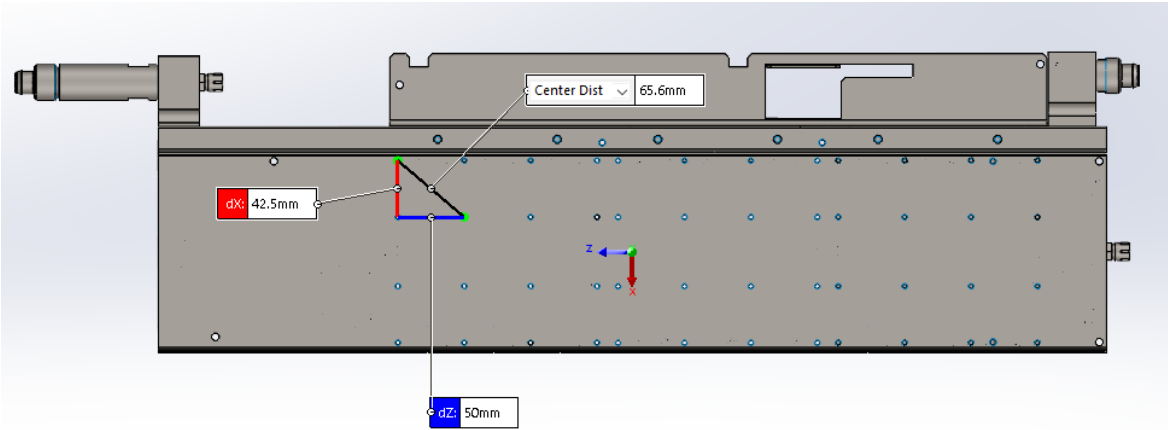


Figure 4.9 Bottom of the heatsink

As the heatsink of the product has holes in it, the selected vacuum pads must be placed in a way that they will not overlap with any of the holes. Otherwise the air will leak and the vacuum will not hold. For that reason, the chosen vacuum pads need to be smaller than 40 mm in diameter to reduce the risk of overlapping the pads with the holes in the heatsink. The jig also needs to be low height due to ergonomic reason, so the vacuum pads are meant to be mounted on the fixture itself. For that purpose, 32 mm diameter SMC flat type heavy-duty vacuum pads are used [19].



Figure 4.10 SMC ZP2-32HN vacuum pad [19]

The holding force of one vacuum pad can be calculated by using formula 4.1

$$F = P * S * 0,1 * \frac{1}{t} \quad (4.1)$$

Where F – Lifting force (N)

P – Vacuum pressure (kPa)

S – Pad area (cm^2)

T – Safety factor

As there is no lifting during this procedure, the safety factor can be considered as $t = 1$ and the lifting force as holding force.

$$F = 70 * 3,2 * \pi * 0,1 = 70,4 N$$

The total holding force with 3 vacuum pads is $3 \times 70,4 = 211 N$. Taking into account that the mass of the product itself is 19 kg, the total force needed to exceed to lift the product is $\sim 400 N$ which is enough for this kind of application. Therefore the fixture is designed with 3 pockets where the vacuum pads fit.

The air that creates the vacuum effect flows through the top fixture, which has specific channels milled on the bottom side of it. The air travels via pneumatic tubes through a threaded elbow which is mounted on the fixture from side.

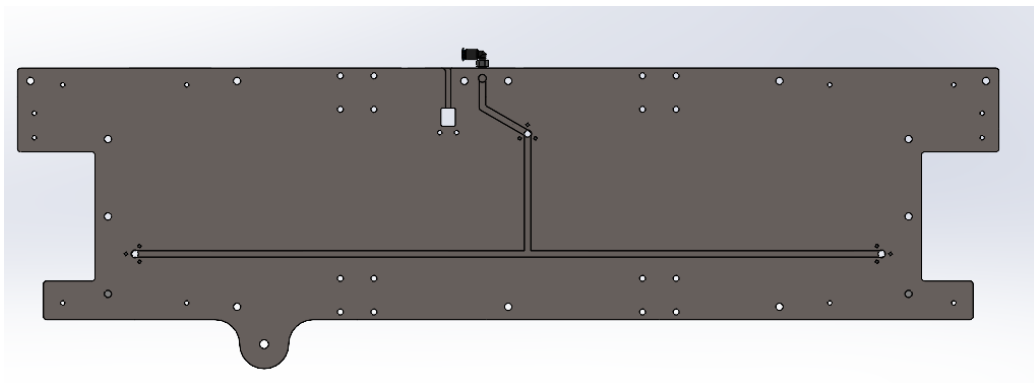


Figure 4.11 Bottom side of the top fixture

To cover the channels airtightly, the top fixture is mounted together with the bottom fixture. The bottom fixture has the same shape as the top fixture. In-between the fixtures, a SBR rubber sheet is placed to avoid air leakages.

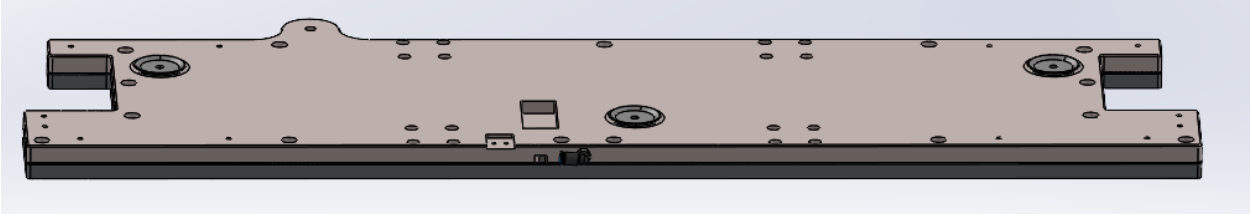


Figure 4.12 Assembled fixture with SBR rubber sheet

4.3 Linear motion between different positions

The vision system is used to acquire an image of the IGBT in three different positions. Linear guides are used to move the jig freely between different positions. The height of the linear guides must be higher than the 15 mm of vacuum ejector, as it is meant to be mounted on the base plate of the jig. For that purpose, MISUMI linear guides with a height of 24 mm are used [20].



Figure 4.13 Misumi linear guides [20]

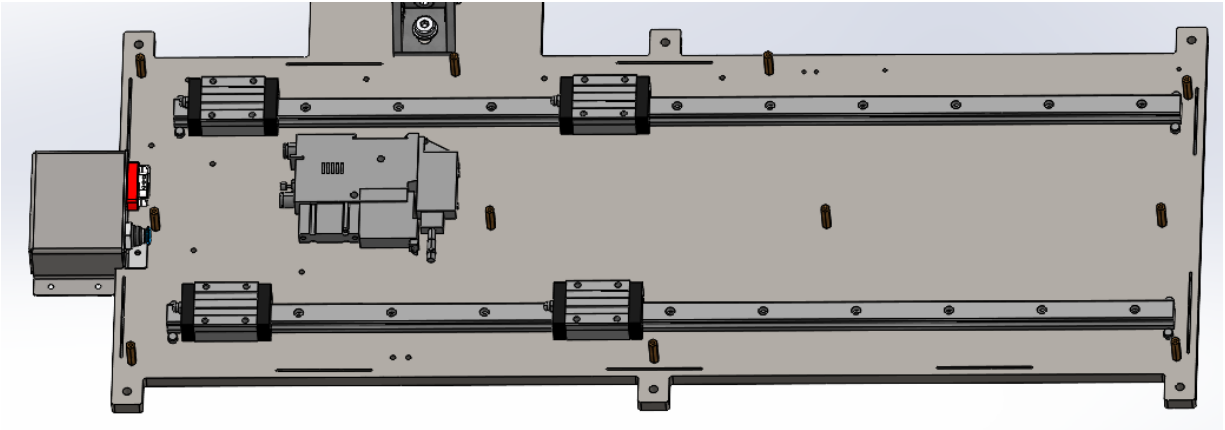


Figure 4.14 Base plate of the jig.

The assembled fixture is mounted on top of the linear blocks. By using an indexing plunger and a positioning bracket, the operator can move and lock the fixture between the 3

different positions, where the vision sensor is used to acquire an image. A rotary ball knob is installed to the fixture to move it more conveniently.

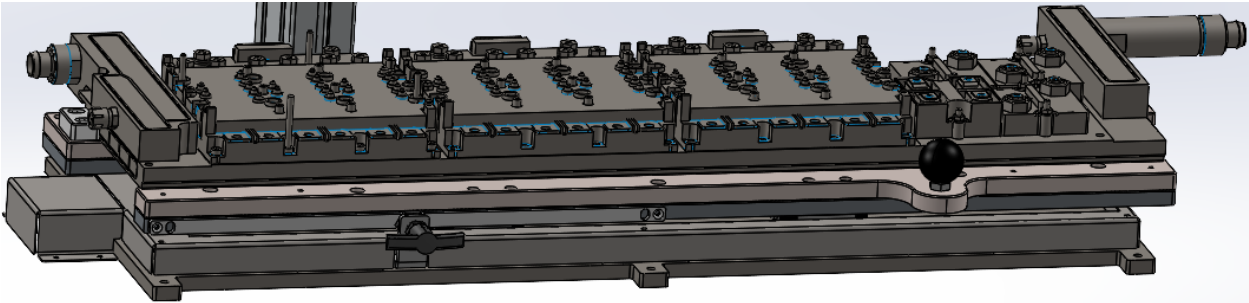


Figure 4.15 Assembled jig

4.4 Cables and pneumatic tubing

The fixture can be moved between 3 different positions, so the jig needs to have an energy chain installed for cables/tubes which move along relative to the linear motion. The moving cables/tubes are the proximity sensor cable and the pneumatic tube through which the vacuum effect is achieved. For convenient assembly and cabling a D-sub 9 connector and push-in fitting are placed on the side of the jig. To protect the incoming cable and the air supply tube, a protective bracket is designed.

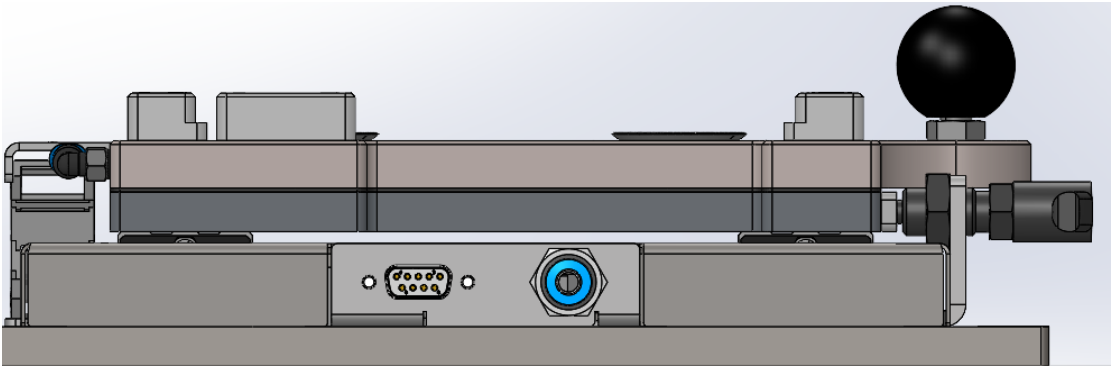


Figure 4.16 Side view of the jig with connector plate.

5 ELECTRONICS

All the electric connections are made inside the electrical cabinet. The author previously agreed to have a junction box with single phase 230 VAC installed nearby the workstation by the client. The incoming voltage to the electric cabinet is set at 230 VAC. The assembly station is turned on and off from the main power switch placed on the electric cabinet. The correct electrical schematics with all the wiring are in the appendix.



Figure 5.1 Electrical enclosure

5.1 System architecture

The PLC communicates with the vision sensor, the PC and act as an intermediate between the barcode scanner and the Power Focus 4000 controller. The vision sensor has an industrial M12 Ethernet connector and the PC in the workstation has an ethernet port. Power Focus 4000 and barcode scanners communicate through serial communication RS232. As there are multiple ethernet communications and the CPU unit has only one ethernet interface, the system is going to need a switch. The system architecture for the assembly station is the following:

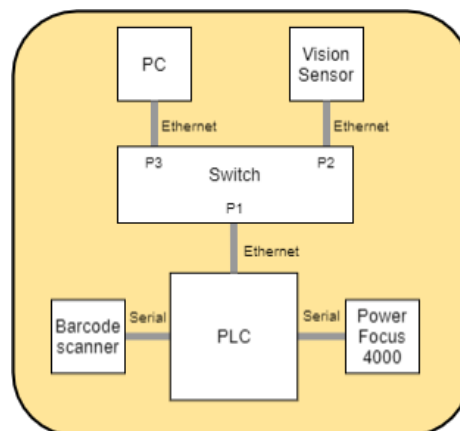


Figure 5.2 System architecture.

5.2 PLC system

The most important component of the assembly station is the PLC. The PLC does not need much computing power and memory as the assembly station has not a lot of data to handle [21]. As the company the author works in, has used a lot of B&R PLCs in the past, this system is going to be based on a B&R PLC. B&R has a flexible modular PLC system design which allows the user to have a high degree of freedom. Every module of the PLC system can be chosen freely and they according to the needs, that includes the CPU, power supply, input/output modules etc. Before the input and output modules can be chosen, all the inputs and outputs from the IO list need to be counted.

Table 5.1 IO list

Description	DO	DI
PF tool disabled	1	
Button LED	1	
Vacuum ON	1	
Vacuum OFF	1	
TPS coordinates OK		1
Job OK		1
Button		1
Reset Button		1
Proximity Sensor		1
Total:	4	5

For this solution, the author chose to use the following B&R PLC system:

Table 5.2 Components of the PLC system

Product	Description
X20CP0410	X20 Compact-S CPU, ARM Cortex-A9 166 MHz, 128 MB RAM and 256 MB built-in flash
X20PS9600	X20 power supply module, for Compact-S CPU and internal I/O supply, X2X Link supply
X20DI8371	X20 digital input module, 8 inputs
X20DO8322	X20 digital output module, 8 outputs
X20CS1020	X20 interface module, RS232

5.3 Power supply

24 VDC has been a standard in the industry for a long time and it is used as a control voltage for majority of industrial-control applications. A power supply must be installed to the electrical cabinet which transforms the 230 VAC to 24 VDC. To calculate the power

output needed for the assembly station, the current consumption of all the components must be taken into consideration. Generally the IO's do not consume a lot power. To have a reserve, a maximum of 100 mA current consumption per input and 200 mA per output is taken into consideration.

The electrical power of inputs and outputs can be calculated with the formula:

$$P = U * I \text{ (6.2)}$$

Where P – Power (W)

I – Electric current (A)

U – Voltage (V)

So the total maximum power consumption for inputs and outputs is:

$$P = 24(5 * 0,1 + 4 * 0,2) = 31,2 \text{ W}$$

Table 5.3 Power consumption of the system.

Component	Power consumption (W)
PLC system	4,2
Vision sensor	48
Moxa	1
Vacuum ejector	0.4
Inputs/Outputs	31,2
Total:	84,8

Therefor a 120 W, 24 VDC, 5 A power supply is more than sufficient for this system. Omron S8VK-C12024 power supply has been used in previous projects and is easily obtainable from Viru Elekrikaubandus, where it is a stock product [22].



Figure 5.3 Omron power supply S8VK-C12024 [22]

5.4 Relays

Relays are used in the system to read and send different signals between Atlas Copco system and the PLC. The PLC needs to read and send 3 different signals from and to the Power Focus controller:

1. PF tool disabled – For switching the input of the PF 4000 to HIGH state, which activates the “Disable tool” function. Therefor the smart arm cannot be used for screwing operations.
2. TPS coordinates OK – For reading the output of the TPS, which switches to HIGH state only when the tool is in the correct predefined position.
3. Job OK – For reading the output of the PF 4000, which is defined as a Job OK and switches HIGH only when the job is done correctly – all screws are screwed with the right torques.

The correct pinout for the cabling is taken from the TPS and PF manuals.

As HOOB has an in-house stock for most of the basic electrical enclosure materials, starting with terminal blocks and ending with relays, the relays used in this system are taken from there. The relay used is from phoenix contact RIF-0-RPT-24DC/21. It has an input voltage of 24 VDC and a minimum switching current of 10 mA. The current needed to activate the PF input is 5 mA, so the chosen relay is sufficient [23].



Figure 5.5 Phoenix contact relay RIF-0-RPT-24DC/21 [23]

5.5 Circuit breaker and fuses

The system will have one main circuit breaker and several fuses to protect different devices. They are both used to protect the electrical circuit from damage caused by short circuits and overloading. The circuit breaker used in this system is 1-pole circuit breaker from ABB S201-B6. Its rated current is 6 A and it has a B trip characteristic, which trips between 3

and 5 times the rated current [24]. B type circuit breakers are most commonly used for resistive loads that are non-inductive or with a very small inductive load, which makes it sufficient for this system.



Figure 5.6 ABB circuit breaker S201-B6 [24]

The time for the circuit breaker to operate is normally longer than it would take for a fuse to blow. This can become a problem because the circuit can be exposed to damaging currents for longer periods of time. Fuses are used instead of circuit breakers in places where sensitive electronic equipment is used. There are two main aspects to keep in mind when choosing the correct fuse rating.

1. Current rating of the smallest cable in the circuit.
2. Continuous current of the circuit.

It is recommended not to let the continuous current surpass $\frac{3}{4}$ of the current rating of the fuse. There are 3 different fuses used in the electrical cabinet.

1. PLC system – 1,6 A fuse
2. Vision system – 3 A fuse
3. Miscellaneous – 1,6 A fuse

According to the vision system's datasheet the maximum current can be 2 A when the illumination is on, so a fuse of 3 A is chosen. For the PLC and miscellaneous circuit, a fuse of 1,6A is chosen as the power consumption is relatively low. HOOB has in-house stock of phoenix contact fuse terminal blocks and various cartridge fuses which are used in the system [25].

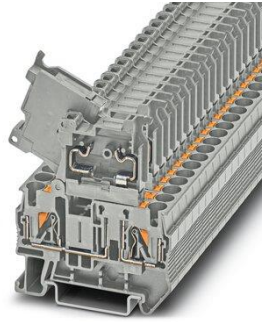


Figure 5.7 Fuse terminal block Phoenix contact PT 4-HESI (5X20) [25]

5.6 Switch

The choice of the switch is based primarily on the price of the product. As another order was going to be made from Elfa Distrelec by HOOB, the switch was chosen from their list of products. The most inexpensive switch is going to be used as the system needs only 3 ports for ethernet communication. The chosen switch is EDS-2005-ELP switch from moxa with 5 available RJ45 ports [26].



Figure 5.8 Moxa EDS-2005 ELP [26]

5.7 Button box

The assembly station is going to have a button box through which the assembler controls the system with. As the system needs two buttons to operate and some other components were order by Hoob from Esvika, the Eaton button box M22-I2-M1 was chosen [27].

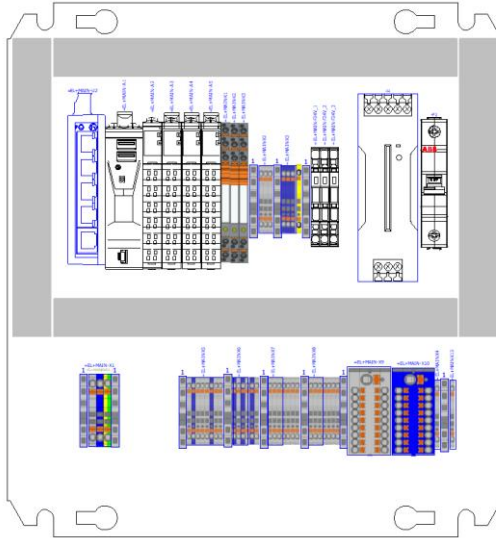


Figure 5.9 Eaton button box M22-I2-M1 [27]

1. Green button – Next step button. The button LED flashes if the system is waiting for a button push, constant green indicates that the vacuum is on, no green light means that the vacuum is off.
2. Red button – Abort button. While holding down the red button for 2 seconds, the vacuum is released and the product can be taken out from the fixture. The results of the previously done process are memorized. If the sensor does not detect the product in the fixture and the abort button is used, the results are reset. The Abort button will not work while the screwing operation takes place.

5.8 Electrical cabinet

The size of the electrical cabinet is determined by the components. The initial layout of the electrical enclosure was proposed through EPLAN Electric software [28]. EPLAN has a part library which has majority of the components from the most common manufacturers. The macros can be downloaded and are scaled to their real size, making it convenient for this application. Hoob uses mostly electrical enclosures from Rittal. A filter for Rittal components was used and a compact enclosure AE 1380.500 with a size of 380x380x210 mm was chosen [29].



6 VISION SENSOR

6.1 Configuration

The configuration and the programming of the vision sensor is done via the Cognex In-Sight Explorer software. To establish a connection between the vision sensor and a PC, the ethernet port of the PC must be in the same subnet as the IP address of the vision sensor. IP address of the ethernet port can be changed under network adapter settings in Windows. A manual IP address can be assigned under properties and IPv4. As each device in the subnet has to have their own IP, the IP address of the vision sensor and the port of the PC have to be different. Validate upon settings must always be ticked to save the changes.

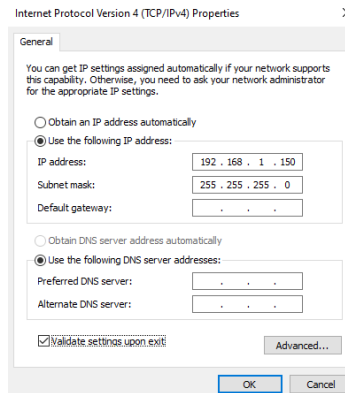


Figure 6.1 IP change of ethernet port

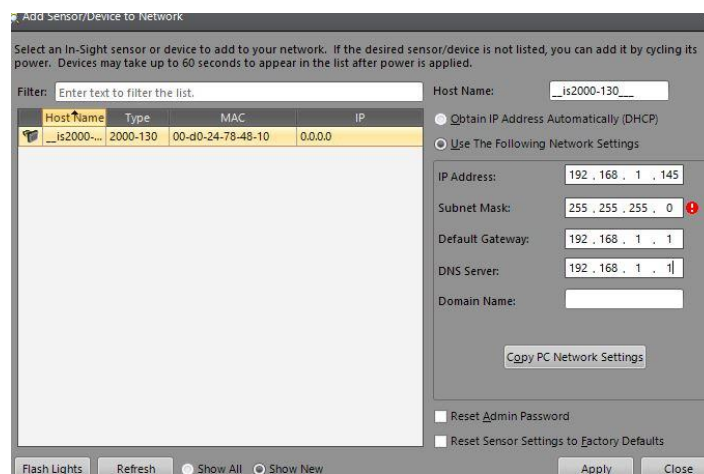


Figure 6.2 Vision sensor settings

To control the vision system via PLC the trigger type must be set to industrial ethernet and from the network settings the corresponding protocol must be selected. In this case it is set to Modbus TCP.

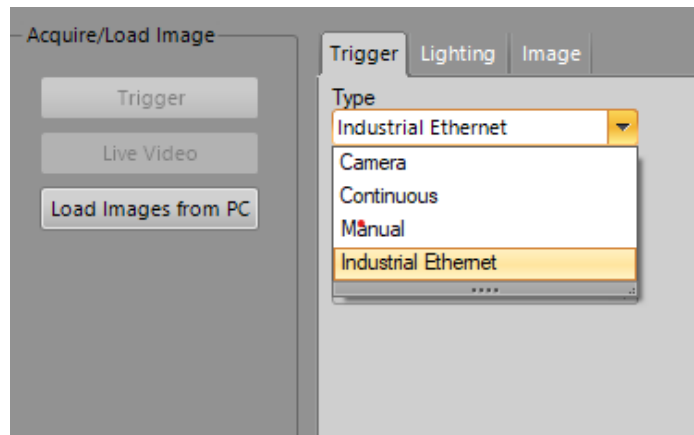


Figure 6.3 Trigger type

6.2 Detection of graphite sheets and springs

Cognex has developed In-Sight Explorer software for programming their vision systems. Cognex has a list of premade vision tools to use to inspect the parts for different kinds of applications. The In-Sight Explorer has two different interfaces for setting up the application. The selected vision sensor In-Sight 2000-130 has only the EasyBuilder configuration available, therefore the setup is done using that.

For the detection of graphite sheets and springs, the brightness tool is used. The brightness tool determines whether a feature is present or absent based on an average grayscale value. The tool reports a Pass if the score of the area is within the limits and Fail if it is outside of the limits. To use the tool, the shape of the ROI is chosen which is positioned directly over the measured feature. For the detection of the springs, the circle shape is used and placed over the positions of the springs. A fixture model needs to be trained from which the positions of the springs are always relative to. The fixture acts as a reference point for all the inspection tools linked to it. For selecting the fixture, a feature needs to be determined which will be in every image of the part and is easily recognizable. The vision sensor always searches for the fixture and once it has been located, the position serves as origin point which is used by other inspection tools to orient their regions.



Figure 6.4 Fixture feature

In this case the fixture model is shown as the blue lines. For training the fixture model the pattern tool was used. It locates a pattern feature, reports the X, Y coordinates, the angle and score of the pattern. The model for the fixture is placed over the ROI where there is an abrupt change between light and dark pixels as the edge detection works by examining for discontinuities in pixel polarity. The trained fixture model has a longer edge and a small arc which are looked for in every other acquired image. It is recommended to use multiple detected features as a fixture as it minimizes the fluctuation of the pattern's angle and X,Y coordinates, ensuring more stable results.

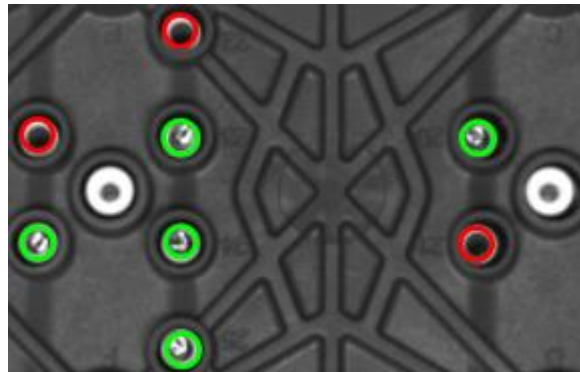


Figure 6.5 Detection of the springs

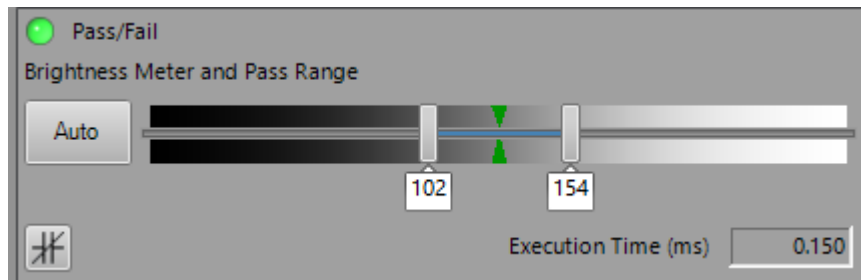


Figure 6.6 Brightness meter and pass range

To distinguish between different positions the pattern tool is used. As the jig is moved on the linear guidelines, the background of the acquired image is changing as well. To differentiate between the 3 positions different models in different ROI's are trained.

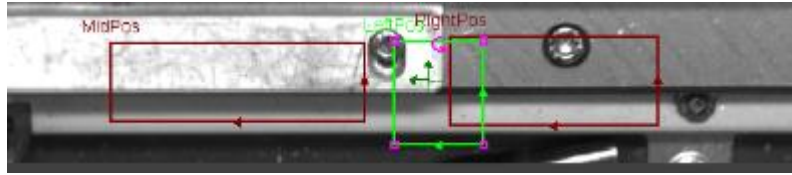


Figure 6.7 Image of the different regions



Figure 6.8 Model of the left position feature

In-sight explorer has in-built math tools, which can be used to create logical formula of tool pass and fail signals. As the results of 3 different positions need to be obtained, the logic tool was used to set up Boolean values, which are going to be sent to the PLC. The overall value is Pass if vision sensor detects the fixture, left position feature and all the springs. SpringPass is created the same way using 21 brightness values.

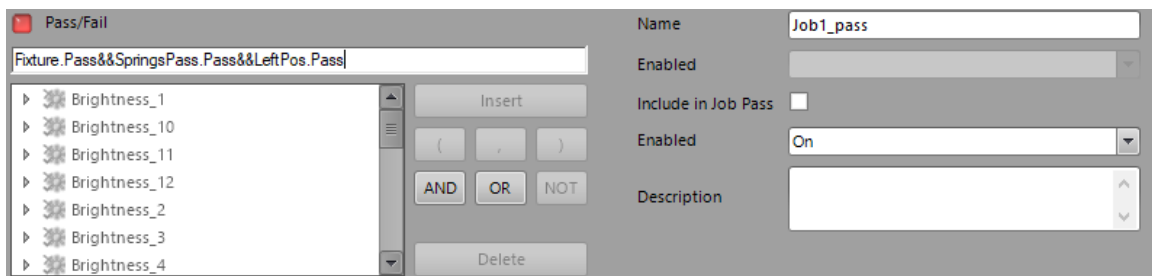


Figure 6.9 Job1_pass for successful detection of IGBT springs in the left jig position

All the necessary results for the PLC are then defined in the Format Output Data tab under communications and Modbus TCP Server. The address of the inspection results is Word 5-2004 of the output block.

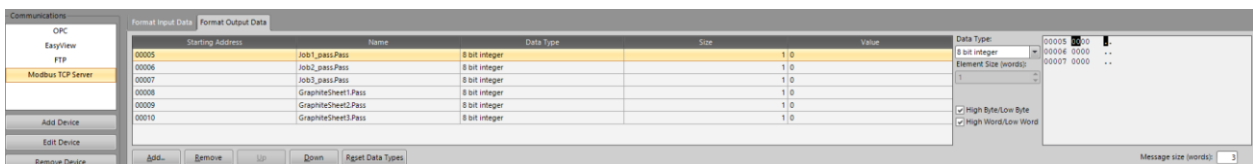


Figure 6.10 Inspection Data results of the vision sensor

6.3 Additional light and polarized cover

During the testing phase it was found that the vision sensor own lightning is not sufficient to ensure stable results. The springs reflect lots of light back and the result fluctuate too much regarding the positioning of the spring. It was also seen that the surrounding lights in the environment have effect on the end result. The upper left spring reflects back more light than the others.

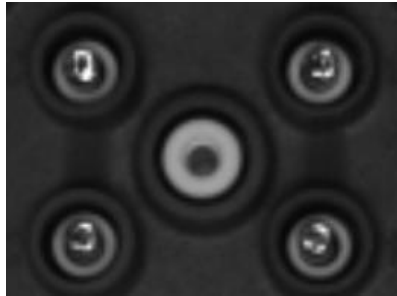


Figure 6.11 Spring detection with unstable light

To make the lightning more stable and to minimize the errors, an additional light and a polarized cover were added to the system. As the inspected area has a rectangular shape, a bar light is suitable for this application. The chosen light is ELB-200SW which is an adjustable, high-power bar light with an integrated controller. The chosen model is wide enough to illuminate the IGBT module and the lens positioning can be modified to change the irradiation distance [30]. Higher illumination compared to the surrounding environment make the results more stable. The additional light is mounted near the vision sensor. The bar light is connected to the sensor's output to trigger the additional light as soon as an image is acquired.



Figure 6.12 ELB-200SW [30]

To reduce undesirable reflections on shiny surfaces a polarized cover can be used. They reduce the glare and hot spots, making the overall results of the acquired images more stable and the image homogenously illuminated. Cognex has a polarized ring light cover as an accessory item for the used vision sensor model.



Figure 6.13 Cognex IMPF-2000-polarized cover [14]

6.4 Assigning a name for the image

The file name for the saved images is corresponding to the scanned product code. The vision sensor receives the string from the PLC. Under the communication panel a new device needs to be added. The Modbus TCP Server is selected, and below Format Input Data tab a new function *WriteImageFtp_1.File_Name* is added. The address for the user data field is word 1-2000 of the input block [31]. The element size is set to 50 words, which is 100 bytes and the process is repeated for 6 times in total with the offset being 50 words. The file name is going to differ depending on the results of the job. If the springs are detected successfully, the file name is going to have *_OK_* in the prefix, otherwise it will be *_NOK_*. The first 50 words are allocated for the pass and the following 50 are for fail condition of the job.

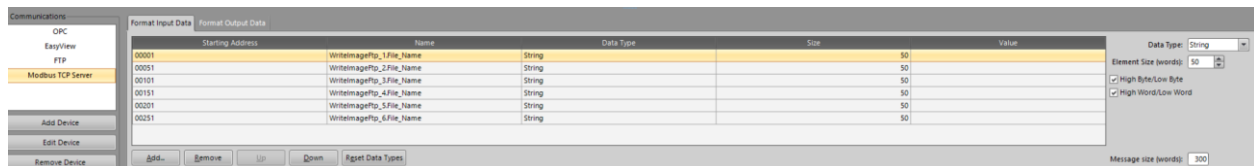


Figure 6.14 WriteImageFTP_File_Name

6.5 Saving the images

One of the requirements of the client was to have a backup of the acquired images. There are multiple methods for saving images from In-Sight vision systems. The different methods of saving images were presented to the client. As the client valued the possibility of also saving the SVG files, the WriteImageFTP function method is used. This function is used to write the image to an FTP server on the network. For testing purposes FTP server was set up in a Windows 10 computer through IIS Manager. The default port for FTP is port 21, which was used during testing. A physical path was given to the server, no SSL and the

user was set as anonymous. From the vision sensor side, the FTP settings must be set under the communication menu and the overall FTP settings. The Host Name is the IP address of the server, in this case it is the address of the Ethernet port of the PC. The User Name of the device must be set as anonymous, otherwise the vision sensor will not be able to have access to the server and upload the images. When saving files to the FTP directory, the File Name path must precisely match the physical path of the server, so the folder address where the images are going to be saved must be in the file name.

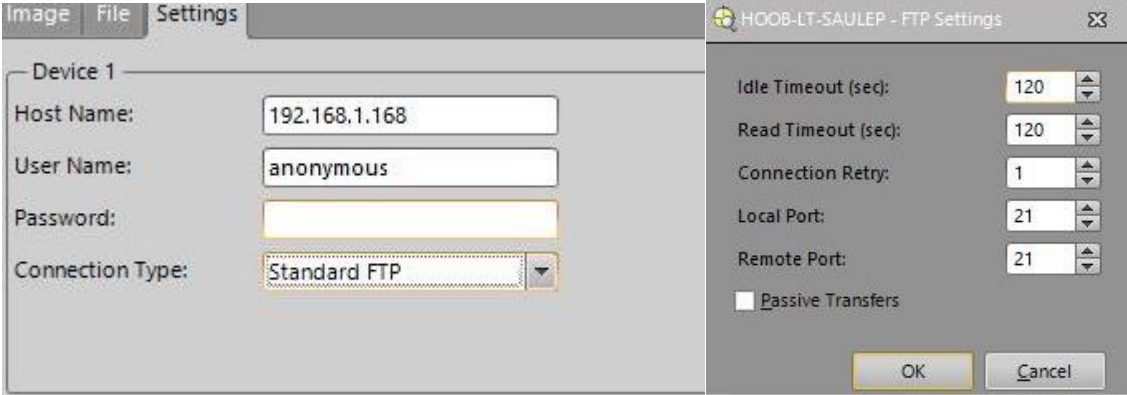


Figure 6.15 FTP settings In-Sight Explorer

During the next image acquisition the images with the corresponding scanned file names are saved to the FTP server. For the Fail images the SVG file is included to see which feature did not pass the vision control. Add Counter is also ticked to add a counter prefix to see how many times the image of a module was acquired.

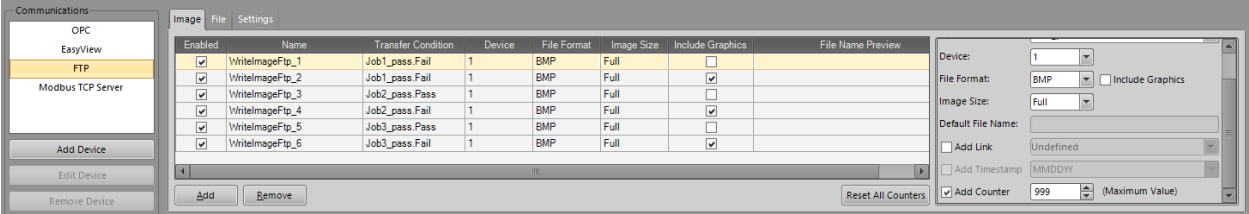


Figure 6.16 WriteImageFTP

	8211002420_NOK_000.bmp	13.03.2021 14:13	BMP File	302 KB
	8211002420_NOK_000.svg	13.03.2021 14:13	Microsoft Edge H...	16 KB
	8211002420_NOK_001.bmp	13.03.2021 14:14	BMP File	302 KB
	8211002420_NOK_001.svg	13.03.2021 14:14	Microsoft Edge H...	16 KB

Figure 6.17 Saved images inside the FTP server

7 PLC PROGRAMMING

All of the configuration and programming is done via B&R Automation Studio software. The client has set the following requirements for the system:

- Can change between two different programs depending on the product.
- Have a visual feedback regarding the state of the program.
- Save the results of the assembly process in case of a power failure.
- Save the acquired images to a folder with corresponding product code.

7.1 Hardware configuration

When starting a new project in the AS, the hardware configuration must be first defined. The chosen CPU with the bus module is then selected from the product catalog.

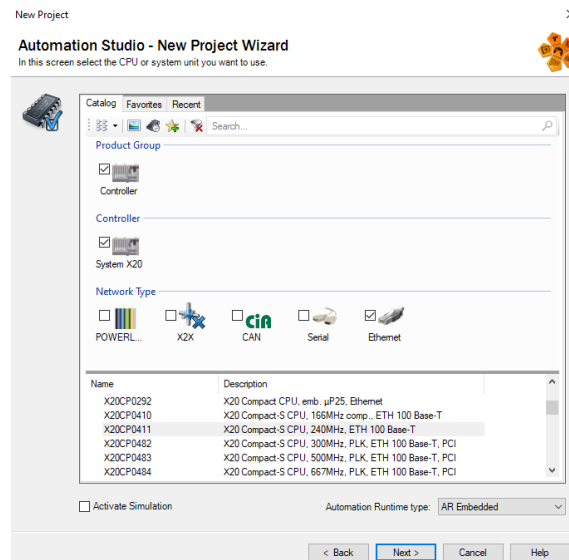


Figure 7.1 AS Hardware configuration

The basis of the PLC system is created and all the other necessary modules can be added to the hardware configuration via the hardware catalog.

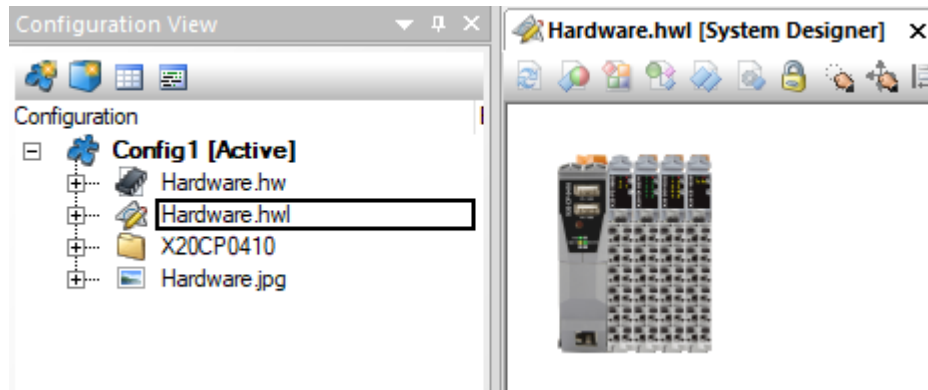


Figure 7.2 PLC system hardware configuration.

7.2 Network configuration

The PLC also needs to be in the same subnet as the vision sensor and PC. The IP address can be manually assigned to the IP under the ethernet port configuration. As Modbus TCP protocol is used to communicate with the vision sensor, it must be first activated from the port configuration.

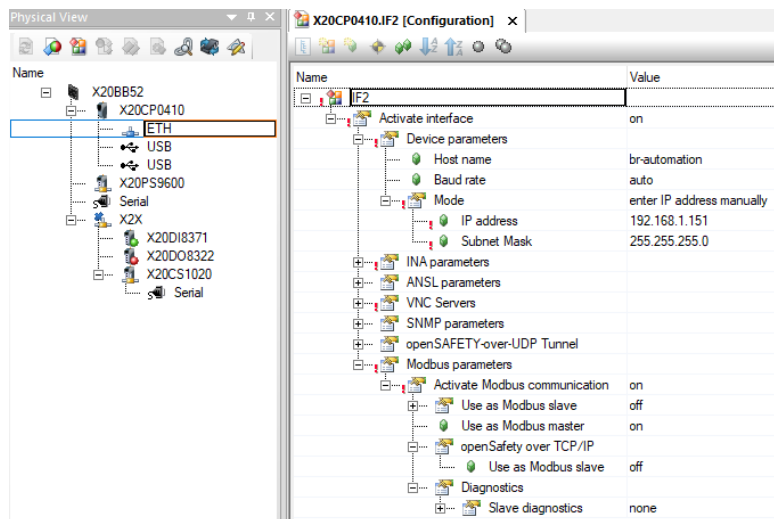


Figure 7.3 PLC configuration

A Generic Modbus Station is also added to the hardware configuration to establish the connection.

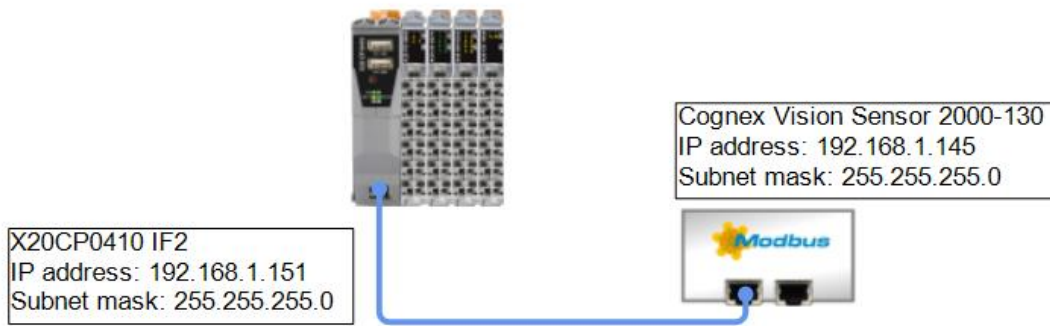


Figure 7.4 Network parameters of the system.

7.3 Structure of the program

The assembly station is built following the state machine principle. The program acts differently regarding to the selected product. The older version of the product does not have the graphite sheet and IGBT where the spring detection is needed, therefore these steps are skipped. The programming language of the system is Structured Text. In addition to the IEC programming languages, B&R supports its own Automation Basic, Continuous Function Chart language and allows to program parts of the project C and C++ [32]. The author chose to program the system in Structured Text for the following reasons:

- Familiarization with ST.
- Similarities to traditional programming languages like C++ or Python.
- Information is easier to interpret.
- Easier to create complex routines compared to ladder logic.

7.4 Important sections of the program

7.4.1 Communication with the vision sensor through ModbusTCP

The first step is to look at the defined data blocks of the vision sensor for successful communication with the PLC. These Modbus TCP data blocks of the vision sensor control the reading and writing from and to the PLC [31]. To communicate via modbus TCP an automation studio library AsMbTCP was used, which has function blocks for reading and

writing the coils and registers. The registers of the vision sensor are 1 word long, equal to 2 bytes or 16 bits. Each of the blocks have their own address space which need to be defined in the PLC. All of the necessary signals for controlling the processes are mapped as variables in the PLC to be used in calling out the function blocks. The same principle applies for both writing and reading to and from the registers. The Modbus TCP vision control block is 4 bytes long equal to 2 registers.

Program code 7.1 Writing the registers (the commands do not appear in the code in sequence).

```
//write registers
mbWriteMultipleRegisters_0(enable := TRUE,
pStation := ADR(mb_station) ,
startAddress := write_register_address ,
nrRegisters := 2,
pData :=ADR(write_register_value) ,
dataSize := SIZEOF(write_register_value));

//Vision control block
ControlByte.0:=VisionControl.TriggerEnable;
ControlByte.1:=VisionControl.Trigger;
ControlByte.2:=VisionControl.ByfResEnable;
ControlByte.3:=VisionControl.InspResultAck;
ControlByte.4:=VisionControl.ExecCommand;
ControlByte.7:=VisionControl.SetOffline;
write_register_value[0] := ControlByte;

write_register_value[2].0 := VisionControl1.SetUserData ;
write_register_value[2].2 := VisionControl1.ClearError ;
write_register_value[2].3 := VisionControl1.ClearExpCompl ;
```

The read_register_value is a variable defined as an array BYTE[0..3]. ControlByte variable is created to make the states of the vision sensor easier to interpret. Each of the bits are mapped according to the Data Blocks of the vision sensor.

7.4.2 Reading the barcode

The PLC will receive all the scanned product codes via RS232 interface. While assembling the newer version of the product, the images acquired by the vision sensor must be saved to the PC. The file name of the image needs to be the scanned product code. For reading and sending information through serial communication, ascii_rs library from AS is used. The function blocks have to be first defined with the enable bit, correct interface, baudrate etc.

Program code 7.2 Reading the barcode (the commands do not appear in the code in sequence).

```
SERIAL_ASCII_READER_0(Enable := ReadBarcode, Mode := '/PHY=RS232 /BD=9600 /DB=8 /PA=N /SB=1' ,
Interface := 'IF1' , Data := Barcode );

ReadBarcode := TRUE;
IF LEN(Barcode) > 2 AND IGBTProgram = 0 THEN
    ImageName := LEFT(Barcode, LEN(Barcode) -1 );
    ImageName := RIGHT(ImageName, LEN(ImageName) -1 );
```



```

END_IF
ReadBarcode := FALSE;
Barcode:='';

```

The variable Barcode is a string which is emptied after each time it is sent to the PF controller. The barcode comes with a prefix and suffix character which are removed and saved to a string ImageName.

7.4.3 Sending the product code to vision sensor

The scanned string with the correct product code is sent to the registers of the vision sensor to save the images with corresponding file names. The strings must be transferred into the UserData section of the data blocks. Each character must be allocated a byte as every character is 8 bits long in ASCII. Once the data is correctly set into the UserData section, SetUserData must be set to 1 after which the SetUserDataAck needs to be acknowledged. Once SetUserDataAck is received, SetUserData can be reset and the data is written into the registers of the vision sensor. For manipulations of strings, an AS library asstring is used.

Program code 7.3 Sending the product code to vision sensor registers (the commands do not appear in the code in sequence).

```

FolderAddress:= 'C:\ImagesSKIM\';
ImagePass := '_OK_';
ImagePath := CONCAT(FolderAddress, ImageName);
ImagePassPath := CONCAT(ImagePath, ImagePass);

//Move data to registers
FOR i:=0 TO SIZEOF(write_userdata_value)-1 DO
    write_userdata_value[i]:=0;
    write_userdata_value1[i]:=0;
    write_userdata_value2[i]:=0;
END_FOR
Offset :=0;
IF LEN(ImagePassPath) > SIZEOF(BufferArray) THEN
    memcpy(ADR(BufferArray),ADR(ImagePassPath),SIZEOF(BufferArray));
ELSE
    memcpy(ADR(BufferArray),ADR(ImagePassPath),LEN(ImagePassPath));
END_IF
FOR i:= 0 TO 99 DO
write_userdata_value[i+Offset] := BufferArray[i];
END_FOR;

FOR i:=0 TO SIZEOF(BufferArray)-1 DO
    BufferArray[i]:=0;
END_FOR

//Set/reset UserData block
VisionControl1.SetUserData := TRUE;

IF VisionStatus3.SetUserDataAck = TRUE THEN
    VisionControl1.SetUserData := FALSE;
END_IF

```

The FolderAddress is a string, which is the physical address of the FTP server. ImagePass is a string, used as a suffix, which is added to the corresponding image name. CONCAT function is used to add the FolderAddress and ImageName to a variable ImagePath. The image name and suffix string are merged together for a variable ImagePassPath. The write_user_data value is an array BYTE[0..199], which is emptied before moving the characters of ImagePassPath to the registers. In this case there are 200 bytes which can hold 200 characters in total. The Offset value is used to differentiate between the "OK" images and "NOK" images. The Offset for "NOK" is 100, so the failed image name starts from 100th register. The BufferArray is a buffer array BYTE[0..99]. Memcpy function is used to copy the memory area of ImagePassPath to BufferArray, which is then used to assigning the values to corresponding registers for vision sensor. The Buffer array is then emptied.

8 HMI

All the important features of the system can be seen via HMI interface. The HMI can be connected to via VNC Viewer by using the IP address of the PLC (192.168.1.151). The HMI is a single page visual feedback interface for the operator for choosing the program and to see the state of the system.

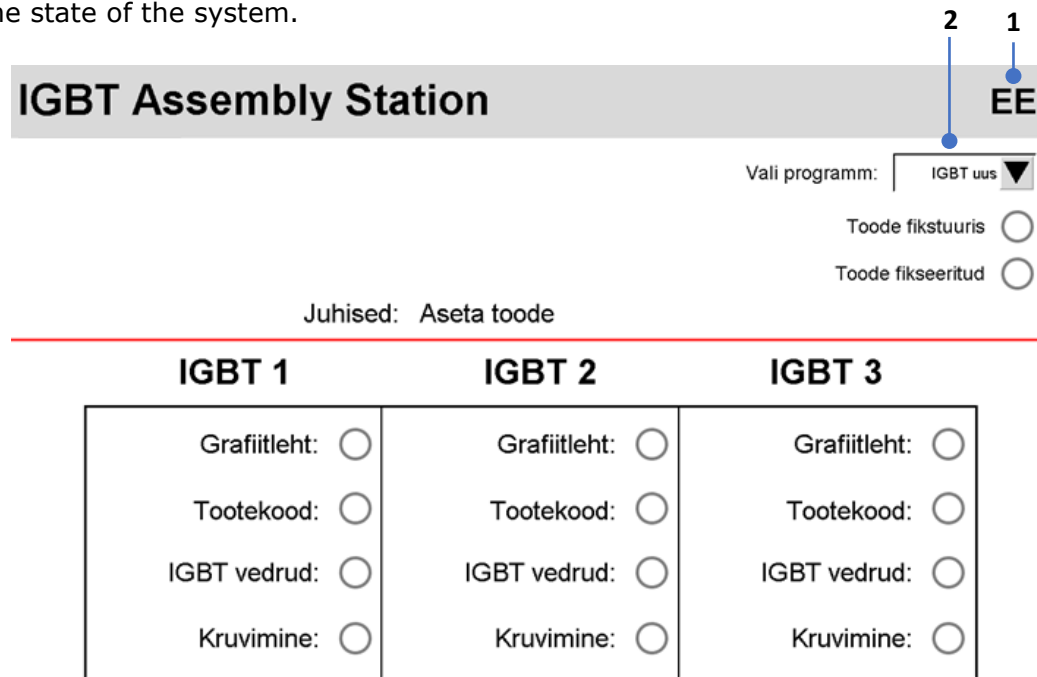


Figure 8.1 – HMI

- 1) Language selection – There are 2 options for the HMI language, Estonian and Russian. By pressing on the language selector, it is possible to switch between the languages.
- 2) Program selection – Dropdown menu for choosing the appropriate program before starting the assembly process. If the sensor detects the product, the currently active program on HMI is locked. In order to change the program the fixture needs to be empty.

8.1 Main page

The system has a single page HMI and all necessary elements required for operating with the system are available on the main page.

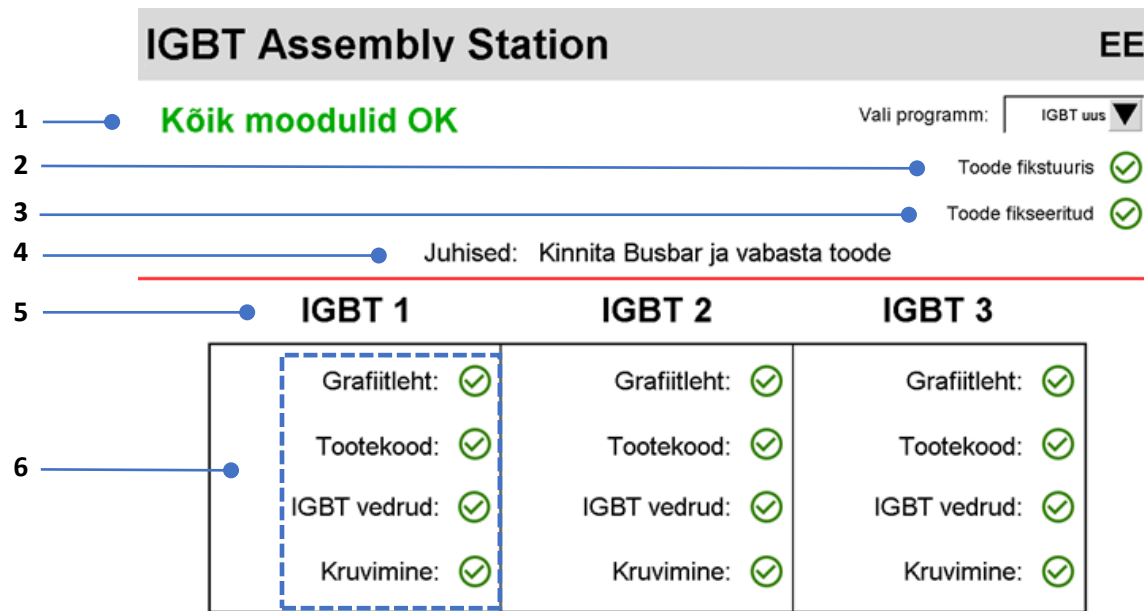


Figure 8.2 Main page

Labels

- 1- End result status – Shows the status of completed cycle.
- 2- Proximity sensor status – Shows the status of proximity sensor. Green tick means that the sensor identifies the product placed in the fixture.
- 3- Vacuum status – Shows the status of the vacuum. Green tick means that the product is locked in the fixture.
- 4- Instructions – Shows the instructions of the current step needed to be performed.
- 5- Active module indication – Indicates the status of currently active IGBT module. The text is red if the module is active.
- 6- IGBT status – Shows the status of the IGBT module.

The statuses of the elements are as follows:

- – Not started element.
- ⊗ – Failed element.
- ✓ – Passed element.

9 Power Focus 4000

For the PLC to communicate with Atlas Copco TPS and Power Focus 4000 controller, some minor configurations must be made to the existing system.

9.1 Configuring the internal I/O

The TPS controller and Power Focus4000 communicate through digital inputs and outputs. The software ToolsTalk Power Focus was used to configure the parameters of the Atlas Copco system. The PF has 4 digital inputs, one of them is almost always used for Tool disable signal, which lets the operator to use the tool only when it is above the correct screwing position. The screwing positions can be taught via TPS controller. The remaining 3 inputs are defined as Pset select bits. 3 bits are occupied, enabling $2^3 = 8$ different Psets. The Psets are a set of screwing operations which can be used when creating a job. The Power Focus controller always checks the result of the screwing operations, sending a OK or NOK signal to TPS. If the result is OK, the TPS and PF increment the position by 1.

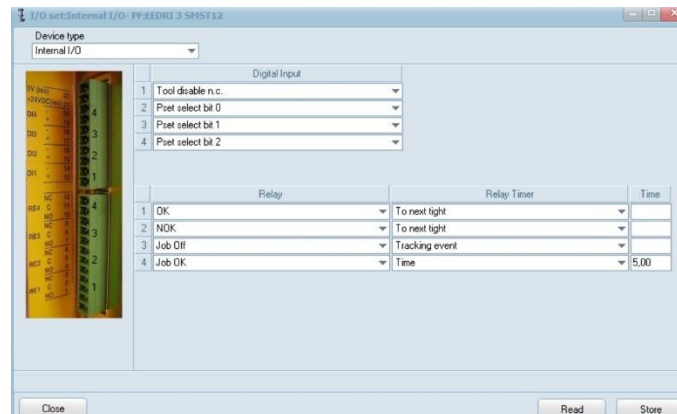


Figure 9.1 Power Focus 4000 digital inputs & outputs.

As the screwing operation can only take place in a certain state of the system, the tool disable signal must be read from the TPS to PLC and sent from PLC to PF. The vacuum in the assembly station needs to stay on during the whole assembly process, to release it the Job OK signal must be read to the PLC. The Job Off relay has no effect in this case.

9.2 Activation of the job

The job for screwing the IGBT with springs includes 5 different Psets and has a total batch size of 56.

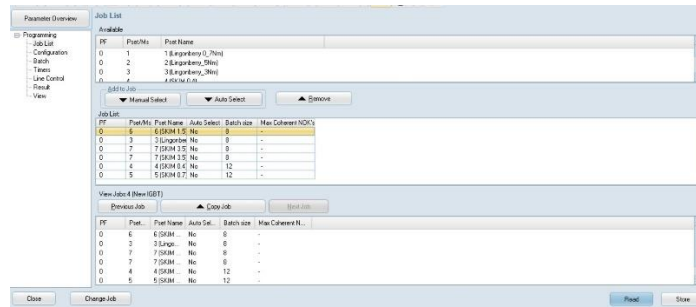


Figure 9.2 Example job containing different Psets

The jobs are activated with the scanned barcode strings. There are 3 different IGBTs mounted on the heatsink, each of them having a barcode of 10 characters. The system is built up in a way that if the Power Focus receives 3 strings, a job will be activated.

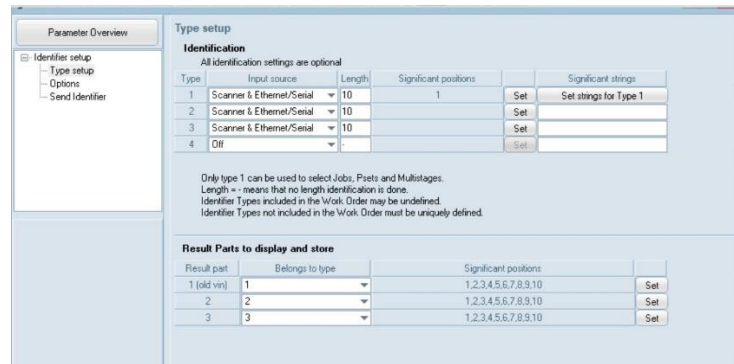


Figure 9.3 Power Focus activation of jobs

There are currently two versions of the product, the job for the older revision is activated if all three strings start with the character 8 and the newer is activated if all the strings start with 9. The scanned product codes for the newer version of the IGBT actually longer in length than 10 characters. To bypass that the PLC sends 3 consecutive strings to Power Focus, all starting with 9, when it has reached the correct state meant for screwing.

Identifier	Pset	Multistage	Job
8			1 (IGBT)
9			4 (New IGBT)

Figure 9.4. String identifiers for activating the jobs.

9.3 Testing the system

To test the system, the necessary signals from Power Focus 4000 and TPS were needed to be sent to the PLC. The communication between TPS controller and Power Focus 4000 is through a 25 pin D-sub cable. To find out which wire color belongs to which pin of the D-sub connector, a multimeter was used on continuity mode. The outputs of the TPS controller were configured accordingly.

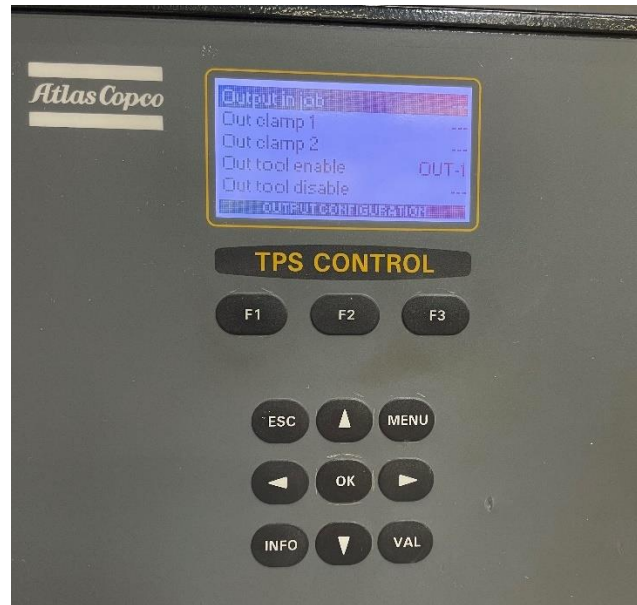


Figure 9.4 TPS outputs

The system was then tested with the existing setup, while the barcode scanner was connected to Power Focus 4000. The state of the inputs/outputs were followed via Watch/Monitor in AS. The relay used in the project has an in-built LED which also indicates the state of the relay.

After the successful testing of the first part of the assembly station integration, some rewiring had to be made for the barcode scanner. A D-sub 9 cable with flying leads was connected to the barcode scanner. The necessary signals for RS232 serial communication are RXD, TXD and GND which were wired to the corresponding terminals of the PLC power supply module. Another D-sub 9 cable with flying leads was used, where the flying leads were wired to the corresponding terminals of the PLC interface module and the D-sub connector to the Power Focus 4000. After opening the serial ports in AS, the scanned barcodes were sent to the Power Focus 4000 controller.

10 SAFETY AND COST OF THE SYSTEM

IGBT Assembly Station has safety stickers placed on parts that are deemed hazardous or dangerous. These stickers are meant to remind the operators that there are hazardous or dangerous areas.

10.1 Mechanical safety requirements

As it is a manually operated station, which has no automatically moving or rotating parts, it has no need for an emergency stop button and has a low risk of causing injuries. Some basic safety standards were followed throughout the mechanical design of the system [33]:

1. Two-hand control (EN ISO 13851).
2. Minimum gaps to avoid damaging the human body (EN ISO 13854).

To move the fixture between the three different positions, the assembler must use one hand to pull the spring plunger and the other to move the fixture. This prevents the operator from most of the mechanical hazards like crushing or entanglement. The only gaps on the assembly station are for the linear guidelines. Safety stickers are placed on both side of the linear side cover indicating the risk of hazard.



- Danger! Moving parts, risk of crushing hands!

10.2 Electrical safety requirements

To place a system on the market, it must meet the safety requirements set by EU legislations. The Low Voltage Directive must be followed to ensure high level of protection of electrical equipment within certain voltage limits [34]. The safety requirements set by the LVD were followed during the project. All the electric equipment is installed in a protective cabinet, placed under the table of the workstation. It must be understood that the work on electrical systems or electrical devices must be managed only by properly trained people and in accordance with the electro-technical rules.



- Dangerous electrical voltage!

10.3 Cost of the system

Throughout the design of the system, multiple components were needed to be purchased and manufactured. The price of the different components is not brought out separately. A definitive version of the cost of the system including the materials and equipment is pointed out in the following table.

Table 10.1 Cost of the assembly station

Item	Price (€)
Vision system (Sensor, cables, mounting etc.)	4000
Purchased components	3700
Manufactured components	300
Assembly fixture (Linear guides, vacuum, etc.)	3000
Purchased components	1100
Manufactured components	1900
PLC system	1100
Purchased components	1100
Additional light and polarized cover	1400
Purchased components	1400
Total cost:	9500

SUMMARY

The work presented in this thesis is a part of a practical project at Hoob OÜ. The thesis involves the development of an assembly station for a client which is used for inspecting the quality of an IGBT assembly process. During the work, the concept of the system was devised and executed, suitable components were selected and necessary calculations were done.

During the first chapters, an overview of the stated problem is given. The author describes the existing set-up, different communication methods and protocols for PLCs, machine vision principles and product locking features. The proposed solution is pointed out with the process flow chart.

The next chapters include the mechanical design of the assembly station, electronics and pneumatics of the system, machine vision, PLC programming, HMI and configuration of Atlas Copco devices. As the final product was made for the client, there were multiple design reviews and meetings regarding the selection of the components and working principles of the system.

Throughout the chapters of the design and electronics, the overview of the assembly station and the system architecture was given. The selection of the necessary components was justified and chosen methods for achieving the desired result were explained.

The chapters of machine vision, PLC programming and Atlas Copco devices include the hardware and software configuration, methods used for object detection, the communication between the controllers and the vision sensor, assigning of the scanned barcode as a file name, saving the acquired images to FTP server and the most important sections of the written program code.

A PC had been installed at the existing workstation which is used as an HMI. The assembler has an overview of all the important process parameters regarding the developed IGBT assembly station, such as the state of the vacuum, results of the acquired images of graphite sheets, scanned barcodes, IGBT springs and the results of the screwing operations performed by Atlas Copco devices.

The stated goals of the thesis were fulfilled and the assembly station is installed at the client's site for manufacturing purposes. Currently the process involves the assembly of 3 consecutive IGBT modules. In future, a rework mode is added to the system which allows for the change of a single IGBT module independent of the position.

KOKKUVÕTE

Käesolev magistritöö on osa praktilisest projektist ettevõttes Hoob OÜ. Lõputöö põhineb IGBT koostamisprotsessi kontrollimise tööjaama väljaarendamisel kliendi jaoks. Töö käigus mõeldi välja ja realiseeriti süsteemi kontseptsioon, valiti sobilikud komponendid ja tehti vajalikud arvutused.

Esimised peatükid annavad ülevaate probleemikirjeldusest. Autor kirjeldab kasutuselolevat süsteemi, erinevaid suhtlusmeetodeid ja protokolle tööstuskontrollerite vahel, masinnägemise põhimõtteid ja toote lukustamise võimalusi. Autor pakub omaltpoolt välja meetodi probleemi lahendamiseks koos blokkdiagrammiga.

Järgnevad peatükid kirjeldavad tööjaama mehaanika projekteerimist, süsteemi elektroonikat ja pneumaatikat, masinnägemist, tööstuskontrolleri programmeerimist, operaatorpaneeli ja Atlas Copco seadmete konfiguratsiooni. Arenduse käigus oli kliendiga mitmeid koosolekuid, mis olid seotud tööjaama disaini, komponentide valiku ja tööpõhimõtetega.

Mehaanika projekteerimise ja elektroonika peatükis on välja toodud ülevaade lõplikust tööjaamast ja süsteemi arhitektuurist. Autor põhjendab vajaminevate komponentide valikut ning selgitab lõpptulemuse saavutamiseks kasutatud meetodeid.

Masinnägemise, tööstuskontrolleri programmeerimise ja Atlas Copco seadmete peatükis on kirjeldatud riist-ja tarkvaralist konfiguratsiooni, objektide tuvastamiseks kasutatud meetodeid, kontrollerite ning kaamera vahelist suhtlust, skanneeritud ribakoodi määramist faili nimeks, tehtud piltide salvestamist FTP serverisse ja programmi olulisemaid lõike.

Antud töökohta on paigaldatud arvuti, mis on kasutusel kui operaatorpaneel. Montööril on ülevaade kõigist kõige olulisematest IGBT tööjaama protsessi parameetritest nagu vaakumi seisund, grafiitlehtede, skaneeritud ribakoodide ja IGBT vedrude tuvastamise tulemus ning kruvimiste tulemus Atlas Copco seadmete abil.

Lõputöös püstitatud eesmärgid said saavutatud ning tööjaam on paigaldatud kliendi juurde tootmiseks. Käesoleval hetkel hõlmab protsess kolme järjestikuse IGBT mooduli koostamist. Edasiarenguna on kliendil soov lisada ümbertöötamise režiim, mis võimaldab ühe IGBT mooduli väljavahetamist sõltumata selle positsioonist.

LIST OF REFERENCES

- [1] V. D. Pasquale, S. Miranda, W. P. Neumann and A. Setayesh, "Human reliability in manual assembly systems: a Systematic Literature Review," *16th IFAC Symposium on Information Control Problems in Manufacturing INCOM*, 2018.
- [2] Stemmer Imaging, *The Imaging & Machine Vision Handbook*, 2016/2017 issue.
- [3] Atlas Copco, "Atlas Copco Power Focus 4000 Manual," [Online]. Available: <http://www.e-pneumatic.com/media/pdf/atlas-copco-power-focus-4000-manual.pdf>. [Accessed 15 December 2020].
- [4] Atlas Copco, "Atlas Copco TPS Manual," [Online]. Available: <http://www.edlosales.com/TPS%20Control%20Guide.pdf>. [Accessed 2020 December 15].
- [5] Fieldbus inc., "Fieldbus Comparison," Fieldbus inc., [Online]. Available: http://www.fieldbusinc.com/downloads/fieldbus_comparison.pdf. [Accessed 05 January 2021].
- [6] R. Roszkowski, "Different machine vision network interface options: choosing the right network interface is an important part of developing successful machine vision applications.," *Quality*, vol. 56, no. 3, March 2017.
- [7] L-Tron Corporation, "Barcode Scanner Interface," [Online]. Available: <https://www.l-tron.com/barcode-scanner-interface-connect-and-communicate/>. [Accessed 05 January 2021].
- [8] AIA Vision Online, "The Fundamentals of Machine Vision," AIA, [Online]. Available: <https://www.visiononline.org/userAssets/aiaUploads/file/T1-The-Fundamentals-of-Machine-Vision.pdf>. [Accessed 20 December 2020].
- [9] E. R. Davies, *Computer and Machine Vision: Theory, Algorithms, Practicalities (Fourth Edition)*, Florida, 2013.
- [10] University of Brunswick, "Ergonomics," [Online]. Available: <https://www.unb.ca/fredericton/wellness/resources/ergonomics.html>. [Accessed 30 December 2020].
- [11] Spreitzer, "Vacuum clamping," [Online]. Available: <https://www.spreitzer.de/en/clamping-technology/vacuum-clamping-technology/>. [Accessed 20 January 2021].

- [12] Nexus Pneumatics, "Pneumatic clamping," [Online]. Available: <http://nexuspneumatics.com/products/toggle-clamps-clamping-solutions/pneumatic-clamps/>. [Accessed 06 January 2021].
- [13] Nexus Pneumatics, "Swing clamping," [Online]. Available: <http://nexuspneumatics.com/products/toggle-clamps-clamping-solutions/swing-clamps/>. [Accessed 06 January 2021].
- [14] Cognex, "In-Sight 2000 specifications," [Online]. Available: <https://www.cognex.com/products/machine-vision/vision-sensors/in-sight-2000-vision-sensors/models-and-specs>. [Accessed 20 December 2020].
- [15] B&R, "X20CP0410 PLC," [Online]. Available: <https://www.br-automation.com/en/products/plc-systems/x20-system/compact-s-cpus/x20cp0410/>. [Accessed 23 December 2020].
- [16] European Circuits LTD, "ESD - What You Need To Know," [Online]. Available: <https://european-circuits.co.uk/esd-what-you-need-to-know/>. [Accessed 2 February 2021].
- [17] SICK, "Inductive proximity sensors," [Online]. Available: <https://www.sick.com/fi/en/inductive-proximity-sensors/inductive-proximity-sensors/iqv/iq20-07bpsdu2s/p/p341544>. [Accessed 20 January 2021].
- [18] SMC, "Vacuum ejector," [Online]. Available: https://content2.smctech.com/pdf/ZK2A-B_EU.pdf. [Accessed 2 February 2021].
- [19] SMC, "Vacuum pad selection," [Online]. Available: https://www.smcworld.com/assets/products/pickup/en-jp/vacuum_device/select/4-P0878-883_en.pdf. [Accessed 20 January 2021].
- [20] Misumi, "Linear Guides," [Online]. Available: <https://uk.misumi-ec.com/vona2/detail/110300048850/>. [Accessed 20 January 2021].
- [21] Mader electric, inc., "Choosing the Right PLC: 6 Things to Consider," [Online]. Available: <https://www.maderelectricinc.com/blog/choosing-the-right-plc-6-things-to-consider>. [Accessed 18 January 2021].
- [22] Omron, "S8VK-C12024," [Online]. Available: <https://industrial.omron.eu/en/products/S8VK-C12024>. [Accessed 20 January 2021].

- [23] Phoenix Contact, "Relay Module - RIF-0-RPT-24DC/21," [Online]. Available: <https://www.phoenixcontact.com/online/portal/us?uri=pxc-oc-itemdetail:pid=2903370>. [Accessed 20 January 2021].
- [24] ABB, "Detailed information for: S201-B6," [Online]. Available: <https://new.abb.com/products/2CDS251001R0065/miniatu-re-circuit-breaker-s200-1p-b-6-ampere>. [Accessed 20 January 2021].
- [25] Phoenix Contact, "Fuse modular terminal block - PT 4-HESI," [Online]. Available: <https://www.phoenixcontact.com/online/portal/us?uri=pxc-oc-itemdetail:pid=3211861>. [Accessed 20 January 2021].
- [26] Moxa, "EDS-2005-ELP Series," [Online]. Available: <https://www.moxa.com/getmedia/1132eabd-c942-4c82-8c2a-4499f6669d19/moxa-eds-2005-elp-series-datasheet-v1.2.pdf>. [Accessed 20 January 2021].
- [27] Eaton, "M22-I2-M1 button box," [Online]. Available: https://datasheet.eaton.com/datasheet.php?model=216529&locale=en_GB. [Accessed 20 January 2021].
- [28] EPLAN, "Eplan Electric P8," [Online]. Available: <https://www.eplan-software.com/solutions/eplan-platform/eplan-electric-p8/>. [Accessed 2 February 2020].
- [29] Rittal, "Compact enclosure AE," [Online]. Available: <https://www.rittal.com/com-en/product/show/variantdetail.action?categoryPath=/PG0001/PG0002SCHRANK1/PG0021SCHRANK1/PRO0023SCHRANK&productID=1030500>. [Accessed 20 January 2021].
- [30] CCS, "ELB Series," [Online]. Available: <http://www.el-series.com/ELB-Series>. [Accessed 16 February 2021].
- [31] Cognex, "ModbusTCP Factory interface," [Online]. Available: https://support.cognex.com/docs/is_574/web/EN/ise/Content/Communications_Reference/ModbusTCP_5x.htm. [Accessed 2 December 2020].
- [32] R. Ramanathan, "The IEC 61131-3 programming languages features for industrial control systems," *2014 World Automation Congress (WAC)*, pp. 598-603, 2014.
- [33] Axelent, "New Standards Defining the Basics of Manual Workstations," [Online]. Available: https://www.axelent.com/media/2rtnr1ie/article-whitepaper-new-standards-defining-the-basics-of-manual-workstations_gb.pdf. [Accessed 11 May 2021].