KU LEUVEN

GROUP T LEUVEN CAMPUS

EE3
Technical file

Date:
01/03/2023

Team:
10

Team members:
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Checked by: Paolo van Dommelen

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General design

Description

This technical documentation provides the design and explanation for a specific automation setup. The task is to rearrange pétanque balls on a pallet with the use of parallel scara arm robot. This specific setup is designed to handle steel balls of 0.75 kg and 75 mm diameter, and works with a standard euro pallet size, where the balls are spaced on the pallet such that they make a 8x12 grid (see pictures for reference).

The installation was designed in different sections namely, a conveyor belt, an indexing table, a set of base tubes and a set of parallel arms for which the combined result yields a parallel SCARA robot, able to lift several kilograms of load with a reach of over 1.5 m. In the following documentation, design decisions calculations and selection of components are thoroughly explained to give an overview of the design process and the results of our designed SCARA robot.

Risk assessment

A risk assessment was done for all possible hazards and dangers of the installation, for which possible solution and safety mechanisms were selected to ensure the safety of our design. This was done according to ISO 14121 standard and was divided for each device namely the conveyor belt and the parallel SCARA robot installation.

For the Conveyor Belt the hazard identification is the following:

<table>
<tr><th colspan="6">Hazard Identification</th></tr>
<tr><td>Machine (identification):</td><td colspan="2">Conveyor Belt</td><td>Method/Tool:</td><td colspan="2"></td></tr>
<tr><td colspan="2">Sources: Technical file</td><td></td><td>Analyst:</td><td colspan="2">Paolo van Dommelen</td></tr>
<tr><td colspan="2" rowspan="2">Extent:</td><td rowspan="2"></td><td>Current Version:</td><td colspan="2">2.1</td></tr>
<tr><td>Date:</td><td colspan="2">3/10/2023</td></tr>
<tr><th rowspan="2">Ref. no.</th><th rowspan="2">Hazard zone</th><th rowspan="2">Task/Operation</th><th colspan="3">Accident scenario</th></tr>
<tr><th>Hazard</th><th>Hazardous situation</th><th>Hazardous event</th></tr>
<tr><td rowspan="2">1</td><td rowspan="4">Working zone</td><td rowspan="4">Transporting Pallet in/out in between robot operations</td><td>Failure of distance sensors</td><td>Conveyor not stopping when intended</td><td rowspan="3">Unintended Motor Overheating causing burns</td></tr>
<tr><td>Failure in communication to motor drive</td><td rowspan="2">Motor not stopping when intended</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Failure to maintain</td></tr>
<tr><td></td><td></td></tr>
</table>

			pallet on conveyor	Pallet falling out of conveyor	damage to machinery and products
					damage to surrounding personnel
3			Danger of Rotating components	Entanglement of loose clothing and hair	injury and draw-in
				Trapping and crushing	severe injury to fingers and other
4			Untrained staff traversing conveyor	Staff on moving conveyor	light injury/ draw-in / severe injury when in machine proximity
				Staff trapped on moving load	
5			Manual intervention during operation danger to trained operators	Entanglement of loose clothing and hair	injury and draw-in
		Conveyor stopped, during operation sequence		Trapping and crushing	severe injury to fingers and other
6			Failure in communication - unintentional motor start	unintentional motor start leads to operator injury during maintenance	severe injury to fingers and other
		Installation stopped for maintenance and inspection			injury and draw-in
7			Failure of stop system		
8		Other	Faulty cables of power supply to motor	Risk of electric shocks and burns due to touching live parts around motor	medium / heavy injury shocks etc.
9			Motor Failure		

From this table we selected possible solutions and safety measures in accordance to the calculated risk index values. This is described in the following:

Hazard Identification			
Machine (identification):	Conveyor Belt	**Method/Tool:**	
Sources: Technical file		**Analyst:**	Paolo van Dommelen
Extent:		**Current Version:**	2.1
		Date:	3/10/2023

Solution	Activity	Hazard	Risk Index	Possible Preventive Measures	Selected Preventive Measures
1a	Transporting Pallet in/out in between robot operations	Failure of distance sensors	1	Predictive maintenance, add a light curtain on the conveyor for 2FA, addition of motor circuit breaker	Predictive Maintenance
1b					Light Curtain
2a		Failure in communication to start motor	1	Predictive maintenance, regular testing	Predictive Maintenance
3a		Failure in communication to stop motor	5	Use of 2 channel safety following ISO12100, covering conveyor components, limiting space to enter workspace	2 channel safety systems
3b					fence around work area
4a		Failure to maintain pallet on conveyor	2	Addition of guard rails to center the pallet, addition of fence around work area	addition of guard rails
4b					addition of fence in work area
5a		Danger of Rotating components	5	Training to staff and safety precautions, addition of protection around conveyor, addition of fence around conveyor	training and safety precautions
5b / 6a					
6b		Untrained staff traversing conveyor	2	Training and safety precautions, addition of protection around conveyor and addition of fence	fence around work area

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6b / 7a		Manual intervention during operation	5	Training to staff and safety precautions, addition of protection around conveyor, addition of fence around conveyor	fence around work area
7b	Failure during maintenance with stopped installation and other				
8a		Failure of Stop System	5	Implement 2 channel safety stop systems following EN12100	2 channel safety systems
9a		Faulty cables of power supply to motor	2	Predictive maintenance, implementation of secure and reliable cable protection systems	Predictive Maintenance
9b					Reliable and secure cables
10a		Motor Failure	3	Predictive maintenance and regular inspection as well as protective devices	Predictive Maintenance
10b					Appropriate Protection devices

After the selection of these possible preventive measures we calculate the risk factors once again to see where improvements were made:

Risk estimation after reduction					
Solution	**S**	**F / E**	**P**	**A**	**Risk Index**
1a	1	1	1	1	1
1b	1	1	1	1	1
2a	1	1	1	1	1

3a	4	1	1	2	4
3b	4	1	1	3	4
4a	2	1	1	2	2
4b	2	1	1	2	2
5a	3	1	1	3	3
5b / 6a					
6b	2	1	1	2	2
6b / 7a	4	1	1	2	4
7b					
8a	4	1	1	1	4
9a	2	1	1	2	2
9b	2	1	1	3	2
10a	3	1	1	2	3
10b	2	1	1	3	2

Ultimately for the conveyor belt several solutions were selected and implemented in our final design such as the light curtain, the choice of 2 channel safety, the presence of a fence around the area and addition of advanced safety operation modes such as safe limited speed, safe stop 1 and 2 and Safe Operating stop which the implementation was made possible thanks to the selection of our servo motor drives.

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Checked by: Marcis Livmanis

The same procedure was repeated for the Parallel Arm Scara Robot of which the risk assessment is as follows:

Hazard Identification						
Machine (identification):		SCARA arm		**Method/Tool:**		
Sources:			Technical file	**Analyst:**		Paolo van Dommelen
Extent:				**Current Version:**		2.1
				Date:		2/20/2023
Ref. no.		**Task/Operation**	**Accident scenario**			
			Hazard		**Hazardous situation**	**Hazardous event**
10	**Hazard zone**	Robot Performing Operation (Sequence)	Ruptured pneumatic lines		Failure of piston	injury/ damage to pallet
11			Vacuum Failure		Gripped object falling during arm motion/ arm standstill	Object falling medium injury to body part Object falling and damaging machine
12			Operators/Personnel in range of the arms		Arms impacting on operators during sequence	medium / heavy injury
13			Maintenance on rotating components		Adjusting rotating components	light / medium injury
14			Encoder Failure		Impact to people/machines from the movement of the arms to unexpected positions	Medium / Heavy injury
15			Failure in communication to drive			
16			Failure in power transmission to arms			
17			Maintenance on pallet		Risk of injuring body parts by adjusting the pallet	light injury

			Mechanical Failures in Arms and base	Failure of shaft between arms	Risk of arms falling damaging pallet / conveyor / injury to operators	medium / heavy injury failure of components during operation or maintanace
				Failure of base shaft connection		
		Robot in stop mode or standstill		Failure of bearings in arm-arm connection		
				Failure of bearings in base connection		
				Failure of arms		
18				Failure of the base		
19			Failure in stop system		Arms moving at unwanted times during maintenance	Medium / Heavy injury arms moving during maintenance
20			Failure in communication to drive			
21			Electrical Hazard from live parts		Touching of live parts during short circuit	medium / heavy injury
22			Ruptured pneumatic lines		Risk of injury due to highly compressed air	medium / light injury
		Other	Environmental Hazards Heat and dust		Cause of overheating of motor	May lead to improper motor operation
23					Risk of motor failure	

24			EMI in motor-drive connection	Risk of improper motor functioning	may lead to injury
25			Damaged power lines to motors	Risk of shock and burns touching live parts	medium / heavy injury

Hazard Identification					
Machine (identification):		SCARA robot		**Method/Tool:**	
Sources:		Technical file		**Analyst:**	Paolo van Dommelen
Extent:				**Current Version:**	2.1
				Date:	2/20/2023
Solution	**Activity**	**Hazard**	**Risk Index**	**Possible Preventive Measures**	**Selected Preventive Measures**
1a	Other	Ruptured pneumatic lines	3	Perform predictive maintenance and regular inspection + add protective devices e.g. noise sensors	Predictive maintenance
1b					protective pneumatic devices noise sensors
2a	Robot Performing Operation (Sequence)	Vacuum Failure	3	Add fence around work area, add stop mechanism when entering work area, safe stop	Fence around work area
2b					Add safe stop trigger on fence door
3a		Operators/ Personnel in range of the arms	4	Safe stop once operator in work zone, fence and door around zone, addition of 2 channel estop	Add safe stop trigger on fence door
3b					Add appropriate 2 channel devices
3a		Maintenance on rotating	4	Safe stop once operator in work zone, fence and door around	Add safe stop trigger on fence door
3b					

		components		zone, addition of 2 channel estop	Add appropriate 2 channel devices
4a		Encoder Failure	5	Predictive maintenance and regular inspection, addition of e-stop for danger	Predictive maintenance
4b / 5a					Add appropriate 2 channel devices
5b		Failure in communication to drive	5	Predictive maintenance and regular inspection, addition of e-stop for danger	Add safe stop trigger on fence door
6a		Failure in power transmission to arms	5	Predictive maintenance and regular inspection, addition of e-stop for danger	Add safe stop trigger on fence door
6b					Predictive maintenance
7a		Maintenance on pallet	3	Provide training and safety precautions, add SSO when operator in work zone and appropriate 2 channel	Training and safety precautions
7b					Add safe stop trigger on fence door
8a		Mechanical Failures in Arms and base	4	Predictive maintenance and regular inspection with fence around to minimize damage	Predictive maintenance
8b					Fence around work area
9a		Failure in stop system	5	Addition of 2 channel safety, addition of safe stop when operator in work zone	Add appropriate 2 channel devices
9b					Add safe stop trigger on fence door
10a		Electrical Hazard from live parts	4	Addition of appropriate electrical safety devices and appropriate cabling	Add electrical safety
10b					Selection of appropriate cables
11a	Robot in stop mode or standstill	Environmental Hazards	2	Choice of appropriate IP	Selection of correct IP grade

11b		Heat and dust		devices and monitoring such as temperature of motor	Selection of motor switch
12a		EMI in motor-drive connection	3	Choice of appropriate cabling and protection devices	Selection of appropriate cables
12b					Add electrical safety
13a		Damaged power lines to motors	3	Choice of appropriate cabling and predictive maintenance and inspection	Selection of appropriate cables
13b					Predictive maintenance

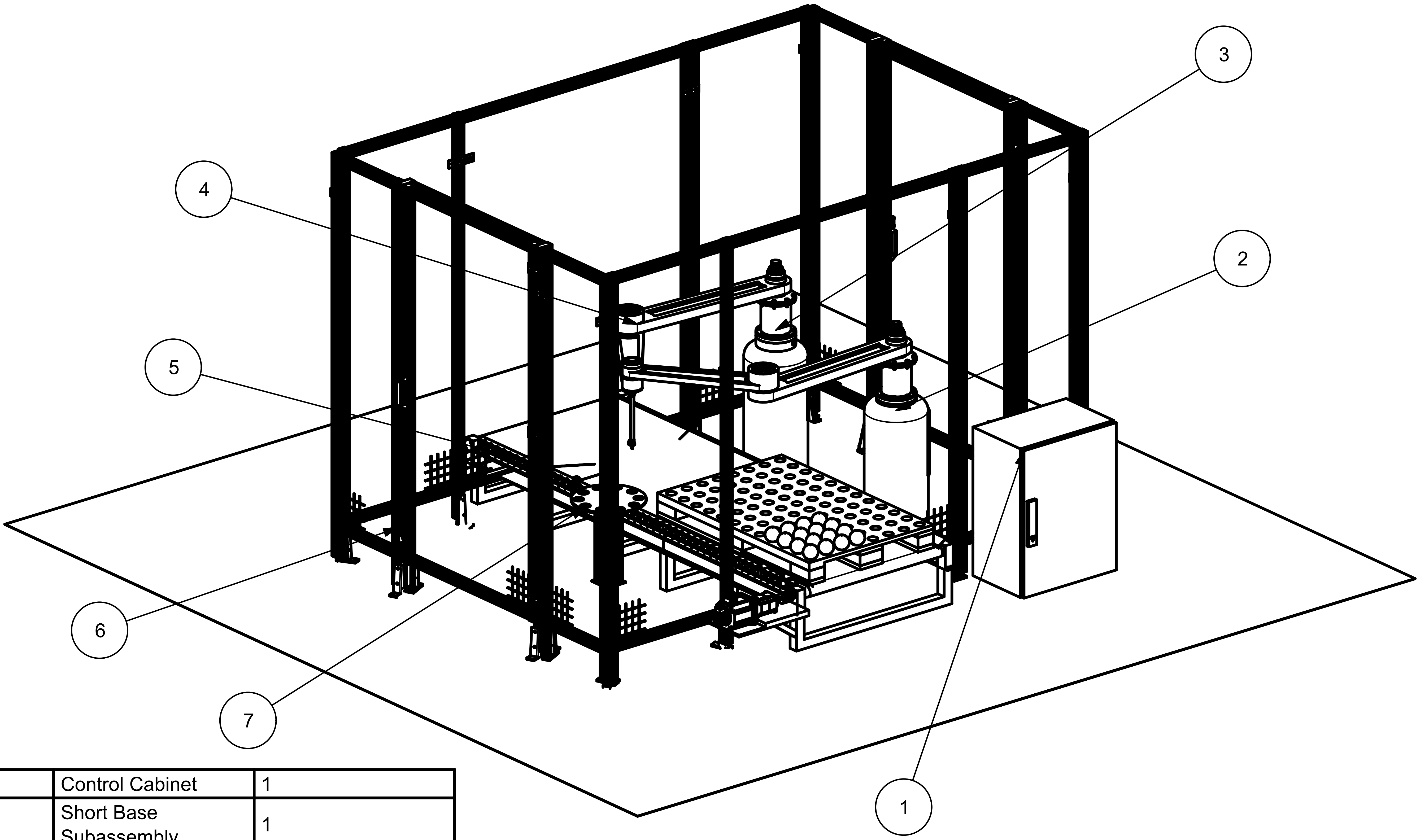
Risk estimation after reduction					
Solution	**S**	**F / E**	**P**	**A**	**Risk Index**
1a	3	1	1	2	3
1b	3	1	1	2	3
2a	3	1	1	3	3
2b	3	1	1	3	3
3a	1	1	1	3	1
3b	3	1	1	3	3
3a	1	1	1	3	1
3b	3	1	1	3	3
4a	5	1	1	2	5

4b / 5a	5	1	1	3	5
5b	1	1	1	1	1
6a	1	1	1	1	1
6b	5	1	1	2	5
7a 7b	3	1	1	2	3
8a	4	1	1	2	4
8b	4	1	1	3	4
9a	5	1	1	2	5
9b	1	1	1	2	1
10a	3	1	1	2	3
10b	5	1	1	3	5
11a	2	1	1	2	2
11b	2	1	1	3	2
12a	3	1	1	2	3
12b	3	1	1	3	3
13a	3	1	1	2	3
13b	3	1	1	1	3

Using the same standard, ISO 14121, conclusions were reached on potential safety measures that had to be taken to ensure the safety of both qualified and non-qualified personnel. Similar safety measures were selected such as the presence of a safety fence, 2 channel safety systems, and the implementation of advanced safety features for the drives, but one very important aspect that we decided would be necessary is the implementation of RFID safety switches at the doors of the surrounding fence. By implementing these switches, we would be able to trigger specific safety functions depending on the situation. While this will be discussed more in detail later, one effective scenario resulting from the chosen safety measures would be that if an operator needs to do maintenance on the scara robot, he/she would need to trigger the safety switch of the door closest to that section of the installation, setting the machine in safe operating stop, allowing safe maintenance on the robot. If on the other hand maintenance on the conveyor on the load needs to be done, the operator would be able to open the door on the opposite side, leading to a safer area, meaning that safe limited speed can be triggered so that the machine can continue operation while in a safer mode, allowing for maintenance.

Ultimately, we are confident in the selected safety measures which will be discussed more in detail in the description of the electrical installation.

Technical drawings



1	Control Cabinet	1
2	Short Base Subassembly	1
3	Tall Base Subassembly	1
4	Arms and Cylinder Subassebly	1
5	Conveyor Belt Subasseebly	1
6	Fences	1
7	Indexing Table Subassembly	1
PC NO	PART NAME	QTY

SCALE	1:20	DRAWN BY	Paolo van Dommelen
UNIT	MM	CHECKED BY	
DATE	4/2/2023	APPROVED BY	

COMMENTS

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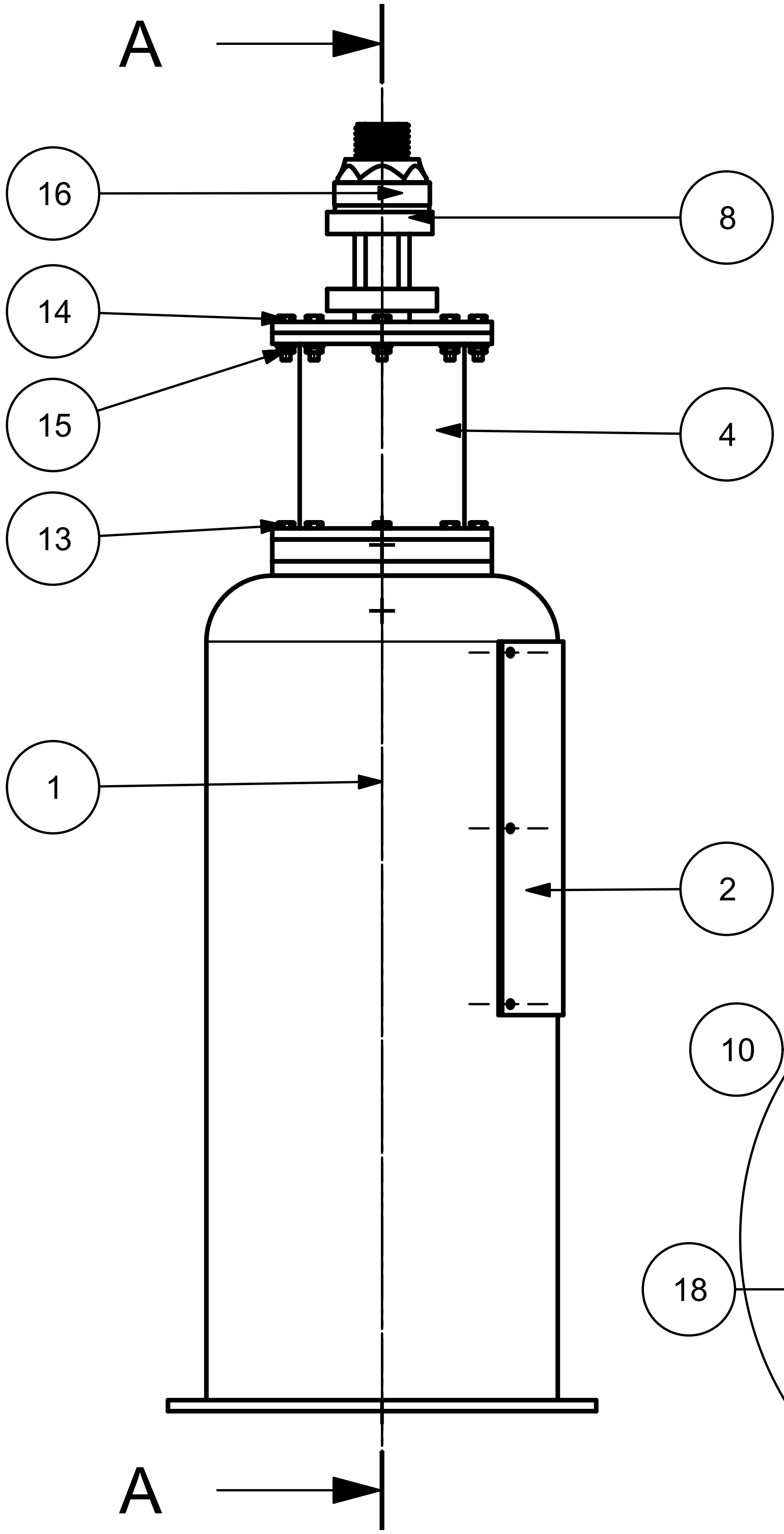
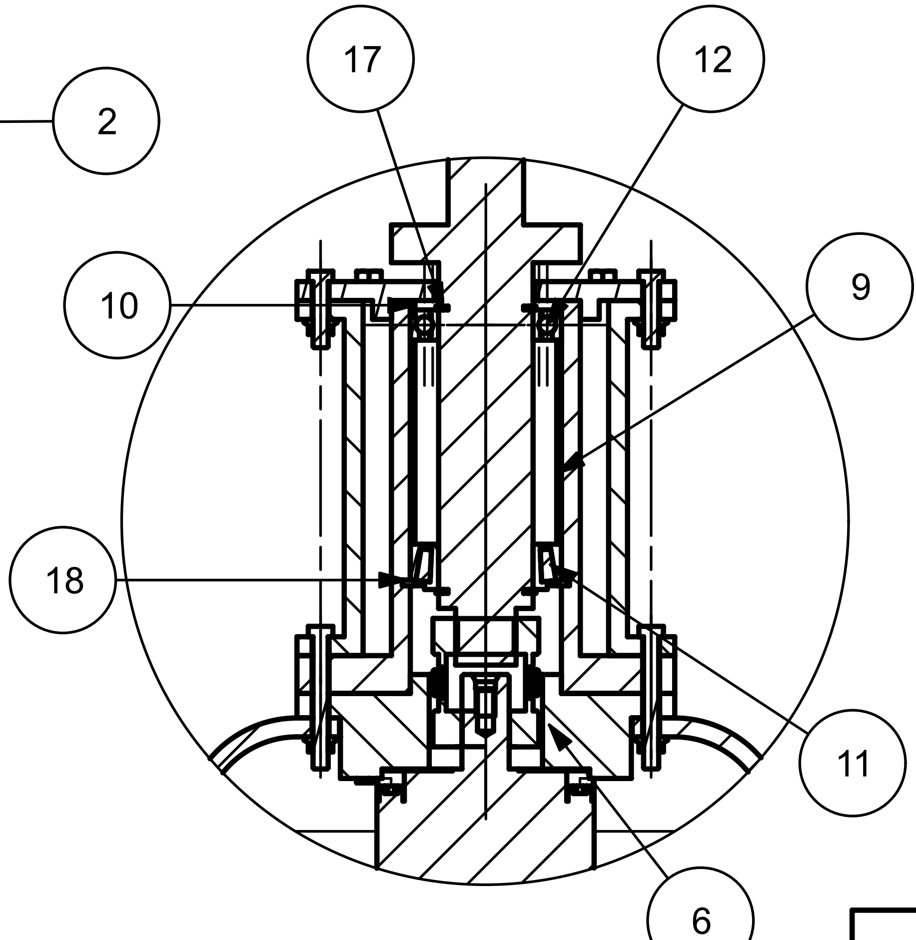
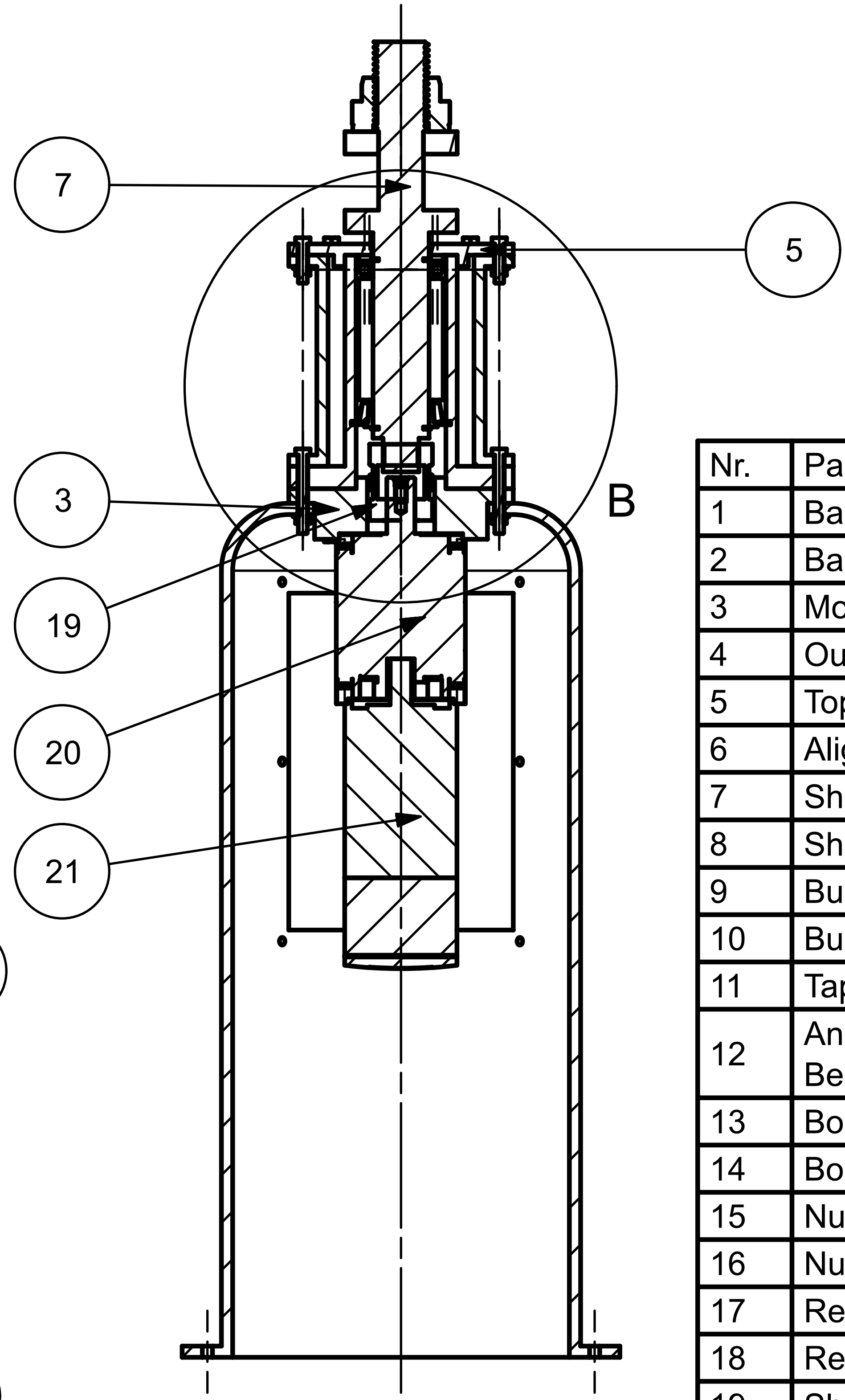
Parallel Scara Assembly

SHEET 1 OF 1





DETAIL B
SCALE 1:4



SECTION A-A

Nr.	Part	QTY
1	Base cylinder	1
2	Base cylinder hatch	1
3	Motor mount	1
4	Outer cover	1
5	Top plate	1
6	Alignment tube	1
7	Shaft	1
8	Shaft cap	1
9	Bushing h100	1
10	Bushing h10	1
11	Tapered Roller Bearing	1
12	Angular Contact Ball Bearing	1
13	Bolt M8x100	8
14	Bolt M8x35	8
15	Nut M8	16
16	Nut M48x5	1
17	Retaining ring DIN 472 50	2
18	Retaining ring DIN 472 85	1
19	Shaft coupler	1
20	Gearbox	1
21	Servo motor	1

SCALE	1:6	DRAWN BY	Marcis Livmanis	COMMENTS
UNIT	MM	CHECKED BY	Paolo van Dommelen	
DATE	01/04/2023	APPROVED BY	Paolo van Dommelen	

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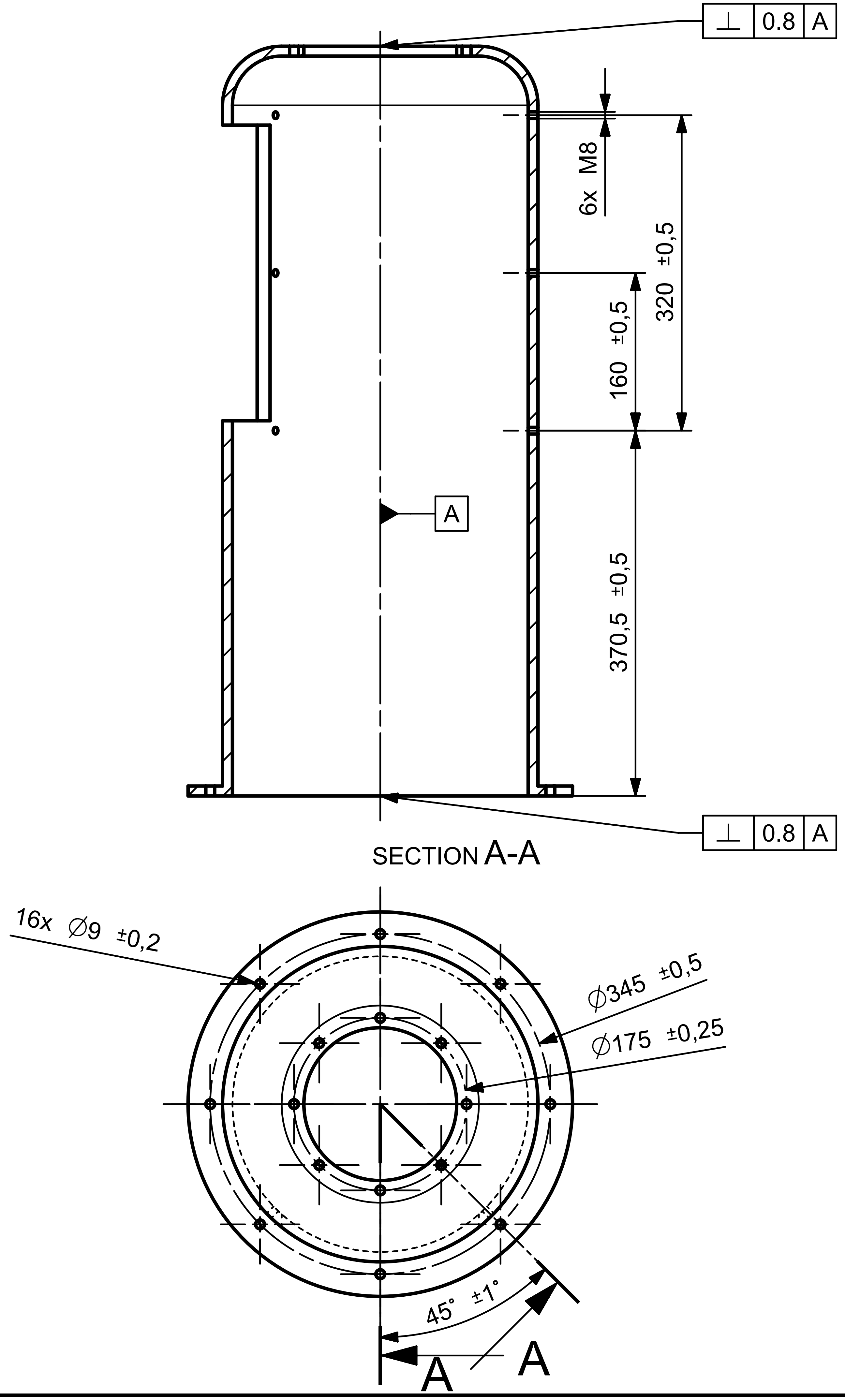
SCARA base short

SHEET 1 OF 1



				General tolerances ISO 8062-3 DCTG 6
SCALE	1:5	DRAWN BY	Jan Rutrle	COMMENTS
UNIT	MM	CHECKED BY	Monique Mainardes	Part will be casted. All dimensioned features need to be machined afterwards.
DATE	22.3.2023	APPROVED BY	Monique Mainardes	

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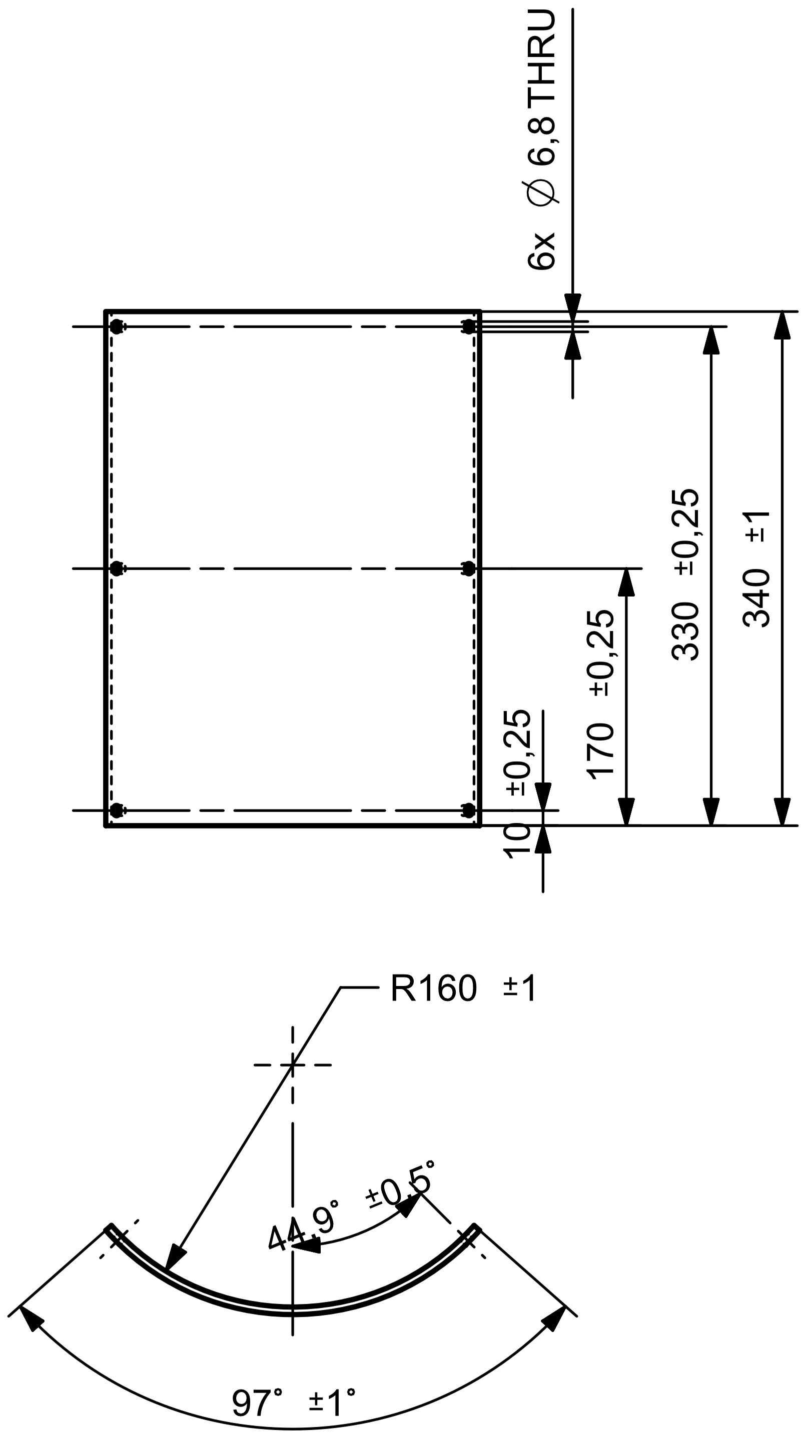
PT- Base Cylinder

SHEET 1 OF 1



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DATE	1.4.2023	APPROVED BY	Monique Mainardes	

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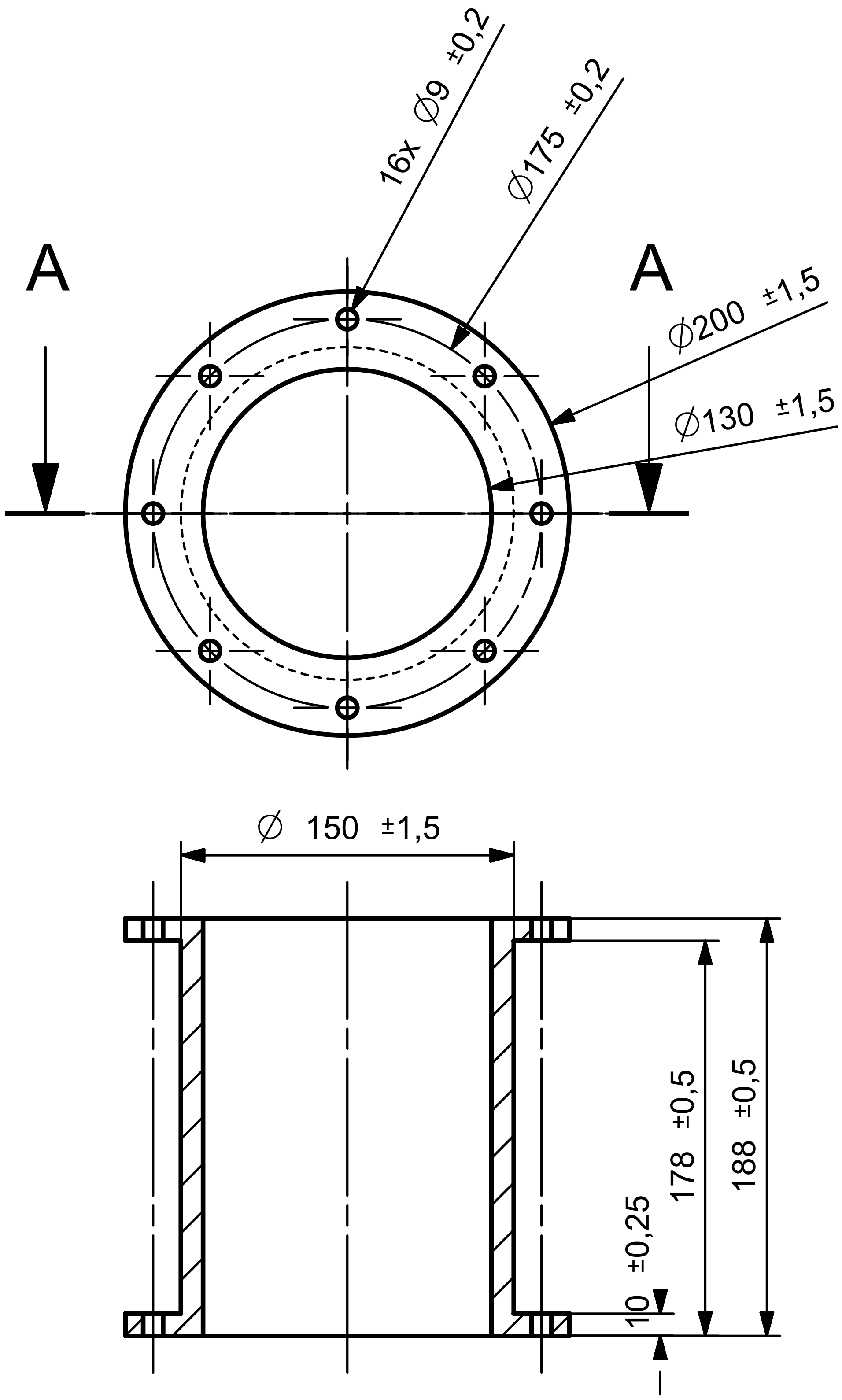
PT- Base Hatch

SHEET 1 OF 1



SECTION A-A

				PT_Head_outer_cover
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UNIT	MM	CHECKED BY	Monique Mainardes	General tolerances ISO 8062-3 DCTG 6
DATE	25.3.2023	APPROVED BY	Monique Mainardes	

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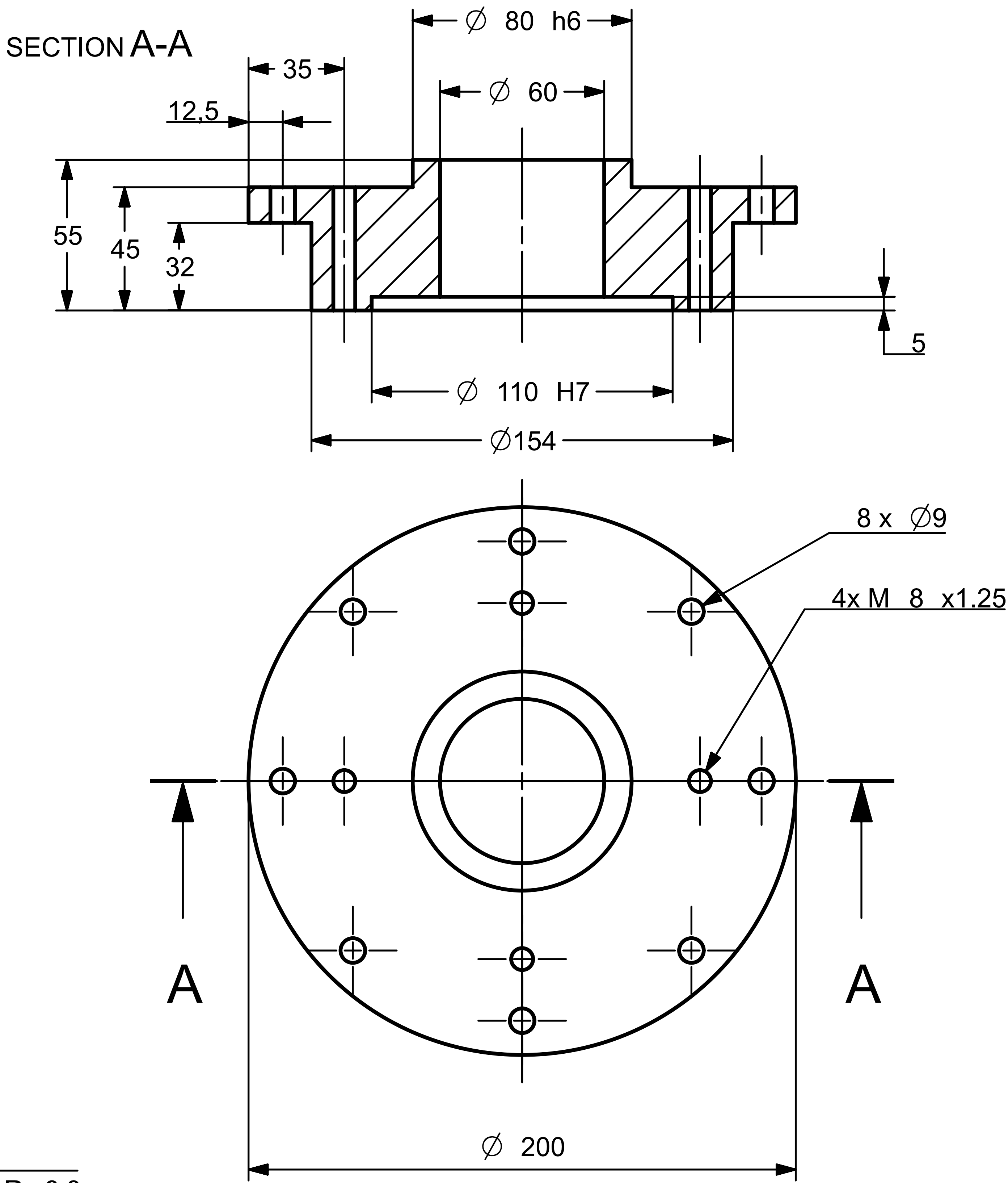
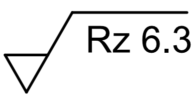
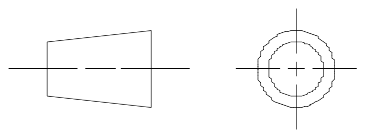
PT- Head Outer Cover

SHEET 1 OF 1





General surface roughness



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UNIT	MM	CHECKED BY	Paolo van Dommelen	General tolerances ISO 2768-m, other DIN EN ISO 286-2
DATE	20/03/2023	APPROVED BY	Paolo van Dommelen	

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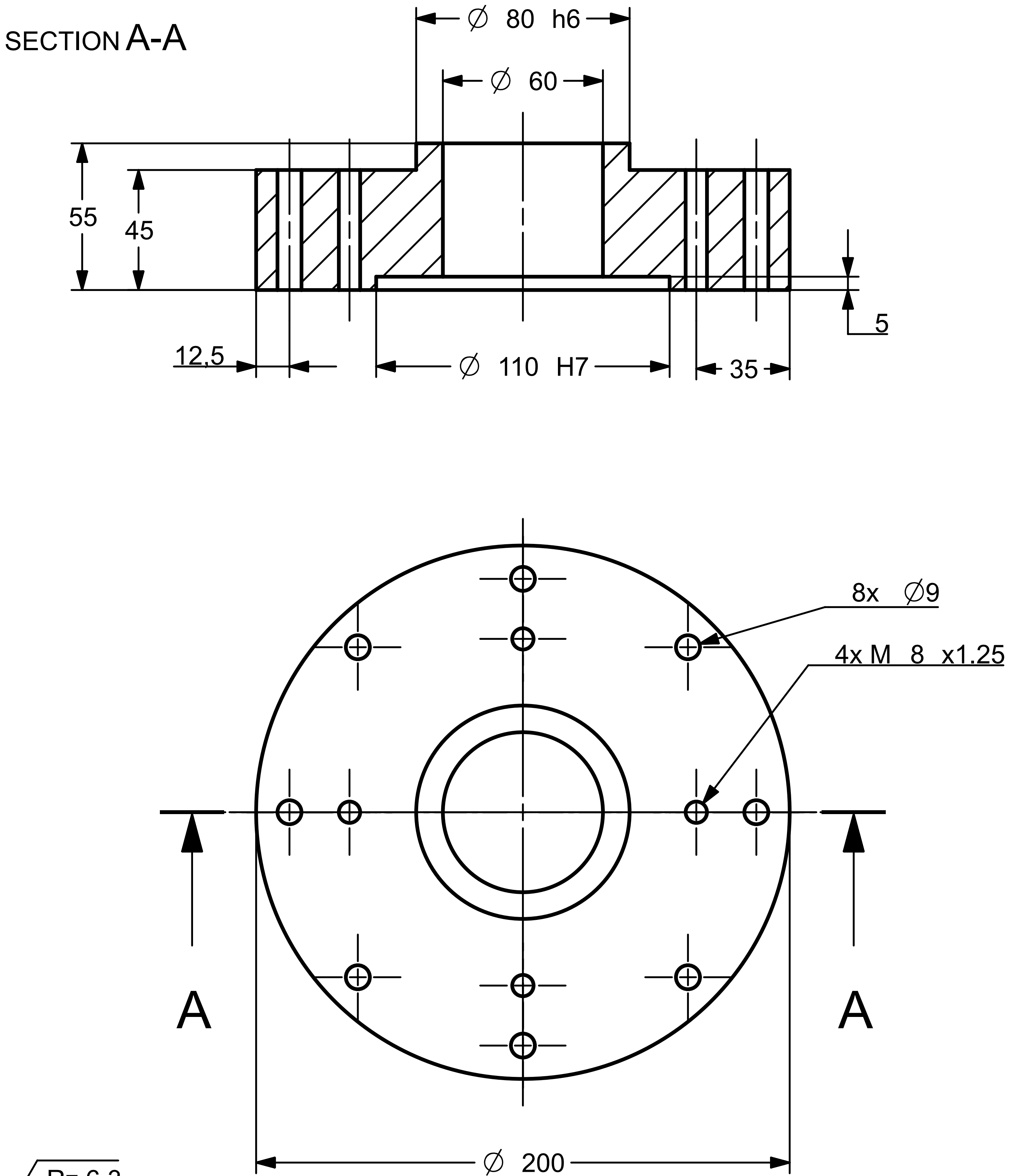
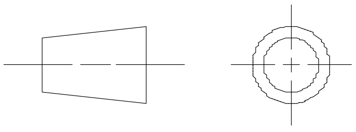
Motor mount (short)

SHEET 1 OF 1



Rz 6.3
General surface roughness



				motor_mount_tb
SCALE	1:2	DRAWN BY	Marcis Livmanis	COMMENTS
UNIT	MM	CHECKED BY	Paolo van Dommelen	General tolerances ISO 2768-m, other DIN EN ISO 286-2
DATE	20/03/2023	APPROVED BY	Paolo van Dommelen	

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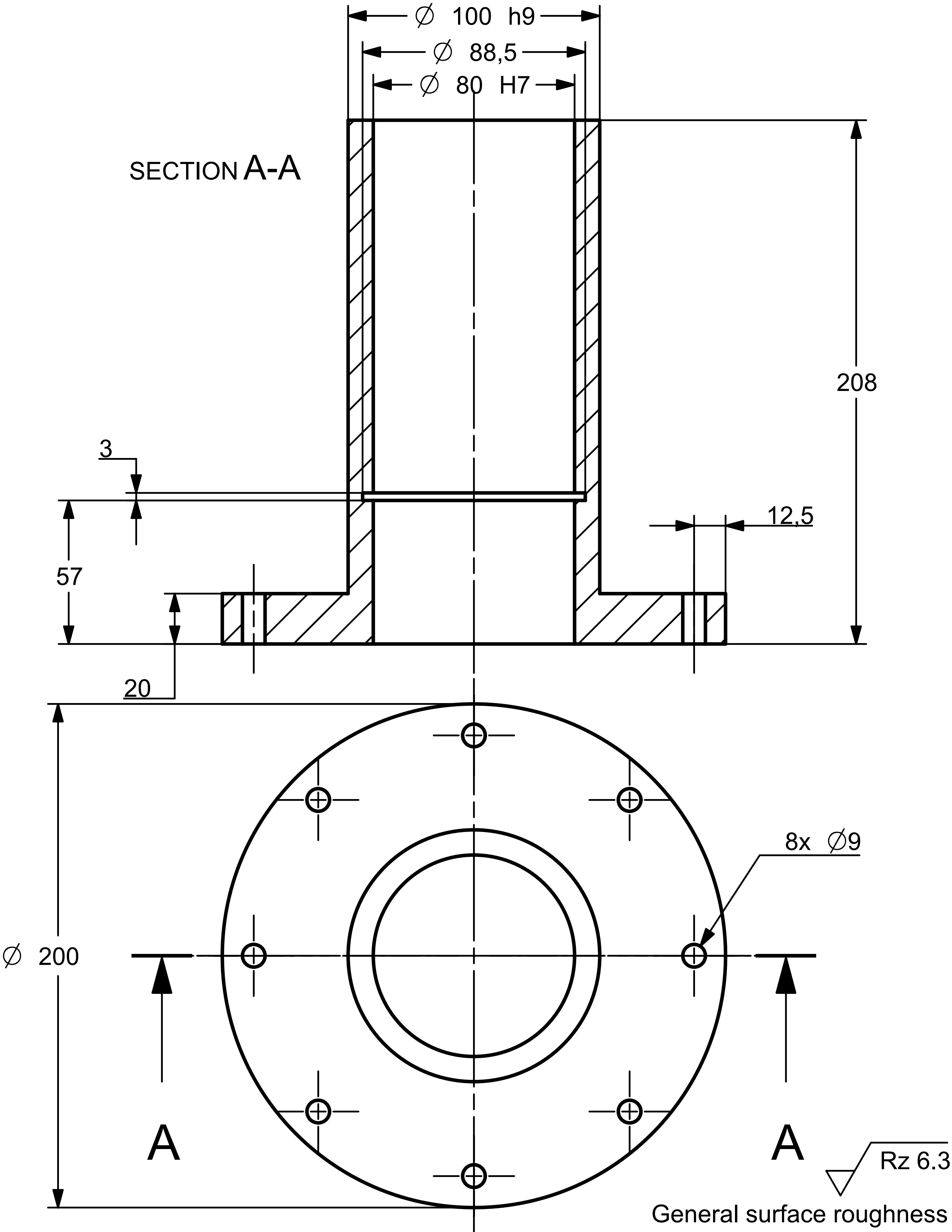
Motor mount (tall)

SHEET 1 OF 1



				PT_Head_alignment_tube_v2
SCALE	1:2	DRAWN BY	Marcis Livmanis	COMMENTS
UNIT	MM	CHECKED BY	Paolo van Dommelen	General tolerances ISO 8062-3 DCTG 4, other DIN EN ISO 286-2
DATE	20/03/2023	APPROVED BY	Paolo van Dommelen	

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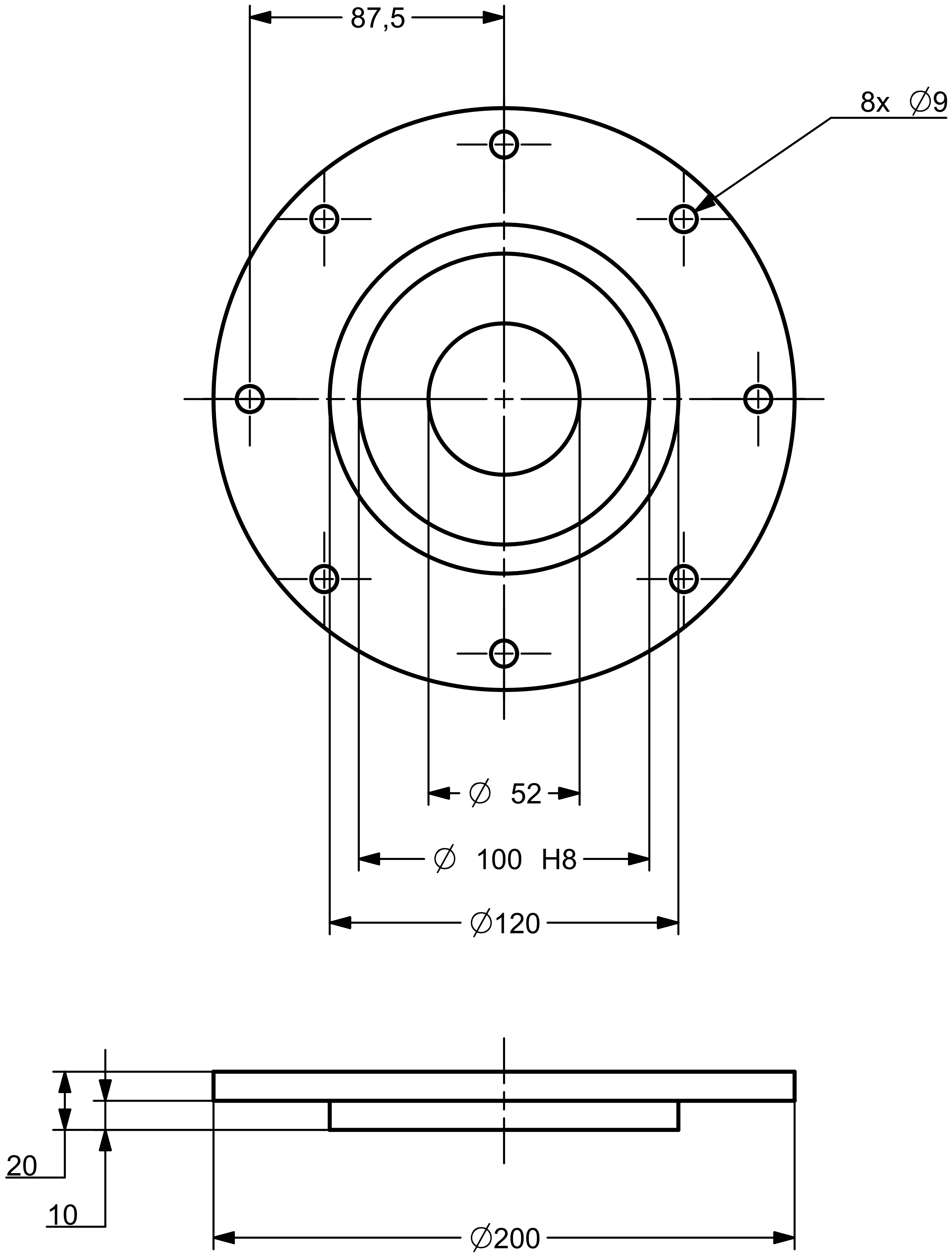
Alignment tube

SHEET 1 OF 1



				PT_Head_top_plate
SCALE	1:2	DRAWN BY	Marcis Livmanis	COMMENTS
UNIT	MM	CHECKED BY	Paolo van Dommelen	General tolerances ISO 2768-m, other DIN EN ISO 286-2
DATE	20/03/2023	APPROVED BY	Paolo van Dommelen	

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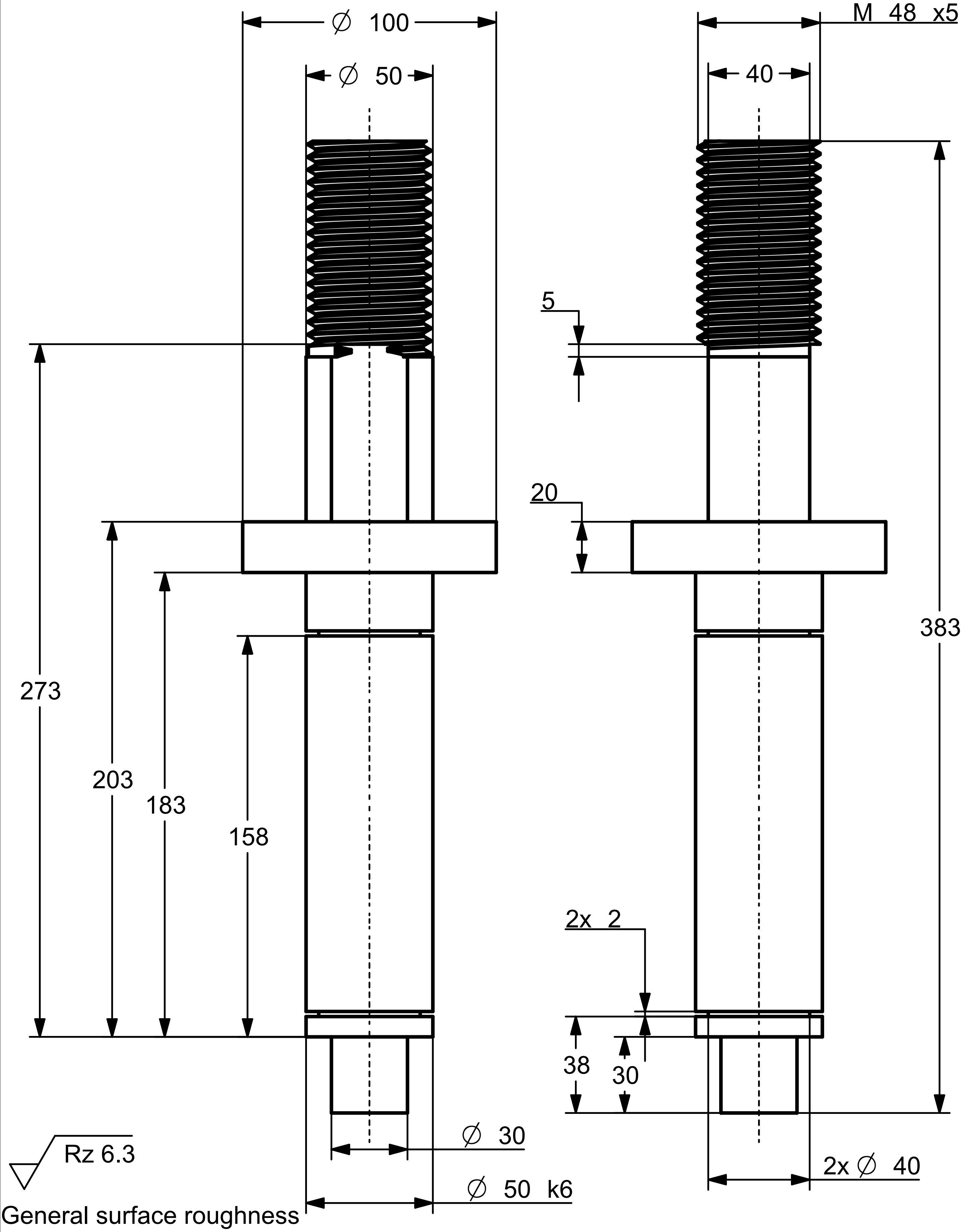
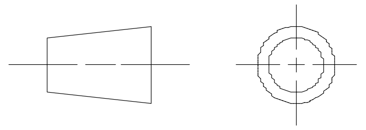
Top plate

SHEET 1 OF 1





				PT_Head_shaft
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UNIT	MM	CHECKED BY	Paolo van Dommelen	General tolerances ISO 2768-m, other DIN EN ISO 286-2
DATE	20/03/2023	APPROVED BY	Paolo van Dommelen	

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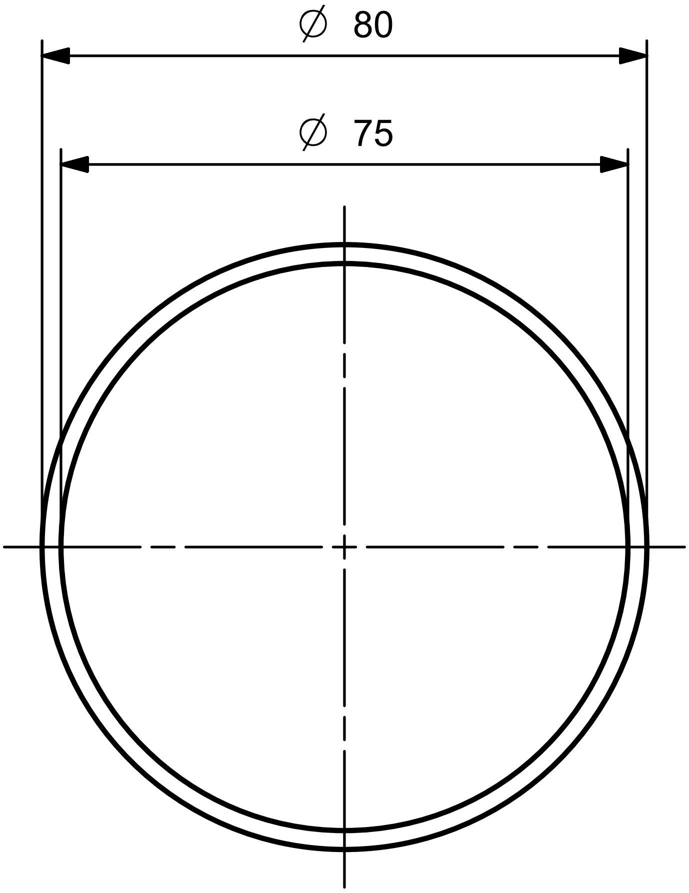
Shaft

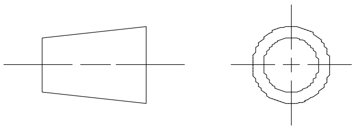
SHEET 1 OF 1



Height 100mm

Rz 6.3

General surface roughness



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UNIT	MM	CHECKED BY	Paolo van Dommelen	General tolerances ISO 8062-3 DCTG 4
DATE	20/03/2023	APPROVED BY	Paolo van Dommelen	

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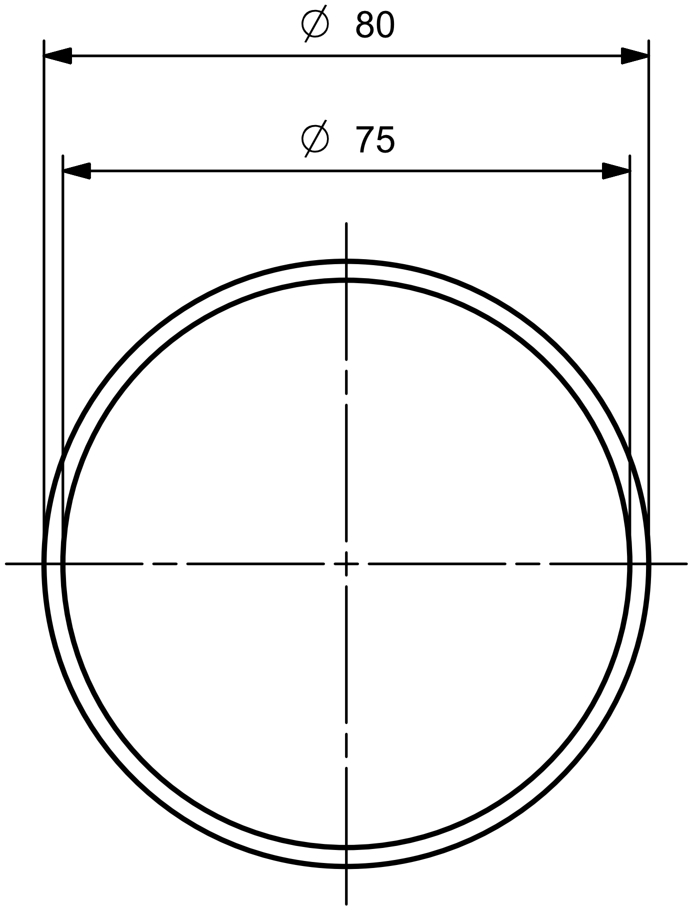
Bushing H100

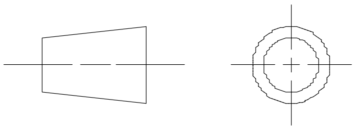
SHEET 1 OF 1



Height 10mm

Rz 6.3

General surface roughness



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UNIT	MM	CHECKED BY	Paolo van Dommelen	General tolerances ISO 8062-3 DCTG 4
DATE	20/03/2023	APPROVED BY	Paolo van Dommelen	

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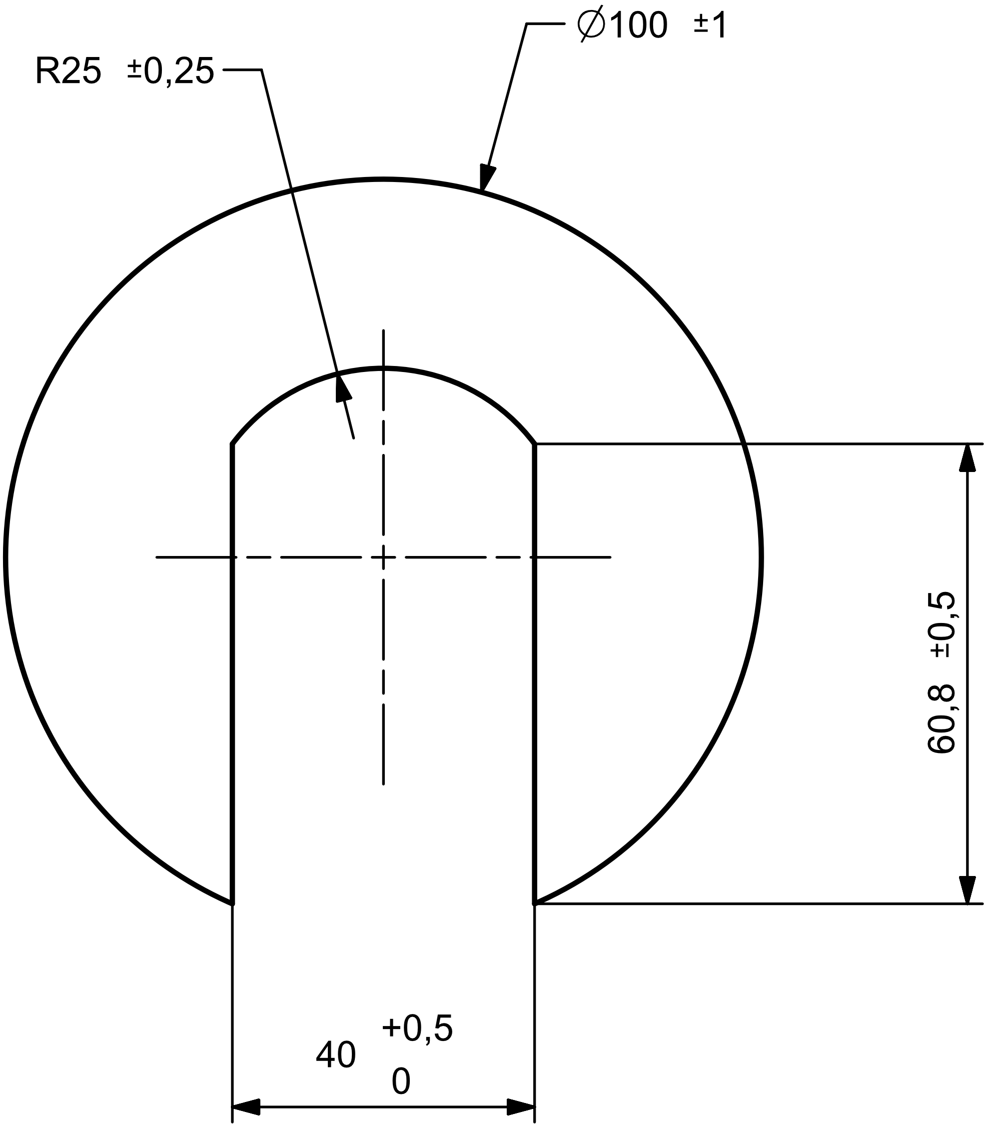
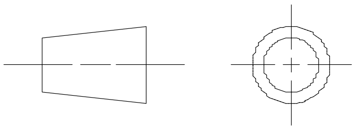
Bushing H10

SHEET 1 OF 1



Thickness = 20mm



SCALE	1:1	DRAWN BY	Jan Rutrle	COMMENTS
UNIT	MM	CHECKED BY	Monique Mainardes	General tolerances ISO 8062-3 DCTG 6
DATE	25.3.2023	APPROVED BY	Monique Mainardes	

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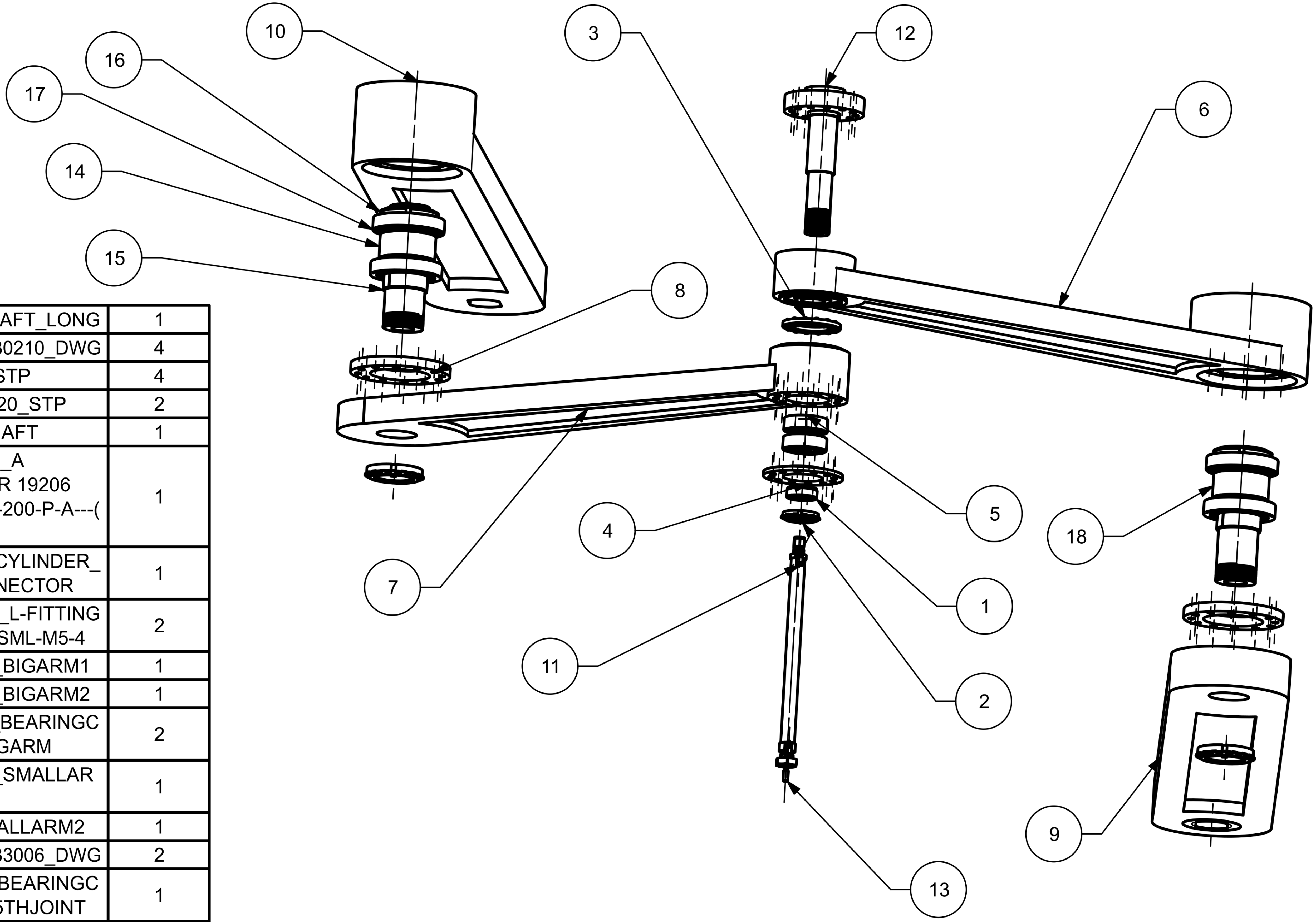
PT- Head Shaft Cap

SHEET 1 OF 1



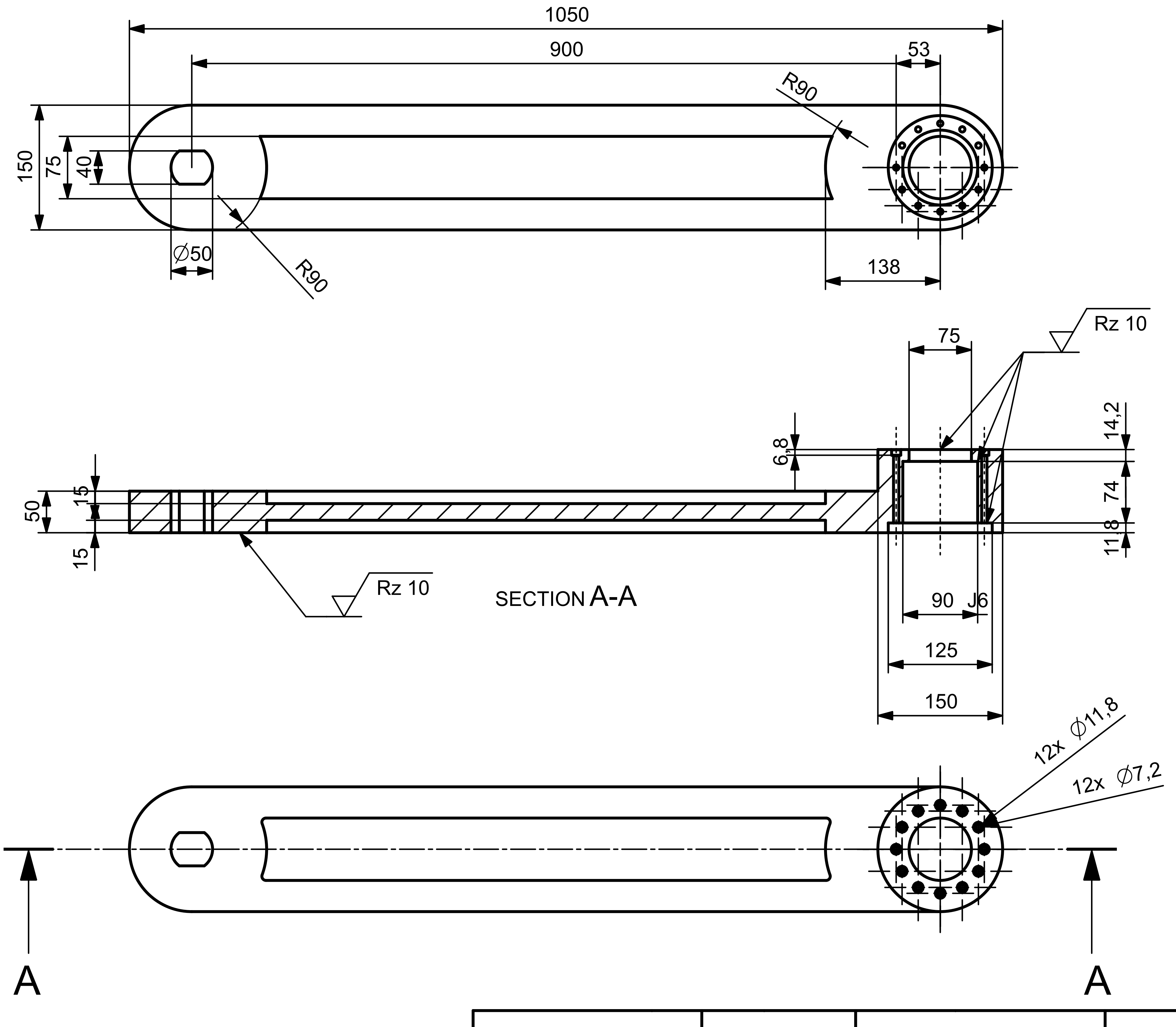
PC NO	PART NAME	QTY
18	HINGESHAFT_LONG	1
17	ARM_4T-30210_DWG	4
16	JLNK50_STP	4
15	MDZB50-20_STP	2
14	HINGESHAFT	1
13	CYL_STD_A CYLINDER 19206 DSNU-16-200-P-A---(0)	1
12	CYL_PT_CYLINDER_ENDCONNECTOR	1
11	CYL_STD_L-FITTING 153333 QSML-M5-4	2
10	ARM_PT_BIGARM1	1
9	ARM_PT_BIGARM2	1
8	ARM_PT_BEARINGCOVER_BIGARM	2
7	ARM_PT_SMALLARM1	1
6	ARM_SMALLARM2	1
5	ARM_4T-33006_DWG	2
4	CYL_PT_BEARINGCONVER_5THJOINT	1
3	CYL_SUB_STD THRUSTBEARING ID40OD68 AZK45739_STP	1
2	JLNK30_STP	1
1	MPBZ30-12_STP	1

SCALE	1:5	DRAWN BY	Paolo van Dommelen	COMMENTS
UNIT	MM	CHECKED BY	Marcis Livmanis	
DATE	4/2/2023	APPROVED BY	Marcis Livmanis	

KU LEUVEN

Scara Arms and Cylinder Subassembly

SHEET 1 OF 1



Rz 20 General surface roughness from die casting process

SCALE	1:5	DRAWN BY	Paolo van Dommelen
UNIT	MM	CHECKED BY	Marcis Livmanis
DATE	27/3/2023	APPROVED BY	Marcis Livmanis

COMMENTS
General Tolerances accourding to ISO 8062-3 DCTG 6, other according to DIN EN ISO 286-1

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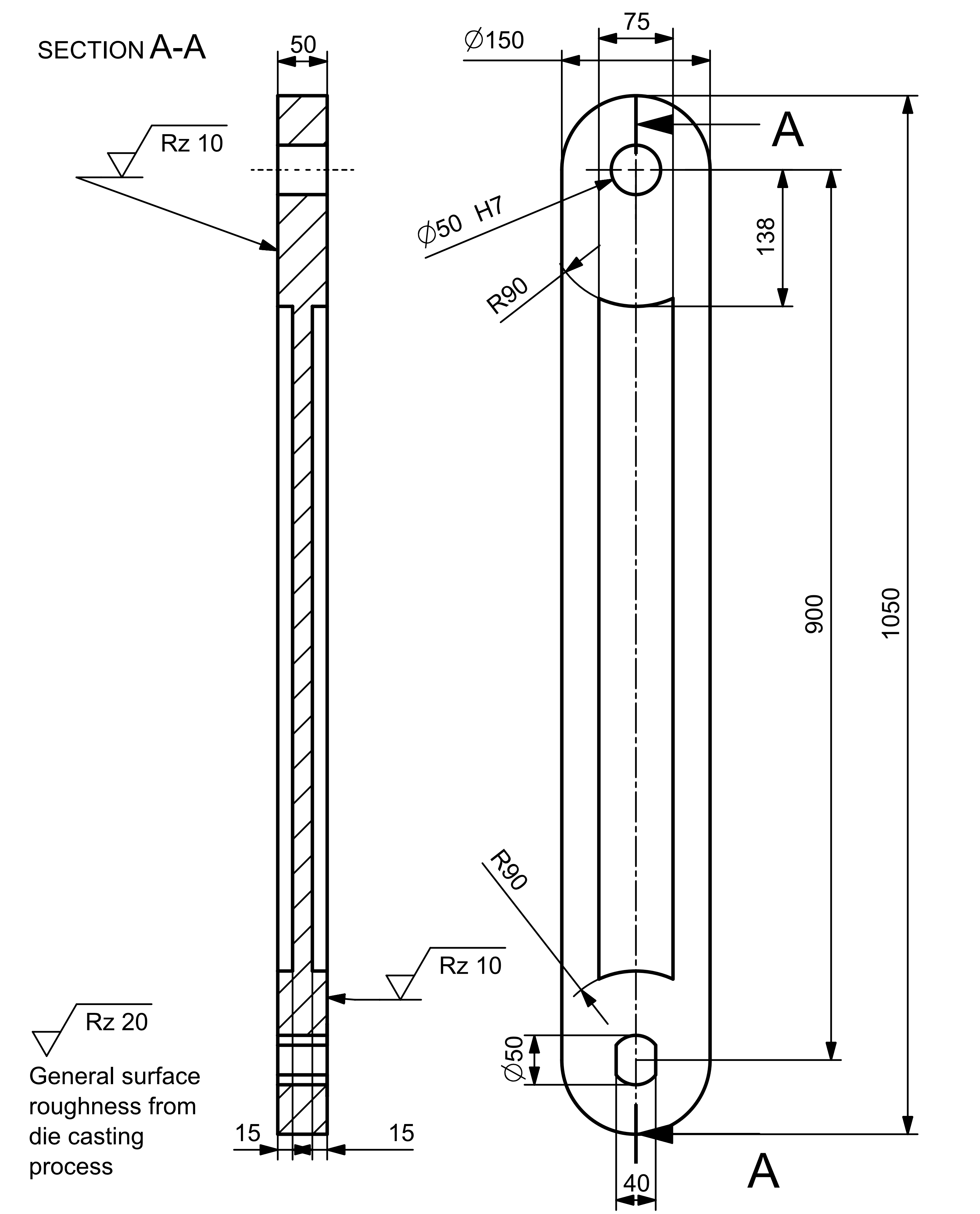
Big Arm 1

SHEET 1 OF 1



SCALE	1:5	DRAWN BY	Paolo van Dommelen	COMMENTS
UNIT	MM	CHECKED BY	Marcis Livmanis	General tolerances according to ISO 8062-3 DCTG 6, other according to DIN EN ISO 286-2
DATE	27/3/2023	APPROVED BY	Marcis Livmanis	

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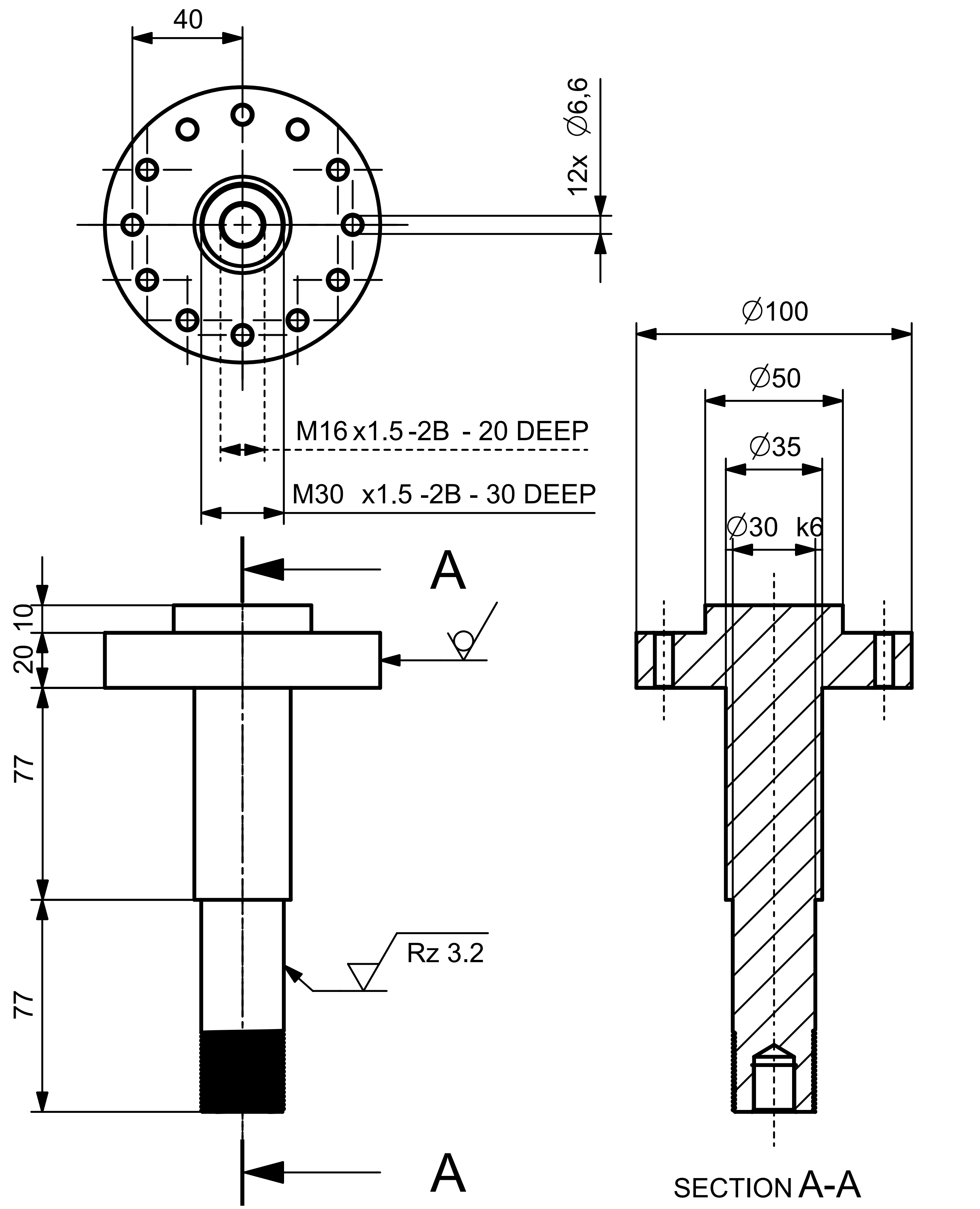
Big Arm 2

SHEET 1 OF 1



Rz 6.3 General surface roughness

SCALE	1:1	DRAWN BY	Paolo van Dommelen	COMMENTS
UNIT	MM	CHECKED BY	Marcis Livmanis	General tolerances according to ISO 2768-m, other according to DIN EN ISO 286-2
DATE	28/3/2023	APPROVED BY	Marcis Livmanis	

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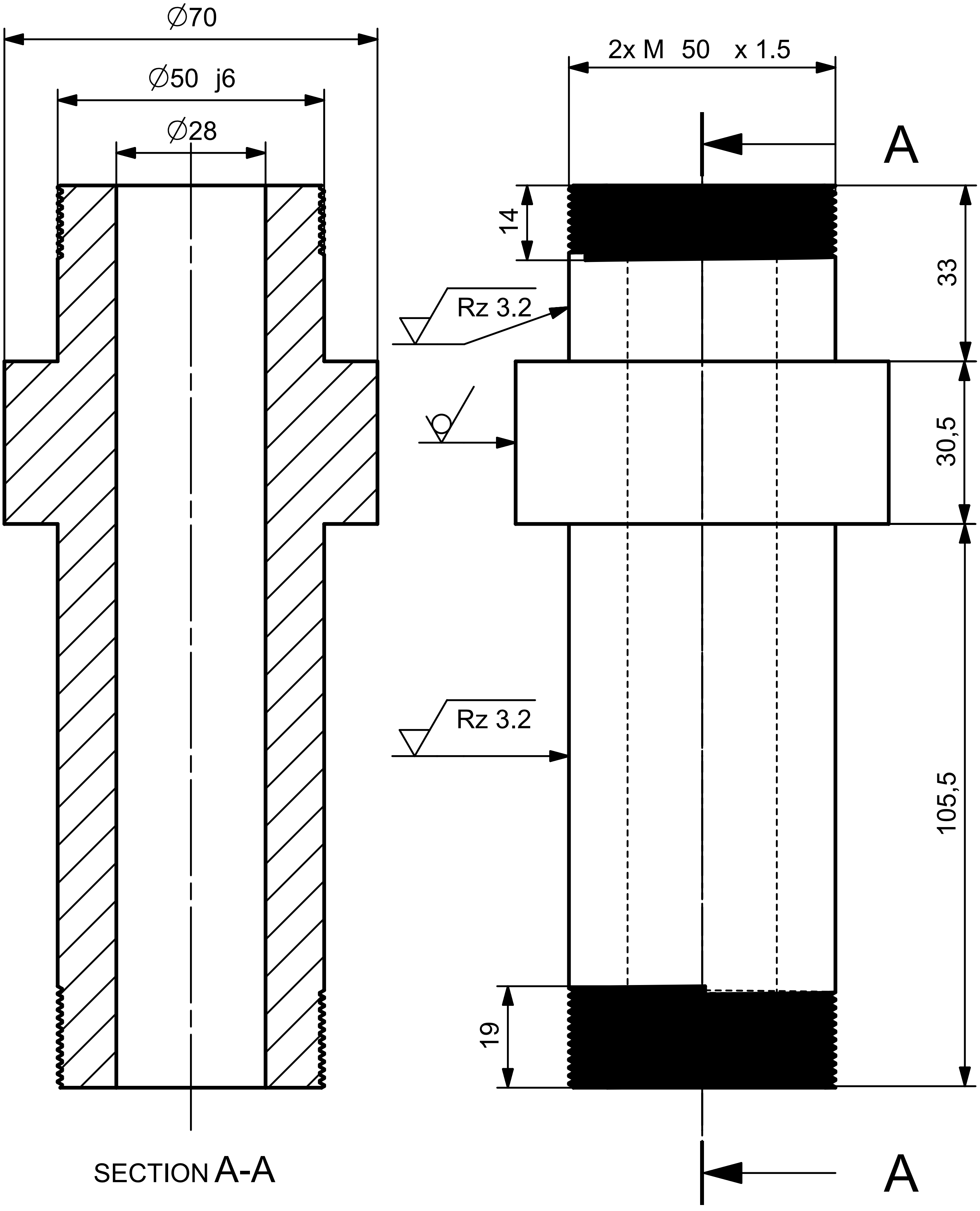
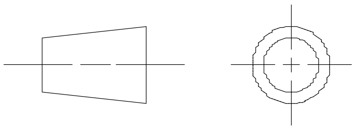
Cylinder End Connector

SHEET 1 OF 1



Rz 6.3 General surface roughness



SCALE	1:1	DRAWN BY	Paolo van Dommelen
UNIT	MM	CHECKED BY	Marcis Livmanis
DATE	28/3/2023	APPROVED BY	Marcis Livmanis

COMMENTS

General tolerances according to ISO 2768-m, other according to DIN EN ISO 286-2

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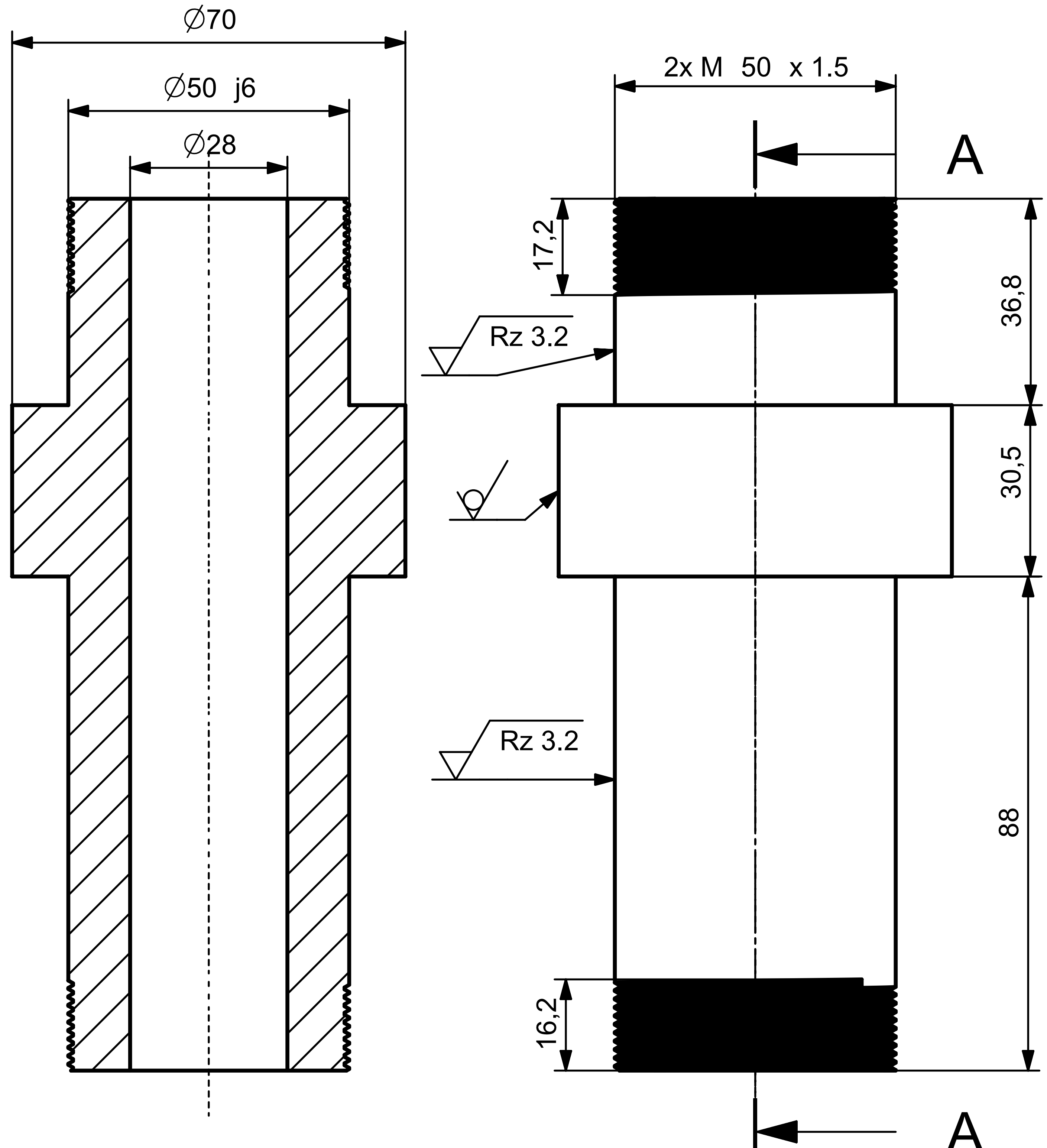
Hinge Shaft Long

SHEET 1 OF 1



SECTION A-A

Rz 6.3 General surface roughness of aluminium bill

SCALE	1:1	DRAWN BY	Paolo van Dommelen	COMMENTS
UNIT	MM	CHECKED BY	Marcis Livmanis	General tolerances according to ISO 2768-m, other according to DIN EN ISO 286-2
DATE	28/3/2023	APPROVED BY	Marcis Livmanis	

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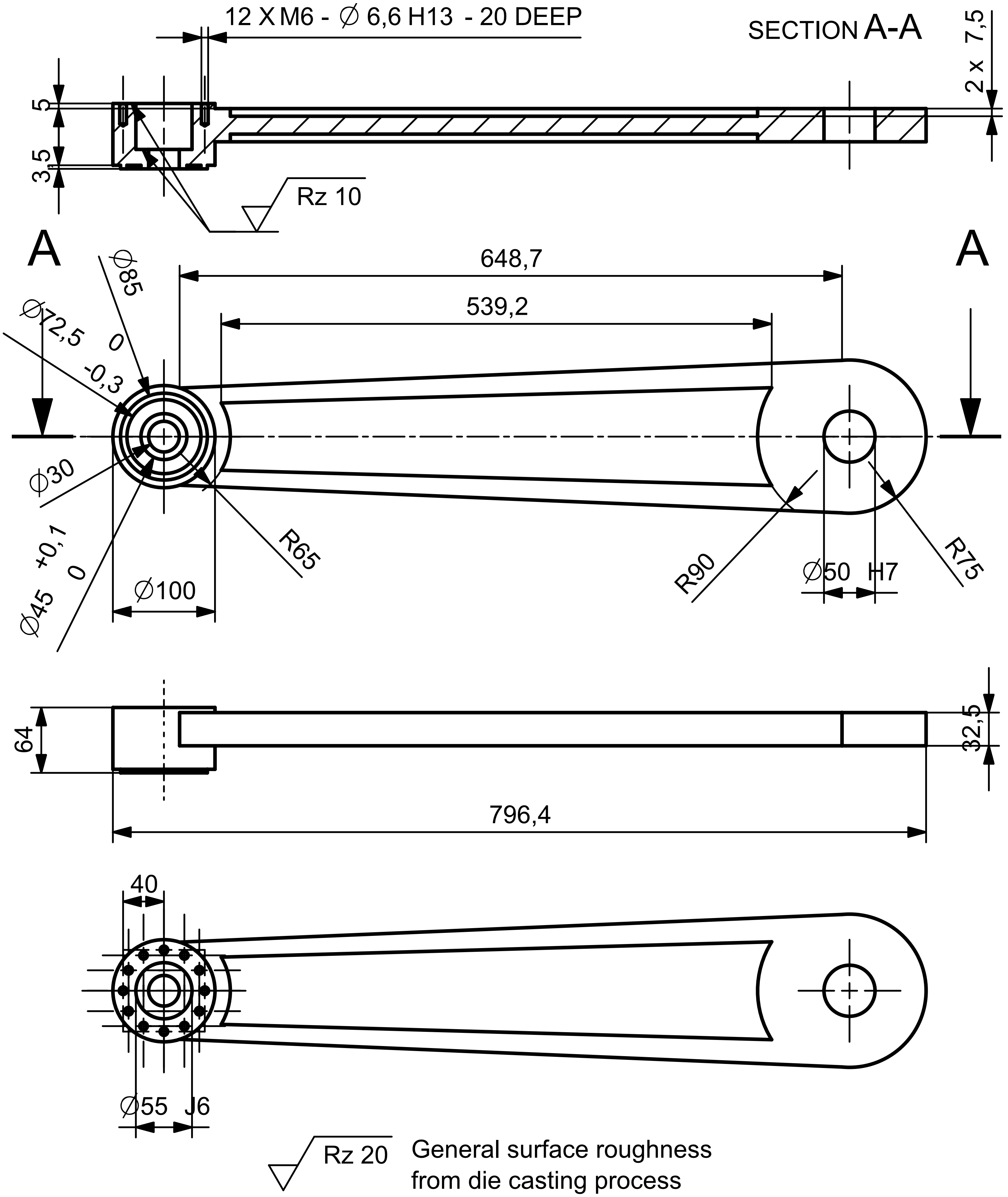
Hinge Shaft Short

SHEET 1 OF 1



SCALE	1:5	DRAWN BY	Paolo van Dommelen	COMMENTS
UNIT	MM	CHECKED BY	Marcis Livmanis	General tolerances according ISO 8062-3 DCTG 6, other according DIN EN ISO 286-2, JIS B1514-2
DATE	28/3/2023	APPROVED BY	Marcis Livmanis	

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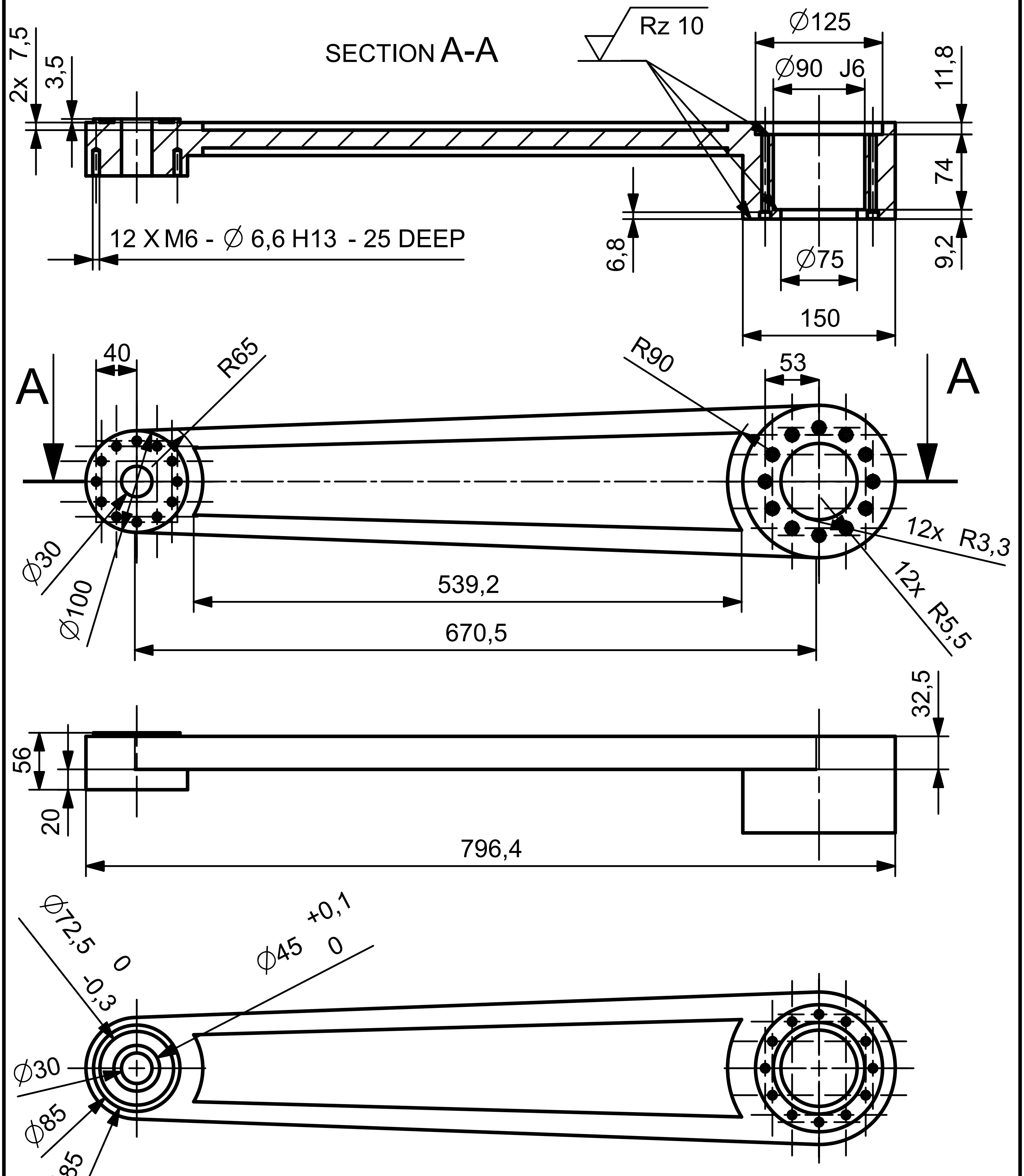
Small Arm 1

SHEET 1 OF 1



Rz 20 General surface roughness from die casting process

SCALE	1:5	DRAWN BY	Paolo van Dommelen	COMMENTS
UNIT	MM	CHECKED BY	Marcis Livmanis	General tolerances according ISO 8062-3 DCTG 6, other according DIN EN ISO 286-2, JIS B1514-2
DATE	28/3/2023	APPROVED BY	Marcis Livmanis	

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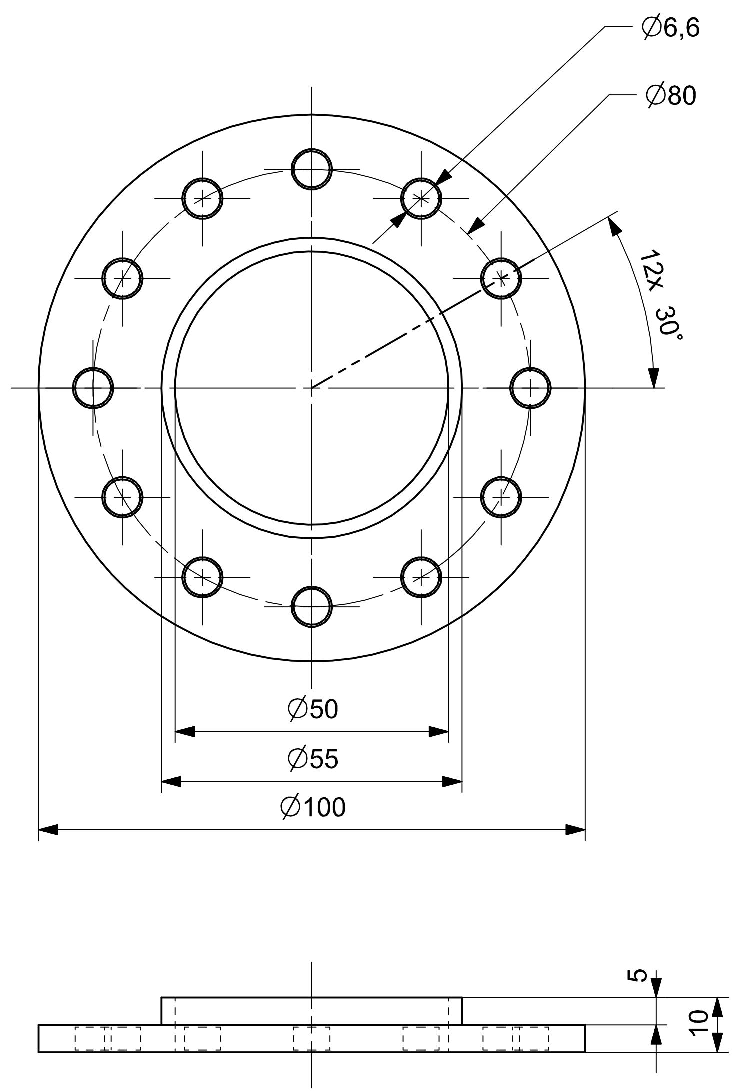
Small Arm 2

SHEET 1 OF 1



				CYL_PT_BearingConver_5thJoint
SCALE	1:1	DRAWN BY	Monique Mainardes	COMMENTS
UNIT	MM	CHECKED BY	Jan Rutrle	ISO 2768-1 medium tolerances apply
DATE	01/04/2023	APPROVED BY		

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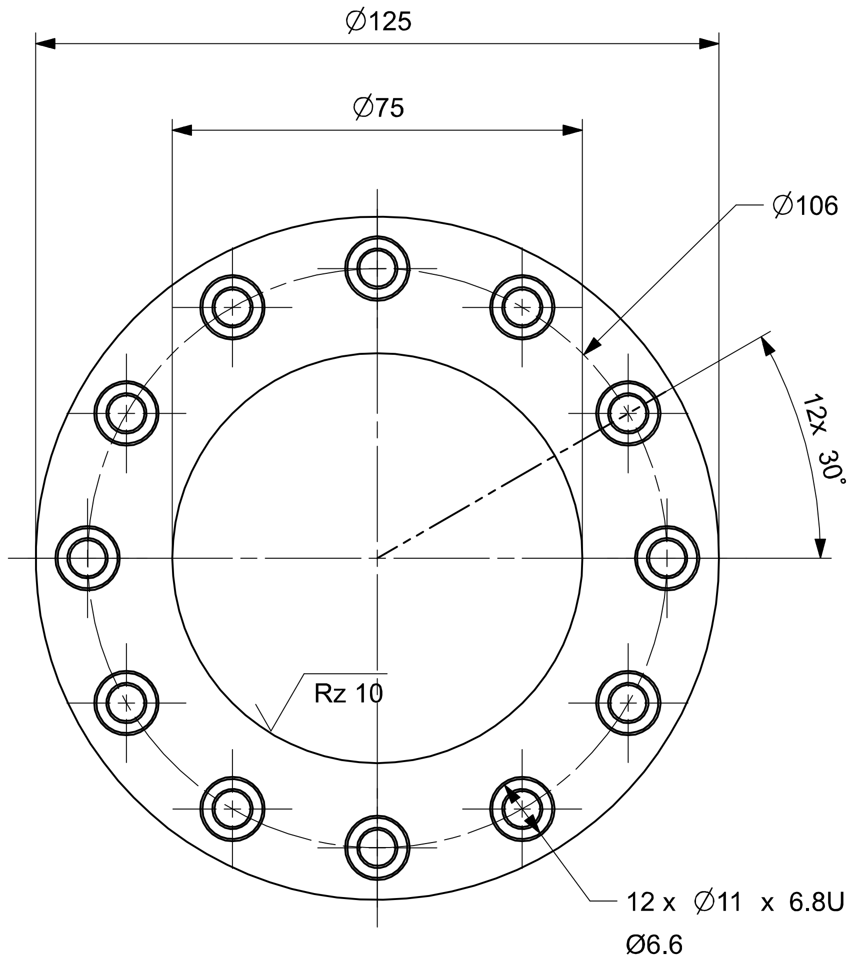
Bearing Cover 5th joint

SHEET 1 OF 1



Thickness 11.75mm

SCALE	1:1	DRAWN BY	Monique Mainardes	COMMENTS
UNIT	MM	CHECKED BY	Jan Rutrle	Aluminium - Casting and Turning - General tolerance fine (DIN ISO 2768-1)
DATE	26/03/2023	APPROVED BY		

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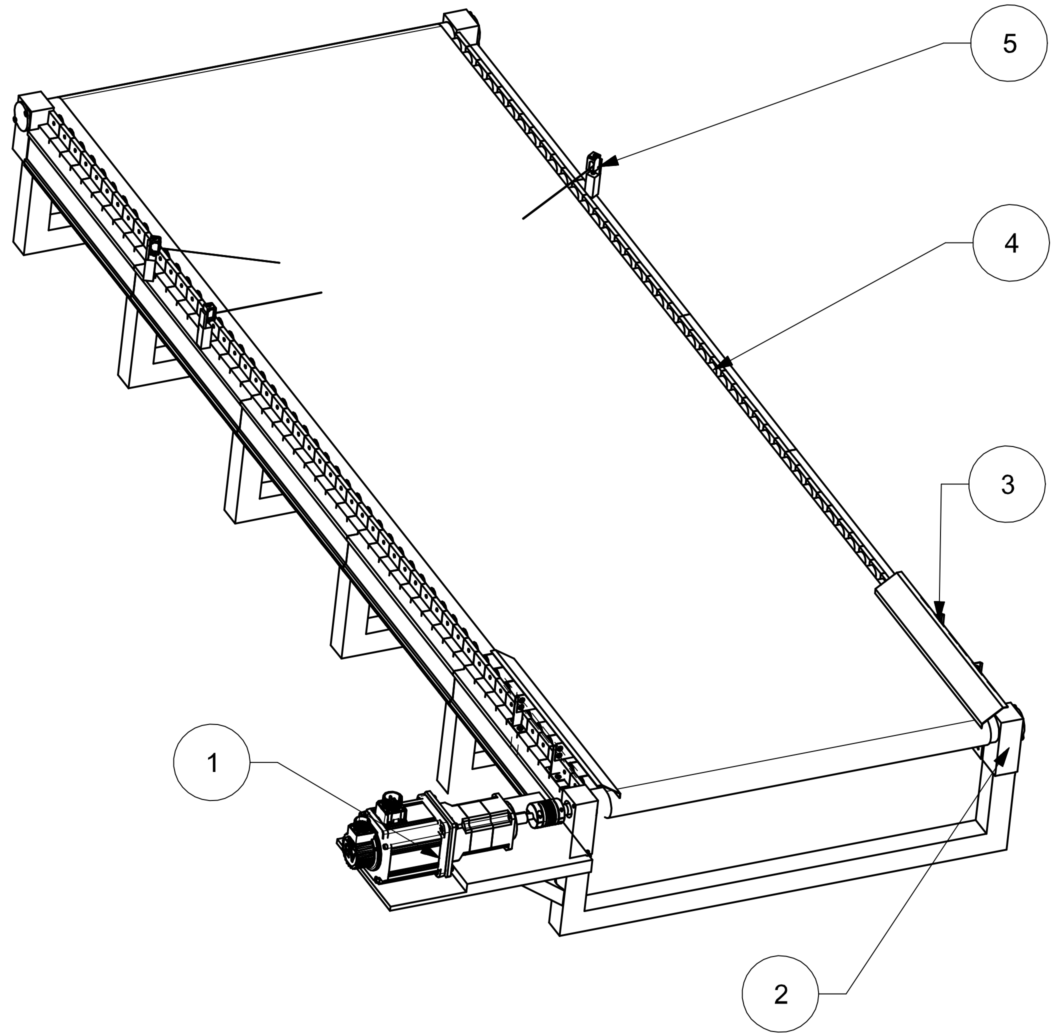
Bearing Cover

SHEET 1 OF 1



1	Driving components	1
2	Bearing casing	4
3	Pallet Aligner	2
4	Idle rollers	60
5	Distance sensors	3
PC NO	PART NAME	QTY

				CB
SCALE	1:11	DRAWN BY	Monique Mainardes	COMMENTS
UNIT	MM	CHECKED BY		
DATE	01/04/2023	APPROVED BY		

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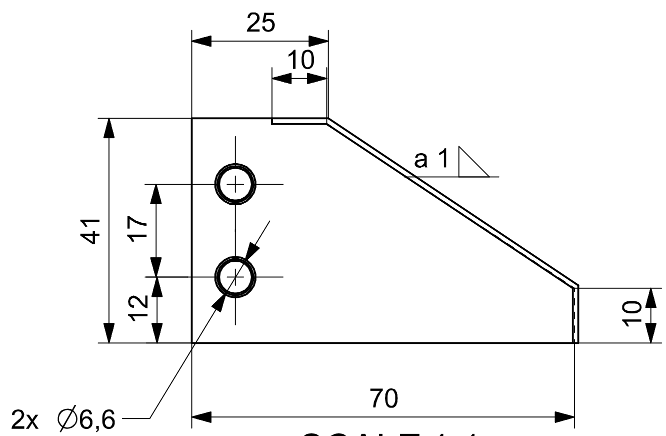
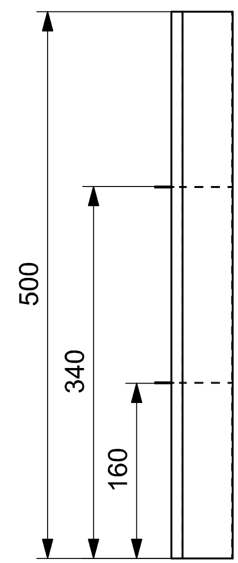
Conveyor Belt Assembly

SHEET 1 OF 1



SCALE 1:1



SCALE 1:5

				alignerv15
SCALE	1:1	DRAWN BY	Monique Mainardes	COMMENTS
UNIT	MM	CHECKED BY		Sheet of aluminum bended and welded. General tolerances v (DIN ISO 2768-1)
DATE	23/03/2023	APPROVED BY		

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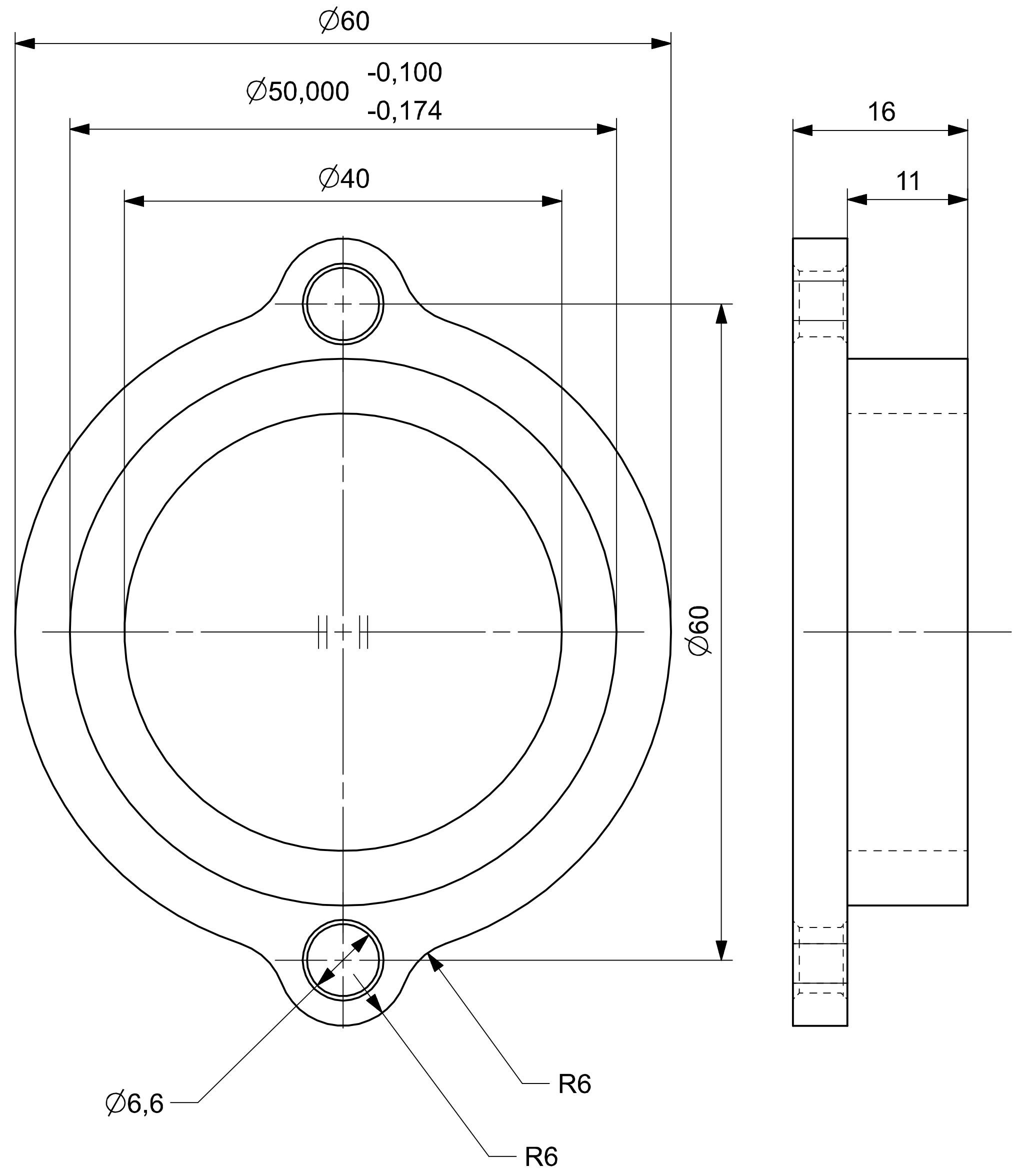
Pallet Aligner

SHEET 1 OF 1



				LidForBearing
SCALE	2:1	DRAWN BY	Monique Mainardes	COMMENTS
UNIT	MM	CHECKED BY	Jan Rutrle	Sandcasting and turning - Aluminium - General Tolerance v (DIN ISO 2768-1) for non specified
DATE	23/03/2023	APPROVED BY		

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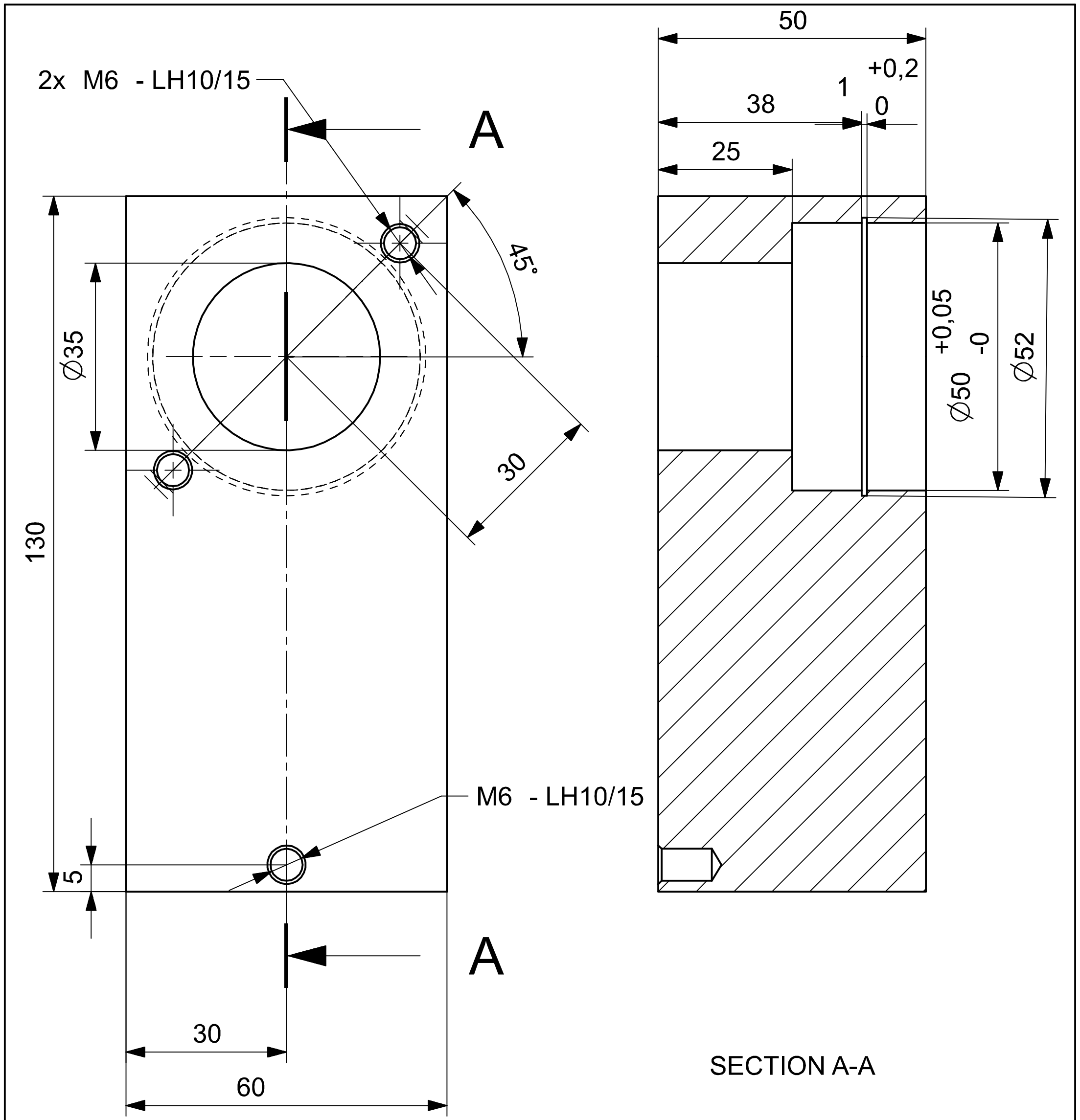
Lid for Bearing Casing

SHEET 1 OF 1



SCALE	1:1	DRAWN BY	Monique Mainardes	COMMENTS
UNIT	MM	CHECKED BY	Jan Rutrle	Part to be casted then bored for tight tolerances - Aluminium. Coarse general tolerance when not indicated (DIN ISO 2768-1)
DATE	23/03/2023	APPROVED BY		

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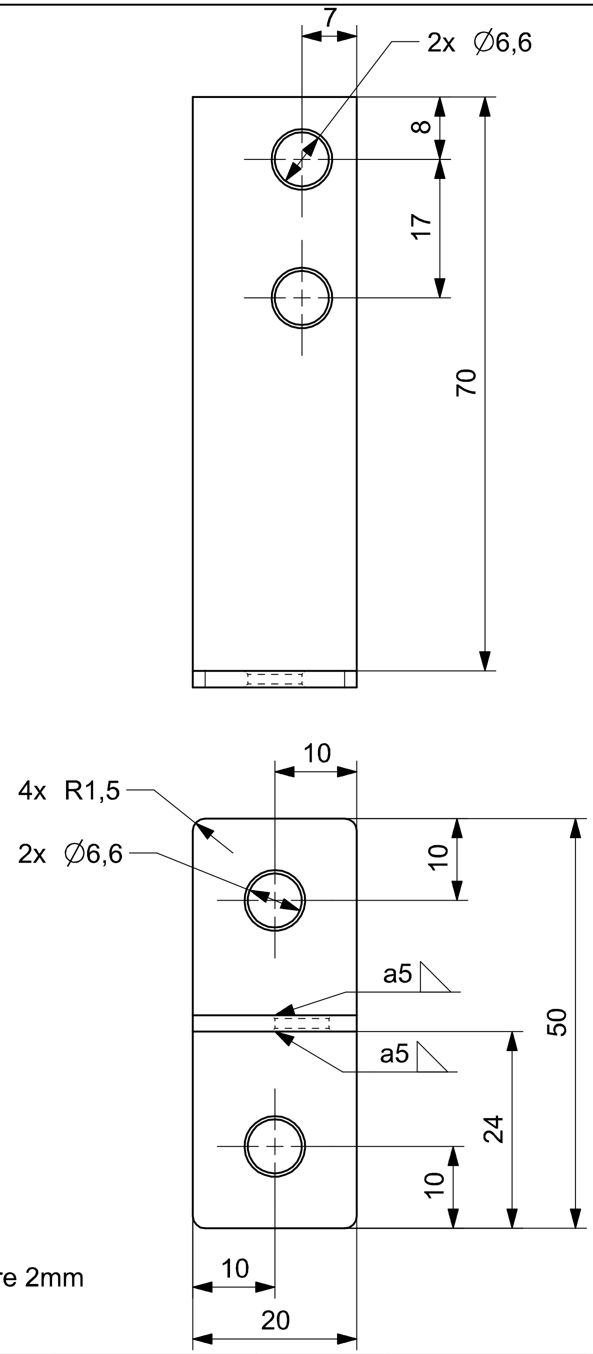
Bearing Casing

SHEET 1 OF 1



All thicknesses are 2mm

				alignv15support
SCALE	1:1	DRAWN BY	Monique Mainardes	COMMENTS
UNIT	MM	CHECKED BY	Jan Rutrle	Aluminium sheets welded and drilled - General tolerance v ISO 2768-1.
DATE	26/03/2023	APPROVED BY		

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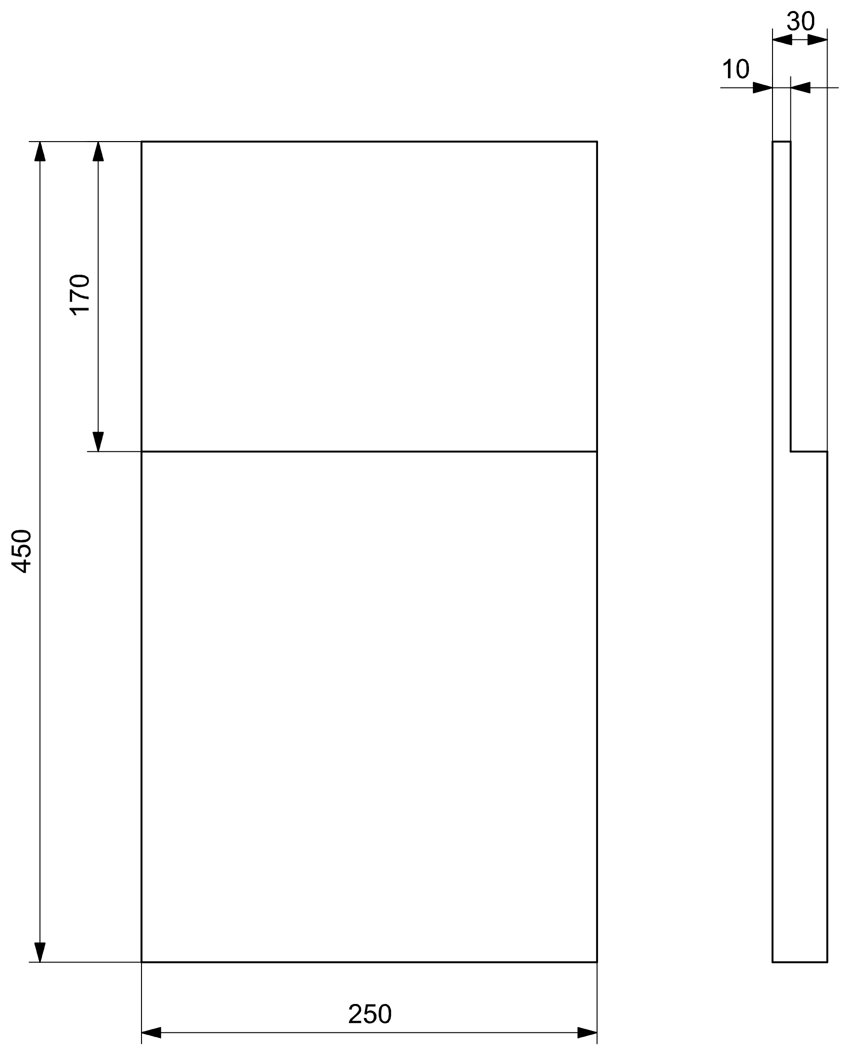
Pallet aligner support

SHEET 1 OF 1



SCALE	1:3	DRAWN BY	Monique Mainardes
UNIT	MM	CHECKED BY	Jan Rutrle
DATE	23/03/2023	APPROVED BY	

COMMENTS
Aluminum part - Sandcasting.
General tolerance v DIN ISO 2768-1

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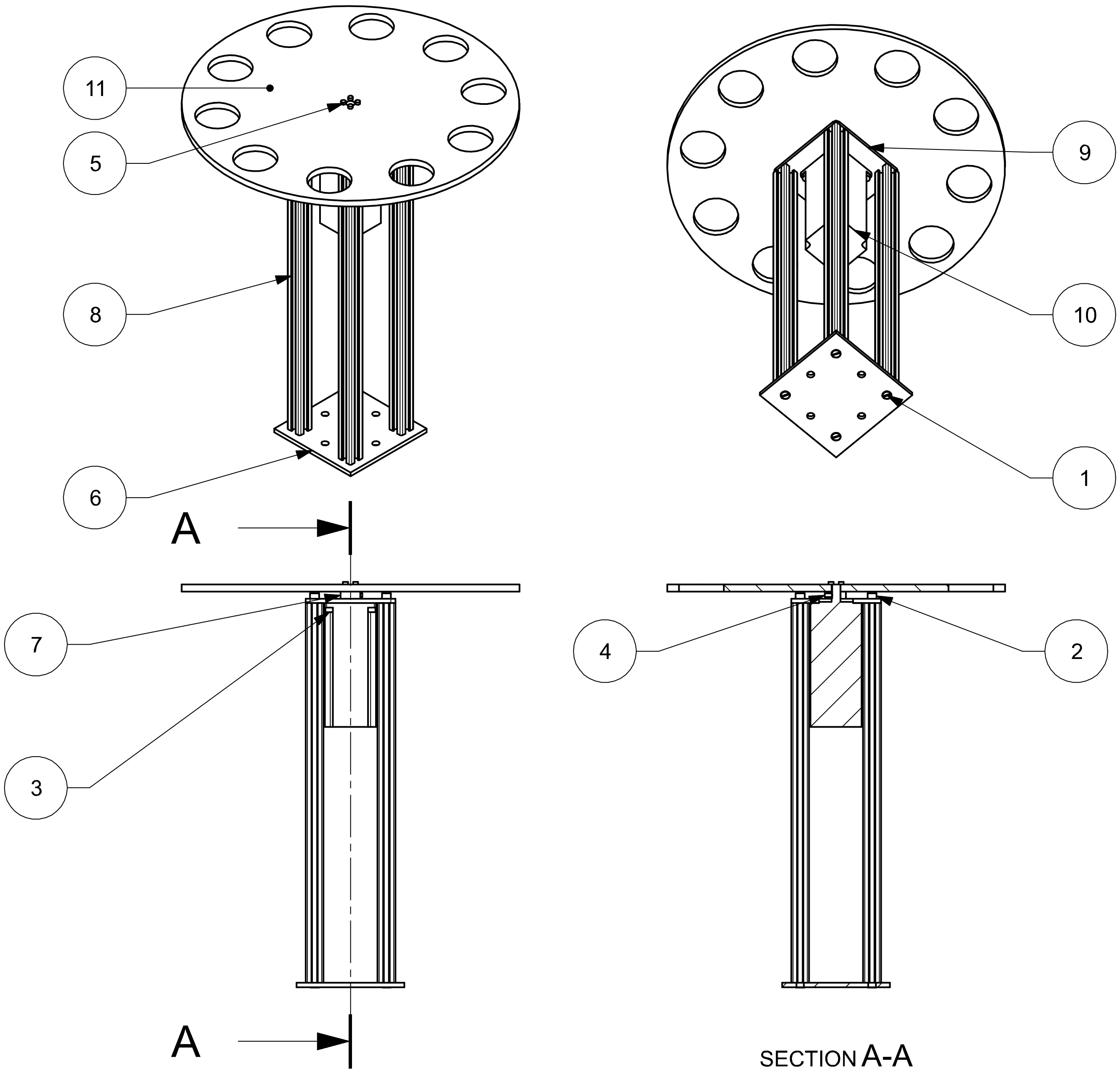
Motor Table

SHEET 1 OF 1



PC NO	PART NAME	QTY
1	M6X20 COUNTERSUNK HEAD	4
2	M6X20	4
3	M5X10	4
4	M4X8 SET SCREW	2
5	M3X16	4
6	IT_MOUNTING PLATE	1
7	IT_SHAFTFIX	1
8	IT_2020X300 ALUMINIUM EXTRUSION	4
9	IT_MAIN PLATE	1
10	IT_NEMA23,3NM	1
11	IT_ROTATING TABLE	1

SCALE	1:5	DRAWN BY	Jan Rutrle	COMMENTS
UNIT	MM	CHECKED BY	Monique Mainardes	
DATE	22.3.2023	APPROVED BY		

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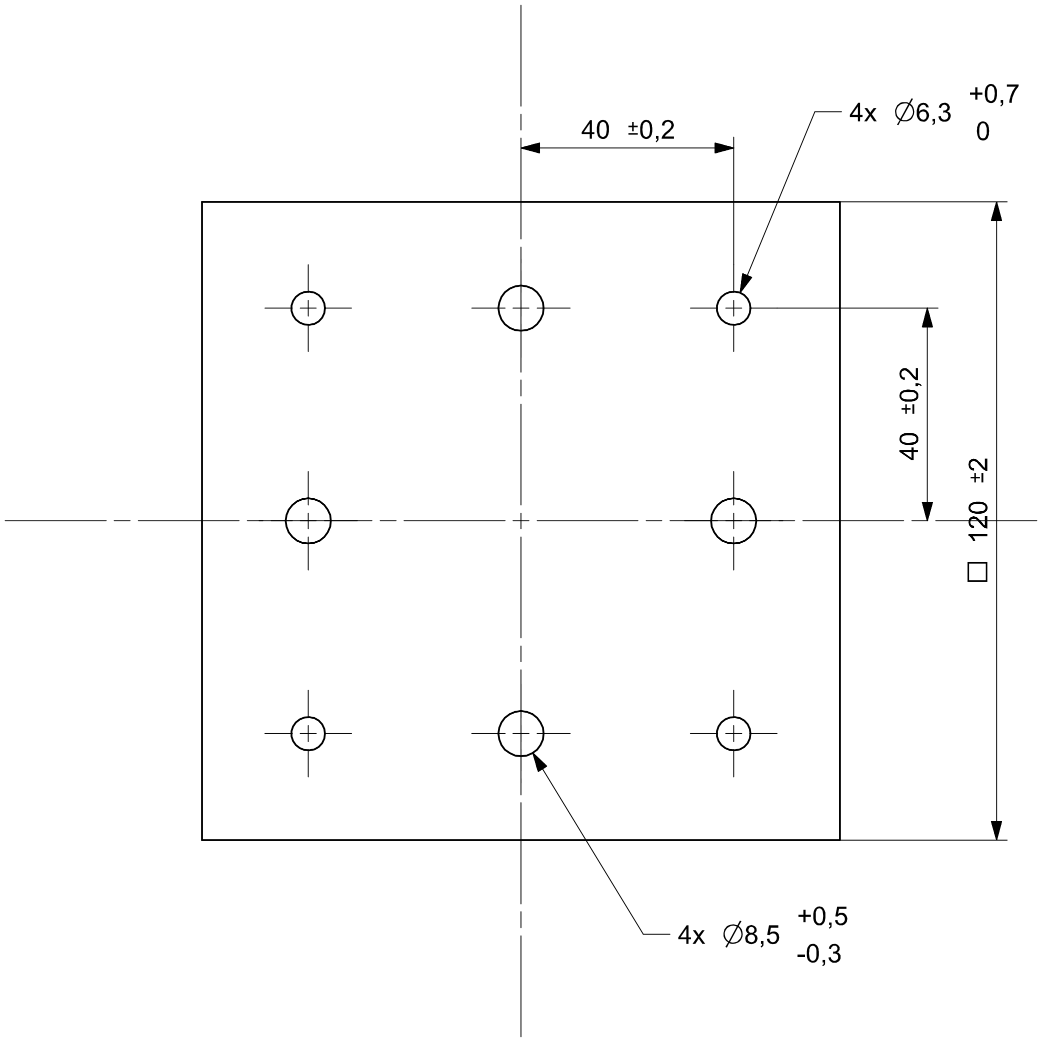
Indexing Table Sub-Assembly

SHEET 1 OF 1



SCALE	1:1	DRAWN BY	Jan Rutrle	COMMENTS
UNIT	MM	CHECKED BY	Monique Mainardes	Thickness = 5mm
DATE	22.3.2023	APPROVED BY		

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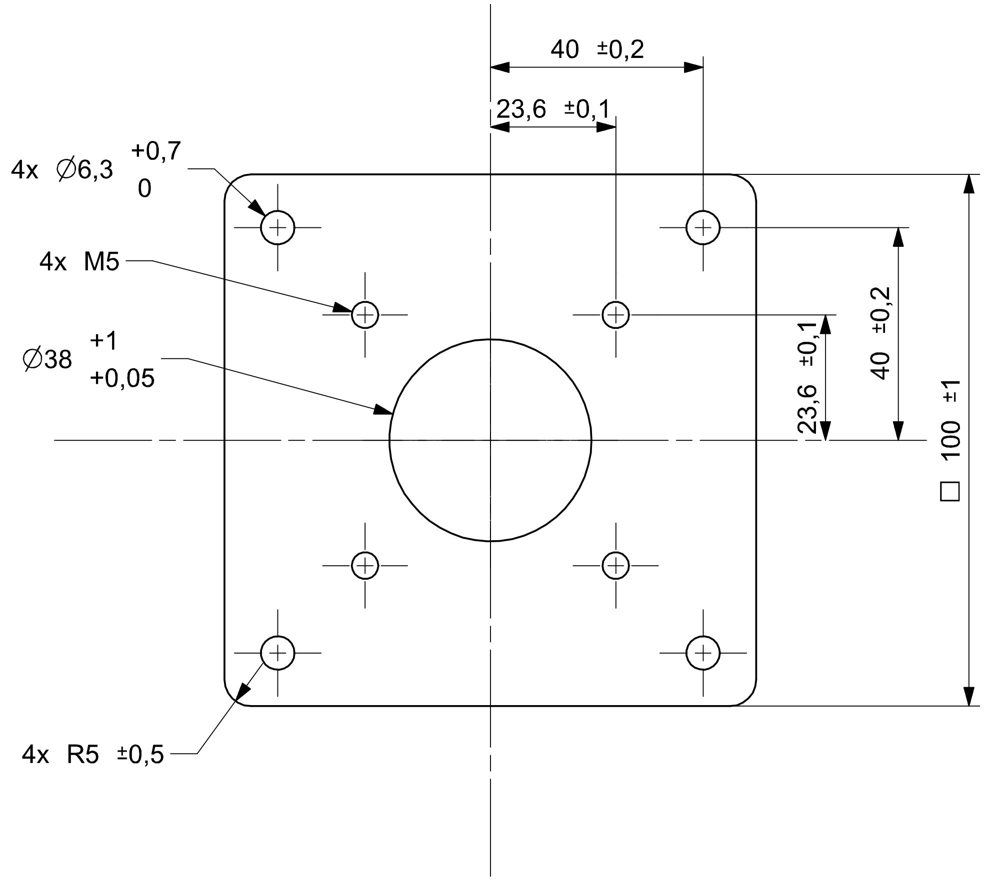
IT-Mounting Plate

SHEET 1 OF 1



SCALE	1:1	DRAWN BY	Jan Rutrle	COMMENTS
UNIT	MM	CHECKED BY	Monique Mainardes	Thickness = 5mm
DATE	22.3.2023	APPROVED BY		

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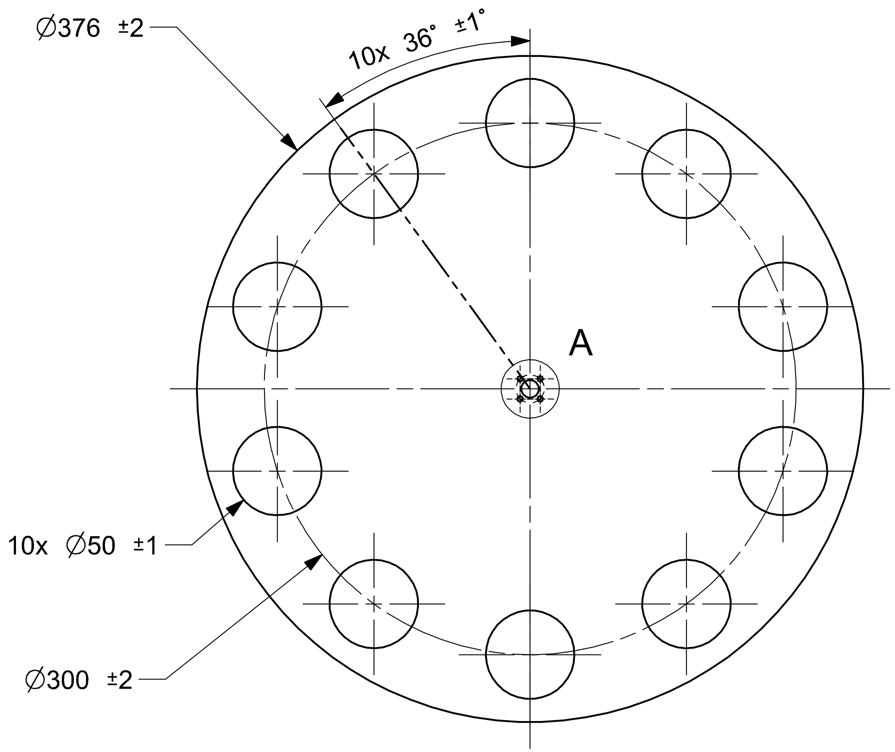
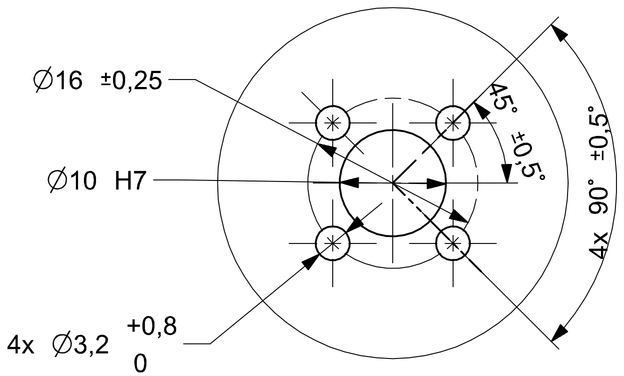
IT- Main Plate

SHEET 1 OF 1





DETAIL A
SCALE 2:1

SCALE	1:3	DRAWN BY	Jan Rutrle	COMMENTS
UNIT	MM	CHECKED BY	Monique Mainardes	Tickness = 8mm
DATE	22.3.2023	APPROVED BY		

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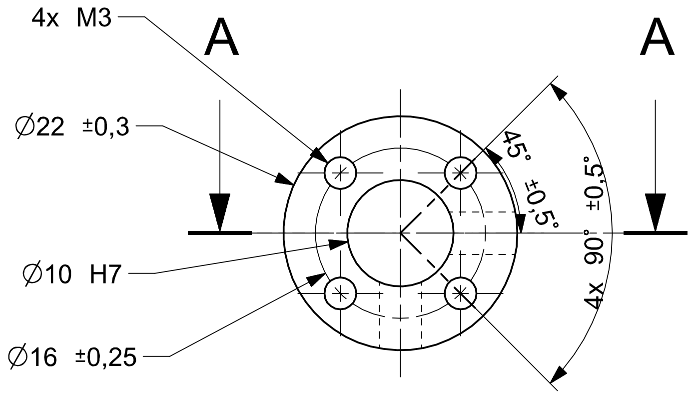
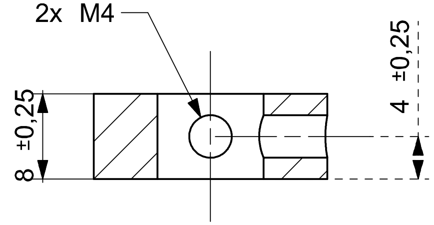
IT- Rotating Table

SHEET 1 OF 1





SECTION A-A

SCALE	2:1	DRAWN BY	Jan Rutrle	COMMENTS
UNIT	MM	CHECKED BY	Monique Mainardes	
DATE	22.3.2023	APPROVED BY		

KU LEUVEN

IT- Shaft Fix

SHEET 1 OF 1

Mechanical design

SCARA Robot

The design of SCARA robot is divided into two parts – SCARA arms and SCARA base. SCARA arms being the moving structure of the robot. And SCARA base being the static structure, housing the motor and providing a stable support point for SCARA arms This is done so that the workload can be divided between two people.

Author: Marcis Livmanis
Checked by: Paolo van Dommelen

SCARA Base

SCARA base consists of two vertical cylinders (short base, tall base) with a purpose to hold SCARA arms at necessary heights in horizontal position, to house the motor and gearbox, and to offer flexibility by allowing use of different motors with minimal design alteration.

Design decisions

To avoid complications, the design of the two SCARA base cylinders utilizes the same parts, with the only difference being the motor mount. This part ensures the height difference for SCARA arms and can be customized for various motors depending on the application. The height difference is implemented by partly inserting the lower section of the motor mount for the short base inside the cylinder that houses the motor and gearbox. For the tall base, the motor mount is attached on top of the cylinder.

SCARA arms are held horizontally by shafts transferring torque from the motor to the arms. For the gearbox to experience only torque, the design of the shaft eliminates moments about the horizontal axis and supports the weight of the arm. Additionally, shafts cannot be pulled out from the top of base cylinders. The design of the shaft system uses a combination of angular contact bearings (which provide force upwards) and tapered roller bearings (which provide force downwards) attached to the shaft via transition fits and held by retaining rings. Bearings are placed with a distance between them to lower the force caused by moment and decrease wear. The connection between SCARA arms and base is form fitting and is clamped in between a M48 nut and the wider part of the shaft. The clamping connection is designed in a way to not allow any torque to be transferred to the nut due to the inertia of the arm. The thread for the M48 nut partly overlaps the clamping region so that enough clamping force can be guaranteed. Just like SCARA arms, shaft and therefore bearings are oversized for the selected application to allow for larger load applications if needed and for safety and reliability reasons.

The motor is attached to the gearbox, which uses flexible shaft couplings with minimal backlash to deliver torque to the shaft. Alignment between the shaft and gearbox is ensured by performing turning operations on parts that hold the shaft and gearbox. Locational clearance fits are used for ease of assembly. The alignment ring of the gearbox is held by the motor mount, a customizable part dependent on the chosen motor and gearbox. Using an alignment ring of its own, the motor mount is aligned with the alignment tube that holds the shaft. The alignment tube serves the purpose of housing shaft supporting structure and bearings. If manufactured according to set tolerances, the motor, gearbox, alignment tube, motor mount, and shaft share the same centerline with insignificant deviations.

The base structure is held together using bolts. The cylinder that houses motors is designed large enough to accommodate any typical motor for the intended application, leaving enough space to tighten the bolts. A hatch is designed in the cylinder for maintenance and installation purposes.

For strength and cost-saving reasons, SCARA base structure is manufactured from carbon steel (e.g. AISI 4340 Alloy Steel). The manufacturing process consists of die casting and turning operations.

List of components

Mechanical Components - Base Custom components				
Number	Name	Product or Part name	Notes	Amount
1	Base cylinder	Pt_base_cylinder	Die cast	2

Author: Marcis Livmanis
Checked by: Paolo van Dommelen

2	Base cylinder hatch	PT_base_hatch	Die cast	2
3	Motor mount (short base)	motor_mount	Turned	1
4	Motor mount (tall base)	motor_mount_tb	Turned	1
5	Outer cover	PT_Head_outer_cover	Die cast	2
6	Top plate	PT_Head_top_plate	Turned	2
7	Alignment tube	PT_Head_alignment_tube_v2	Die cast and turned	2
8	Shaft	PT_Head_shaft	Turned	2
9	Shaft cap	PT_Head_shaft_cap	Die cast	2
10	Bushing h100	bushing_od80_h100	Die cast	2
11	Bushing h10	bushing_od80_h10	Die cast	2

Mechanical Components - Base Standard components				
Number	Name	Product or Part name	Notes	Amount
1	Tapered Roller Bearing	Bearing 4T-33010	https://us.misumi-ec.com/	2
2	Angular Contact Ball Bearing	Bearing 7010	https://us.misumi-ec.com/	2
3	Bolt M8x100			16
4	Bolt M8x35			16
5	Nut M8			32
6	Nut M48x5			2
7	Retaining ring	DIN 472 50		4
8	Retaining ring	DIN 472 85		2
9	Shaft coupler	BKL/30/25/32	https://us.misumi-ec.com/	2

Component selection

The main purpose of angular contact bearings is to hold the weight of the arm. Yet they also play a role in counteracting the moment created by the arm. The tapered roller bearing was chosen because it endures radial forces better. It is used to counteract the moment created by the arm as well as provide downward force in case the shaft is pulled out of the base structure. Tolerances on bearings are chosen (according to DIN 5425-1 (1984-11)) to ensure that SCARA arms remain as horizontal as possible while still maintaining ease of assembly. By using different bearings, the section of the shaft that holds the bearings can be manufactured with one tolerance grade. The reason being that roller bearings require tighter tolerance, so in the setup they are used as non-locating bearings. meaning that if the shaft expands, roller bearings can adjust by design. On the other hand, if the shaft contracts, the roller bearing adjusts because of the type of fit. Even though normally the outer part has a looser fit, this approach was chosen due to the construction of the shaft assembly and to ensure that the shaft remains as vertical as possible. The outer ring of bearings uses a locational clearance fit for assembling reasons.

Retaining rings in combination with thin cylindrical bushings are used to hold bearings in place. This allows easier manufacturing and assembly. The other option would have been to manufacture supports for bearings on the shaft and in the housing. That would require multiple bores on the same part, which is not desirable.

As the shaft differs in size from the gearbox shaft, a flexible shaft coupling for different-sized shafts is used. Moreover, the end of the shaft is made smaller in diameter to allow a smaller shaft coupler, as it is located in the motor mount and alignment tube.

Shaft dimensions were confirmed using FEA technique to confirm if shaft dimensions satisfy the requirements. Simulation was modeled by applying force and moment to the respective sections of the shaft and constraining sections where bearings are mounted. Results show neglectable deformation and acceptable stress. Therefore, I conclude shaft and bearings are sufficiently large for the application.

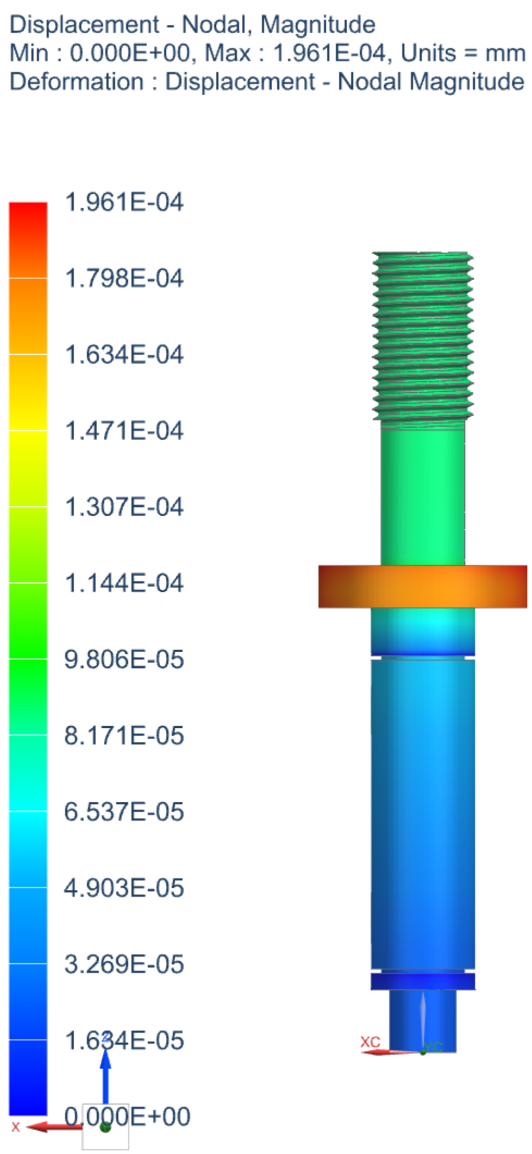


Figure 1. Displacement of the shaft

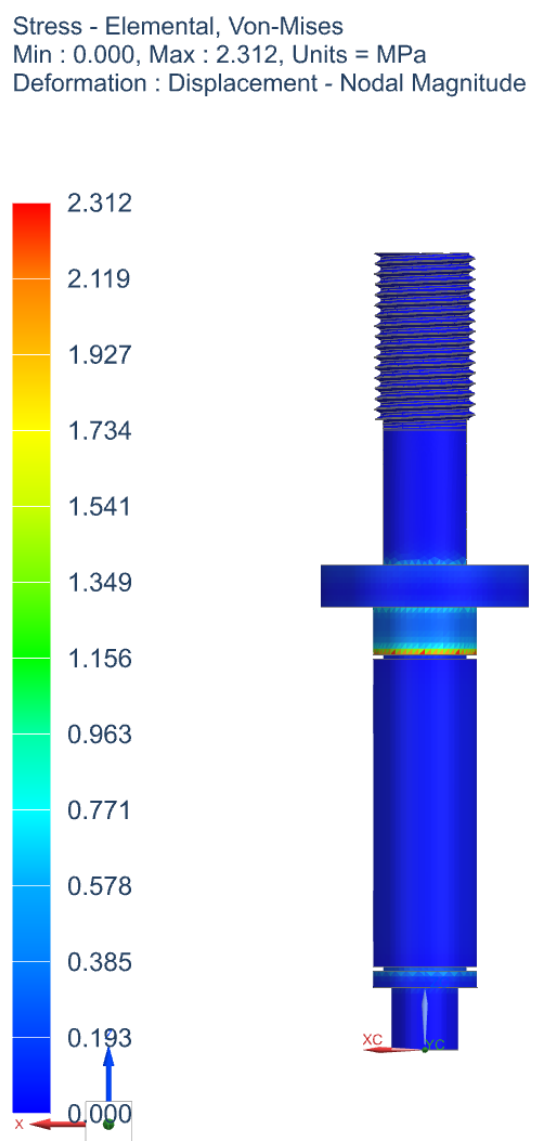


Figure 2. Stress on the shaft

Author: Marcis Livmanis
Checked by: Paolo van Dommelen

SCARA Arms

The goal for the design of arms of the parallel SCARA robot is to allow accurate positioning of the pneumatic cylinder and at the same time support the loads during operation. Due to the long distance the arms must reach, their deflection was of critical importance and had to therefore be designed as stiff as possible in order to achieve the intended accuracy.

Design decisions

During a preliminary analysis a conclusion was reached that using standard off-the shelf shafts, which would in turn require custom fittings to house the shafts, would lead to unnecessary deflections and complexity which could be avoided by having the arms die casted in a single piece. Therefore, the choice was made to cast the arms in aluminum and then have the critical/functional surfaces be machined for the required precision. This allowed the housings for the bearings at the joints to be part of the arms instead of a separate component. To further improve the design of the arms, cutouts were made to reduce the weight of the components while maintaining their stiffness and a triangular shape was given to the small arms. It was also attempted to implement triangle-shaped hatching pattern to further reduce the weight but without much success as only 2kg of material could be removed and would also require intensive machining.

By die casting the components of the arms, several surfaces that come in contact with bearings need to be finished through a milling process while the others can be left unfinished. The surface roughness of the cast aluminum was assumed to be 20 um and the values for roughness's were chosen according to required precision and handbook recommendations. Because of the nature of die casting some dimensions were left ideal such the cutouts in the small arms. While these could realistically not be machined conventionally, using molds based on a 3D printed model of these components it would be possible to achieve such dimensions. The precision of holes and shafts on the other hand was done on the basis of the tolerances of the chosen bearings, namely 4T-30210-NTN and 4T-33006-NTN. These tapered roller bearings were chosen and implemented in pairs to be able to resist axial and radial forces that occur at the joints. Within their technical specifications it is mentioned that their tolerances are according to ABEC 1, tolerances according to the "Annular Bearings Engineers Committee" [1], resulting in the following:

Bearing type	dimension	Value	Upper tolerance	Lower Tolerance
4T-30210-NTN	Bore	50 mm	0 um	-15 um
	Outer Diameter	90 mm	0 um	-15 um
4T-33006-NTN	Bore	30 mm	0 um	-12 um
	Outer Diameter	55 mm	0 um	-13 um

Based on the specified tolerances, appropriate dimensions can be determined for critical surfaces. The bore of the bearing casing of Big Arm 1 and Small Arm 2 needs to be dimensioned to avoid the need for press fitting the 4T-30210-NTN bearings while also preventing excessive clearance that would result in

Author: Paolo van Dommelen
Checked by: Marcis Livmanis

unwanted play between the arms. To achieve this, a transition fit is chosen following the DIN EN ISO 286-2 standard. The outer diameter tolerance of the bearing corresponds closely to an h5 fit, which allows us to select a J6 fit for the bore of the bearing casing for the aforementioned components.

Similarly, the tolerances for the short and long Hinge Shafts are chosen based on the ABEC 1 tolerance of the bearings' bores. A J6 fit according to DIN EN ISO 286-2 is selected with upper and lower allowances of +12 um and – 7 um resulting in a tighter transition fit (wrt. tolerances of the bore of the bearings), which may require force to mount the bearings onto the shafts although within acceptable limits. The 50 mm holes in the Small Arm 1 and Big Arm 2 are dimensioned with an H7 tolerance to ensure that the hinge shafts with tolerance j6 are static with respect to the former components through another transition fit. This transition fit, in conjunction with the friction caused by the pressing of the locknuts at both ends ensure that this condition is met.

Lastly, in a similar manner and according to the same standard, the tolerances for the bearing casing of Small Arm 1 holding the pair of 4T-33006-NTN bearings and the tolerances for the End Connector shaft of the 5th joint were chosen. These bearings follow the same ABEC 1 standard previously mentioned and through the same process a J6 fit was chosen for the bearing casing of Small Arm 1 and a k6 tolerance was chosen for the section of End Connector Shaft holding the two tapered bearings.

The rings holding the thrust bearing positioned between Small Arm 1 and Small Arm 2 were also toleranced according to the tolerances of the outer and inner diameters of the bearing as found in the AZK45739 catalog [2].

The assembly of the components was designed to be as simple as possible to allow for easy mounting and dismounting for maintenance and replacement of components. The Big Arms are initially mounted to the base, and the Hinge Shaft subassemblies are mounted together by sliding the 4T-30210-NTN bearings onto the Hinge Shafts after which the bushings are added at the bottom. The sub-assembly including the Hinge Shaft Long is then positioned through the 50mm hole with an interference fit of Small Arm 1 while the sub assembly with the Hinge Shaft Short is connected in the same way to Big Arm 2. Then the bottom locknuts are tightened to connect the components together. The next step is the mounting of the 5th joint where the Cylinder end connector first aligns the two small arms together with the thrust bearing in the middle, after which the bearings are slid in from the bottom into the bearing casing of Small Arm 1 and tightened with the 5th joint Bearing Cover. Lastly the MPBZ30-12 bushing is added and everything is tightened with the JLNK30 locknut. At this point the Small Arms, are mounted and aligned through the Cylinder end connector and can easily be positioned on the Hinge Shafts which are ultimately tightened with locknuts at the top.

Lastly, the pneumatic cylinder together with the suction cup and necessary adapters is connected to the Cylinder End Connector via the M16 thread. The M5 pneumatic tubing can be passed through the hole at the long Hinge Shaft to be then connected using QSML-M5-4 L fittings on one side and to a 10bar compressed air supply and vacuum generator on the other end.

List of components

The list of all the components used in the arms and cylinder assembly are the following:

ARMS and CYLINDER			
Custom Components			
Number	**Name**	**Amount**	**Production Method**
1	Big Arm 1	1	Die cast and Milled
2	Big Arm 2	1	Die cast and Milled
3	Small Arm 1	1	Die cast and Milled
4	Small Arm 2	1	Die cast and Milled
5	Bearing Covers	2	Turned and Milled
6	Hinge Shaft Long [Long]	1	Turned
7	Hinge Shaft Short	1	Turned
8	Cylinder End Connector	1	Turned and Milled
9	Bearing Cover 5th Joint	1	Turned and Milled
Standard Components			
Number	**Name**	**Amount**	**Notes**
10	Bearing 4T-30210	4	https://eshop.ntn-snr.com/en/product/4T-30210-NTN/4T-30210
11	Bushing MDZB50-20	2	https://us.misumi-ec.com/vona2/detail/110302640070/?HissuCode=MDZB50-20
12	Locknut JLNK50 x4	4	https://us.misumi-ec.com/vona2/detail/110300119550/?HissuCode=JLNK50
13	Cylinder DSNU-16-200	1	https://www.festo.com/us/en/a/19235/
14	Thrust Bearing AZK45739	1	https://us.misumi-ec.com/vona2/detail/221302297121/?HissuCode=AZK45739

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15	L fitting QSML-M5-4	2	https://www.festo.com/us/en/a/153333/
16	Bearing 4T-33006	2	https://eshop.ntn-snr.com/en/product/4T-33006-NTN/4T-33006
17	Locknut JLNK30	1	https://us.misumi-ec.com/vona2/detail/110300119550/?HissuCode=JLNK30
18	Bushing MPBZ30-12	1	https://uk.misumi-ec.com/vona2/detail/110302578920/?HissuCode=MPBZ30-12#
19	Gripper ESG-30	1	https://www.festo.com/ee/en/a/189174/?q=~:sortByFacetValues-asc

Component selection

While the components were gradually chosen while building the design the main critical criteria that had to be met were the following:

- DSNU-16-200-P-A: The choice for the pneumatic cylinder was based on few criteria namely its pulling force and its length. Within these criteria the components that Festo provided were either DSNU-16-200 or DSNU-16-160 as shorter cylinders would not leave enough clearance. Both cylinders at 6 bar are rated for slightly over 100N of force, well enough to lift a 1kg ball. The choice was therefore made to choose a longer cylinder and have a larger clearance between the cylinder and the conveyor.
- The L fittings, the M5 pneumatic tubing and the 30mm suction cup were all based upon the selection of the pneumatic cylinder and the size of the pétanque ball.
- For the arms, theoretical calculations performed previously showed that the deflection in the arms for a 20N load would result in deflections between 0.5 mm and 1mm, which were within our acceptable range. A FEM analysis was performed to confirm this and can be found in Figure 3. Considering an approximate total arm length of 1700 mm and full piston extension of 400 mm with a total deflection 0.5 mm we can calculate the error upon the ideal piston position:

$$\Delta\theta = \tan^{-1}\left(\frac{0.5}{1700}\right) = 0.017deg \quad \text{and} \quad \Delta x = 400 \cdot \sin(0.017) = 0.19\ mm$$

  This allows us to find that for the given arm deflection the position the piston when in full extension will deviate only by 0.19 mm which is very acceptable.
  It also has to be considered that this analysis was computed only for one of the two arms of the parallel scara robot. This is because it is not possible to assume that the loading will be split 50-50 between both arms meaning that with a 20N load one arm theoretically holds 10N and so

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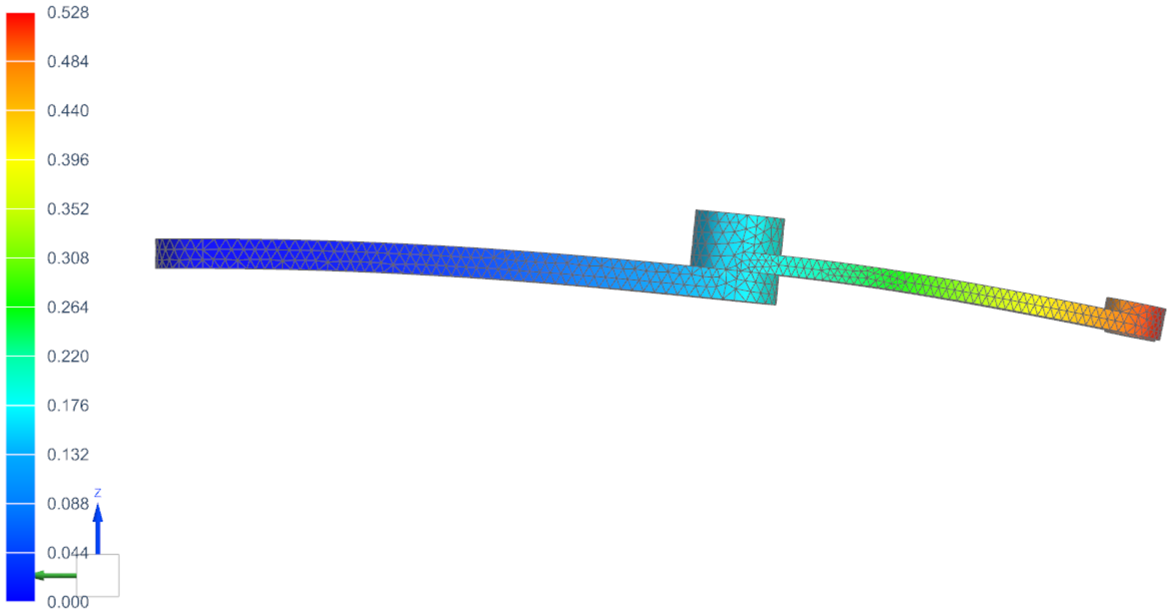

Figure 1: FEA of one set of arms with a 20N force on one end and a fixed constraint on the other

does the other. For this reason, we performed an analysis at full load for a single arm implying that in reality the deflection will be much less than that meaning that the accuracy for positioning will almost not rely on the structure of the arms. Further deflection could be caused by the joints within the bearing casings in the arms but thanks to the chose transition fits and assembly of components that too should prove not to be an issue. This design ultimately is able to withstand much larger loadings than simple pétanque balls and was designed with operation of different loads in mind although requiring slightly oversized components.

- Lastly, the locknuts were chosen appropriately considering that the shafts they are positioned on will be rotating and therefore were chosen to be able to not loosen during operating conditions.
- The bearings were selected with oversizing in mind and were verified using the following calculations:

Bearing Calculations

Using the digital twin of the parallel scara arm, the forces in each joint can be obtained, which then can be checked with the actual bearings used.

Table 1: Summary of all relevant bearing data

	Total Moment [Nm]	Radial Force [N]	Axial Force [N]	Equivalent Static Force [N]	Bearing Static Load Capacity Required [N]
Big Arm Left	57.8	451.4	278	451.4	1805.6
Big Arm Right	51.9	405.1	279	405.1	1620.5
Small Arm Left	7	119	83	117.6	470.3
Small Arm Right	5.1	85.8	89	105.2	420.7

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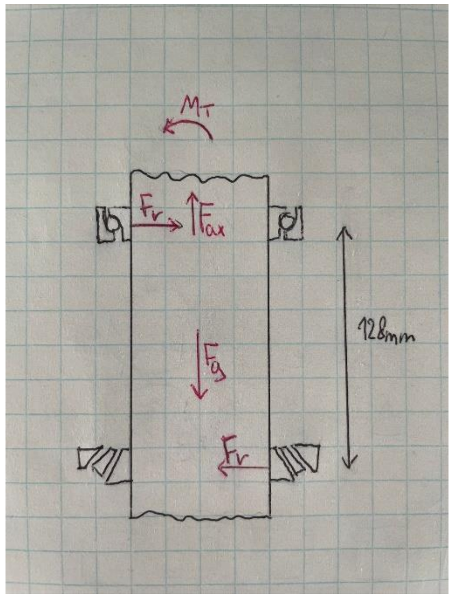

Figure 1: FBD of the large arm joints

Example calculation for the angular contact bearing in the joint of the big left arm:

$$F_r = \frac{M_T}{0.128} = \frac{57.8}{0.128} = 451.4N$$

$$P_o = X * F_r + Y * F_r = 1 * 451.4 + 0 * 278 = 451.4N$$

$$C_{o,req} = S_o * P_o = 4 * 451.4 = 1805.6N$$

For all calculations, safety factor S_o of 4 was taken, as well as the maximal value for the moments and forces was taken to ensure that the mechanical construction can handle the worst-case scenarios. It is also worth mentioning that only the most loaded bearing in each joint was looked at, as the other bearing is of the same size but will see lower loads, hence a calculation is not required.

As can be seen, the required static load capacity for each bearing is quite small, even with a large safety factor. This means that the bearings used in this parallel scara arm will have no problem handling the loads. The selected bearings have static load capacities between 25kN and 30kN, which seems like an overkill for this application, however their size is constrained by other geometrical design requirements.

Conveyer belt

Design decisions

The size of the euro pallet is supposed to be such that any worker dealing with loading/unloading can be far enough away from the robot, to avoid accidents. The size is 2.5 m x 0.8 m. Therefore, the conveyor is also sized to carry two loaded pallets at the same time. Taking the size decided upon, the design makes sure that, in the case of the conveyor is loaded with as many pallets as it fits, it will still be able to bear and accelerate it.

The spacing of the rollers takes in consideration the maximum value of 10DaN per idle, to ensure that the inside shaft can have a smaller cross section and therefore diminish the cost.

List of components

Table 1: Mechanical components for conveyor belt

Mechanical Components - Conveyor Belt				
Nr	Name	Product	Notes	Amount
1	Driving drum pulley	HDR Pulley 60D, 900mm, internal shaft 25mm, longer shaft: 1m	HDR® Conveyor Pulleys - Van GorpVan Gorp	1
2	Returning drum pulley	HDR Pulley 60D, 900mm, internal shaft 25mm	HDR® Conveyor Pulleys - Van GorpVan Gorp	1
3	Idles	Beta Roller Steel Tube 30/7	https://www.rollven.com/idlers-for-gravity-and-belt-driven-conveyors/beta-roller-steel-tube	60
4	Support idles	Serie 100 support	https://www.rollven.com/supports/serie-100	120
5	Belt	Rubber flat belt	https://www.belting.be/en/Products/Rubber-conveyor-belts/Flat-rubber-conveyor-belts/	1
6	Aluminum profile side	40 x 80 KJN profile	Catalog 2018	5 meter
7	Aluminum profile legs	50 x 50 KJN profile	Catalog 2018	6 meter
8	Bearings drum pulley	62/22 bearing	https://www.skf.com/group/products/rolling-bearings/ball-bearings/deep-groove-ball-bearings/productid-62%2F22	4
9	Coupler Gearbox Shaft to pulley	MBC51-22-12-A	https://www.ruland.com/mbc51-22-12-a.html	1
10	Shaft gearbox	Simple Shaft d=12mm, l=50mm	To be produced, technical drawing deemed unnecessary	1
11	Locknut	N Retaining Nut 22mm	http://www.whittet-higgins.com/part.php?series_id=40	1
12	Circlips	External circlip 50mm	https://www.bearingboys.co.uk/External-Circlip/D14000500-50mm-External-Circlip-Pack-of-10-31488-p	2
13	Sensor mounting	BEF-WN-DX35	BEF-WN-DX35 SICK	3

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Component selection

Critical components

1. **Idles:** from the data sheet shown in Table 1 the type 30/7 was chosen. This results in a load of, roughly, 10DaN per roller. For a 900mm long roller, shaft 7 has no longer a linear relationship with the load capacity, but the value is still well above what is needed.

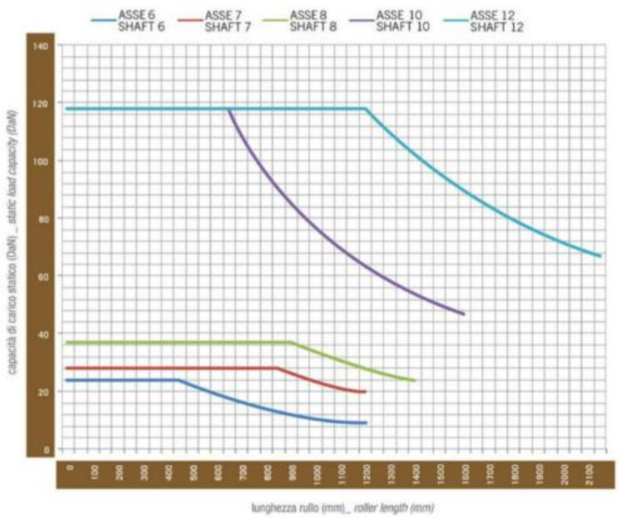

Figure 2: Load carrying capacity graph, taken from the datasheet of the roller by RollVen

   The idles are fixed to the conveyor using the support idles offered by the manufacturer of the idles, those supports have a self-clamping function, and themselves are fixed to the structure of the conveyor using bolts.

2. **Drum pulley:** Chosen from size constraints the diameter is 60mm, for this, the size of the internal shaft is 25mm, with a step down to 22mm in the ends for connection. For the driving pulley, an extended shaft is chosen, so that connection to the coupling and therefore the gearbox is made possible.

3. **Bearings:** groove ball bearings type 62/22 were chosen from a catalog. The torque used for the calculation was the maximum torque coming out of the gearbox, such that the design is more flexible and consistent.
   T = 40 N.m
   L_{10h} = 175200
   N = 3.5 rpm
   p = 3
   X = 1

$$C = \left(X \cdot \frac{2T}{D}\right) \cdot \sqrt[p]{\frac{60 \cdot n \cdot L_{10h}}{10^6}} = \left(1 \cdot \frac{2 \cdot 40}{25}\right) \cdot \sqrt[p]{\frac{60 \cdot 3.5 \cdot 175200}{10^6}} = 10583$$

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From the SKF catalog, the bearing 62/22 satisfies the dynamic load.

4. **Restraining the bearings:** When restraining the drum pulleys the returning pulley is fully locating at one side using a locknut and non-locating at the other side, making use of a circlips instead. The driving pulley, both bearings are non-located.

Custom Components:

- **Bearing casing:** The casing needs an inside cut with thickness of 1mm to include a circlips, for this reason die casting is needed due to the smaller tolerances possible and the freedom of shaping. In the inside of 50mm part the contact with the bearing will occur, according to the Tolerances for the Installation of Friction Bearing DIN 5425-1 (1984-11) and that the outer casing of the bearing only experiences loads that can be approximated by a point load, a minimal clearance fit of H8/h9 is chosen, which means that further machining will be necessary after casting to ensure that. The machining technique chosen in this case was boring, since it is a dimension that can be easily found standardized and boring allows for such a tolerance.
- **Lid for bearing casing:** Used to constrain the bearing movement, the importance of this part lies in the force exerted by it in the axial direction on the bearing, to restrain it. Therefore, M6 screws will be used to fix the part from the outside, so a clearance fit is enough inside. Since the hole will be already in the H8 limit deviations, the lid will be in the d9 category, so that a large clearance fit is achieved and the mounting is easier.
- **Pallet aligner:** This aligner was made with the purpose of showing visual limits for loading the conveyor, causing it will be at least roughly aligned by whoever is loading it. Since it does not carry any load a 2mm aluminum sheet is enough. The manufacturing process chosen is metal sheet bending.
- **Pallet aligner support:** Since the height needed to fix the pallet aligner is not a value that can be found in standardized parts, this part also needs to be customized. The manufacturing process chosen is sand casting.
- **Motor table:** Support for the motor, fixed by an aluminum profile and bolts.
- **Outline structure:** The whole conveyor has many parts that are made using aluminum profiles, that are put together by welding.

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Indexing table

List of components

Product	Notes	Amount
Bolt M3x16		4
Set Screw M4x8		2
Bolt M5x10		4
Bolt M6x20		4
Bolt M6x20 Countersunk		4
Aluminum Extrusion 2020x300mm		4
NEMA 23 Stepper Motor	https://www.omc-stepperonline.com/p-series-nema-23-bipolar-3nm-425oz-in-4-2a-57x57x114mm-4-wires-stepper-motor-cnc-23hp45-4204s	1
Stepper Motor Driver	https://www.omc-stepperonline.com/integrated-stepper-motor-driver-3-8a-10-40vdc-for-nema-23-24-34-stepper-motor-isd08	1

Component selection and Design Decisions

The indexing table itself is not very complex. Once the number of balls it should be able to handle is determined, which is 10 in this scenario, then we only have to select a motor that can rotate the table sufficiently fast. Normally, the motor would be only used to transfer torque to the table, and extra external bearings would be used to supper the axially and radially forces of the table. However, considering the low loads that the table will experience, we can directly attach the table onto the shaft of the motor, and use the motor bearings to handle all the loads.

Considering the simplicity, it is easier to simply calculate the loads by hand. Let us assume worst case scenario where the table is fully loaded with 10 balls. Each ball is 75mm in diameter and has 0.75kg. At the same time, each ball is 150mm from the center of the table, and the table is 376mm in diameter and 8mm thick. The table is also made out of Aluminum 6061 and we can approximate and estimate it as being fully solid. Knowing all this information we can calculate the axial load on the motor, as well as the required torque to move the table by 180 degrees in 1 second, which is more than sufficient.

$$I_{balls} = 10 * (\frac{2}{5} * m * r^2 + m * x^2)$$

$$I_{balls} = 10 * (\frac{2}{5} * 0.75 * \left(\frac{0.075}{2}\right)^2 + 0.75 * 0.15^2)$$

$$I_{balls} = 0.173kg * m^2$$

$$I_{table} = \frac{1}{2} * m * r^2 = \frac{1}{2} * \pi * r^2 * t * \rho * r^2$$

$$I_{table} = \frac{1}{2} * \pi * \left(\frac{0.376}{2}\right)^2 * 0.008 * 2710 * \left(\frac{0.376}{2}\right)^2$$

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$$I_{table} = 0.043kg * m^2$$

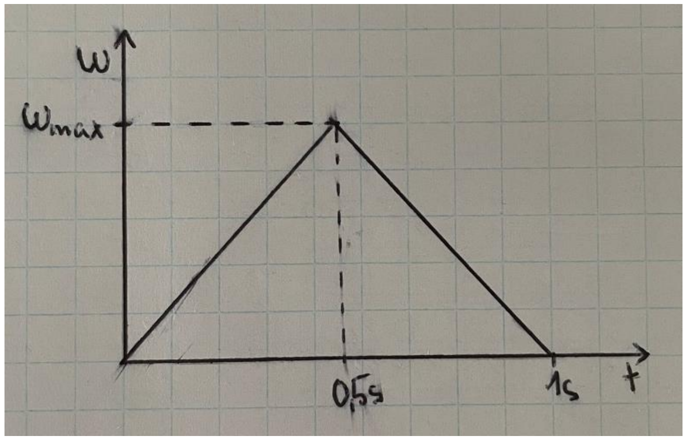

Figure 2: Velocity profile of the indexing table

By creating a simple velocity profile for the desired movement, we can calculate the required top speed, acceleration, and torque.

$$\theta = \frac{0.5 * \omega_{max}}{2} + \frac{0.5 * \omega_{max}}{2} = 0.5 * \omega_{max}$$

$$\omega_{max} = \frac{180}{0.5} = 360°/s = 6.28rad/s = 60RPM$$

$$\alpha = \frac{\omega_{max}}{0.5} = \frac{6.28}{0.5} = 12.56rad/s^2$$

$$T = \alpha * I = 12.56 * (0.173 + 0.043) = 2.71Nm$$

Based on these numbers, a motor that can deliver 2.71Nm at 60RPM is required. This is relatively small power, so a good motor choice is a stepper motor, as it can be run open-loop, which makes the overall design simpler, and is generally simple to control. For these reasons, a Nema23 stepper motor was chosen that has a holding torque of 3Nm. Checking the speed-torque curve shows that at such low RPMs, it is able to deliver about 2.8-2.9Nm, meaning it suffices for this application. At the same time, the driver can be bolted directly to the back of the motor, making the electrical wiring tidier.

Last thing that needs to be considered is the axial force. As mentioned already, to keep the mechanical design simple and minimize the number of parts that needs to be machined, the motor bearings can be used to handle all the loads. It is important to include the mass of the motor in the calculation as the rotor itself is relatively heavy and also needs to be held by the bearings.

$$F_{ax} = g * (m_{table} + m_{balls} + m_{motor}) = g * (\pi * r^2 * t * \rho + m_{balls} + m_{motor})$$

$$F_{ax} = 9.81 * (\pi * \left(\frac{0.376}{2}\right)^2 * 0.008 * 2710 + 10 * 0.75 + 1.8)$$

$$F_{ax} = 115N$$

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Since there is no radial force, this axial load also equals the equivalent static load. If we take a reasonable safety factor S_o of 2, then the required static load capacity is 230N. There is no information on how much the motor shaft is allowed to be loaded axially, however knowing that the output shaft is 10mm, it is safe to assume that the bearings in the motor have an internal diameter of 10mm, are simple deep groove ball bearings, and are constructed in a fixed/floating configuration. Knowing this, the typical values of static load capacity of 10mm internal diameter ball bearings can be checked. Going through a few catalogues shows that typical values for these bearings are around 2000N. According to a bearing manufacturer, SKF, the pure axial load for smaller bearings should not exceed 25% of the static load capacity, so around 500N. This means, that the motor bearings will handle carrying the indexing table without a problem.

Lastly, the indexing table is held up by aluminum extrusions as those are a cheap and rigid solution. All the parts are designed to be flat simple aluminum parts such that they are easy and cheap to machine. The table itself slides onto the shaft with a locating clearance fit and two set screws are used to firmly attach it to the shaft.

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Electric design

Component selection

Robot Arm:

Motor, gearbox, and drive:

Inertia of the arm: $9.95 kgm^2$. This inertia was calculated by NX with the arm positioned in its worst-case scenario. Looking at the torque necessary to accelerate the arm at the chosen angular acceleration of $8.4 rad/s^2$.

$$T = I \cdot \alpha = 9.95 \cdot 8.4 = 83.6\ N \cdot m$$

This will be our peak torque, the peak torque that can be delivered by the gearbox with our motor is 270N.m. For this sizing we also made use of the sizing tool Motion Analyzer.

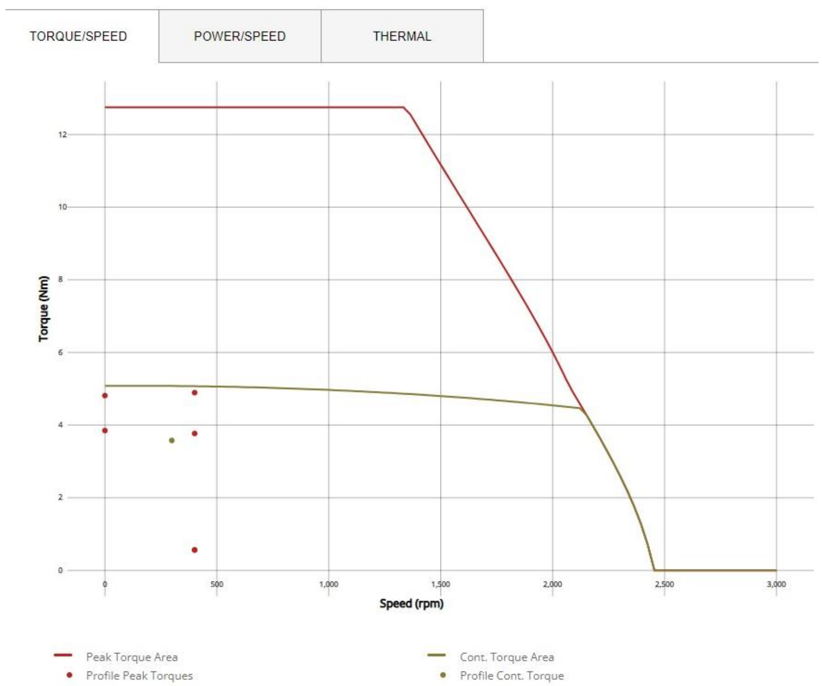

Figure 3: Torque speed characteristic of the motor and gearbox combination

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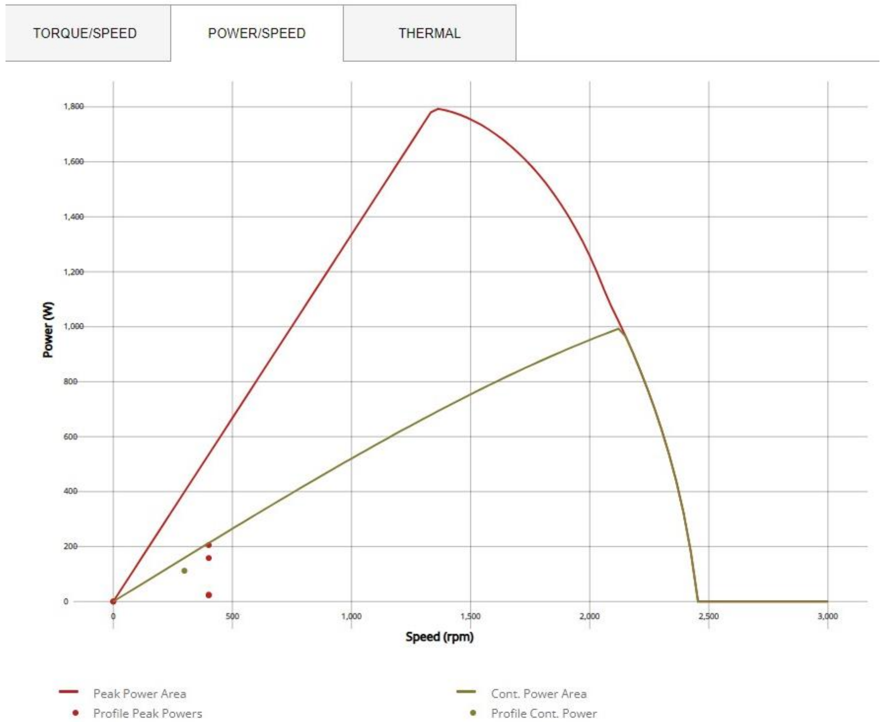

Figure 4: Power speed characteristic of the motor and gearbox combination

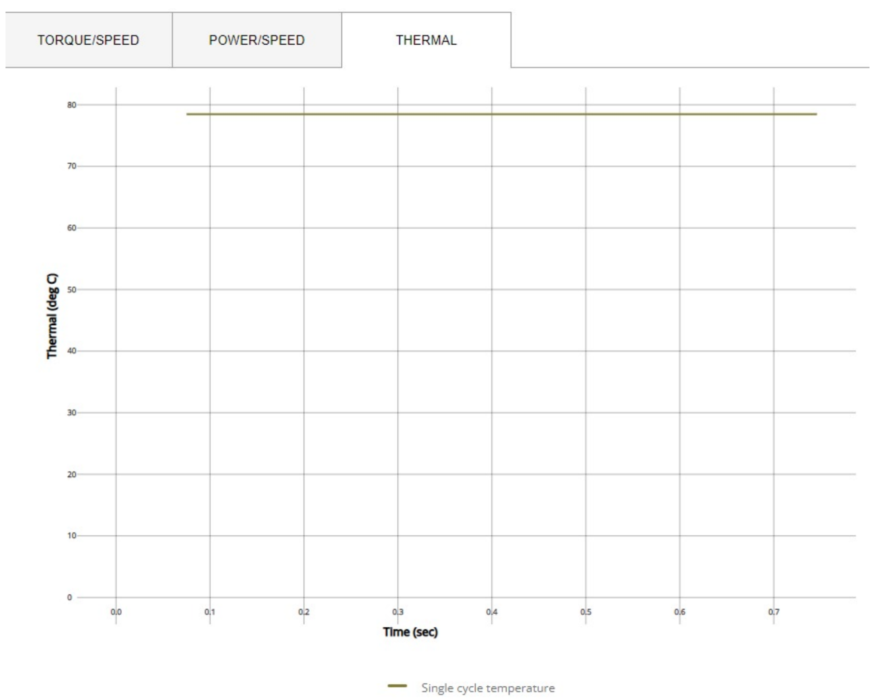

Figure 5: Thermal behavior of the application

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Figure 3, Figure 4 and

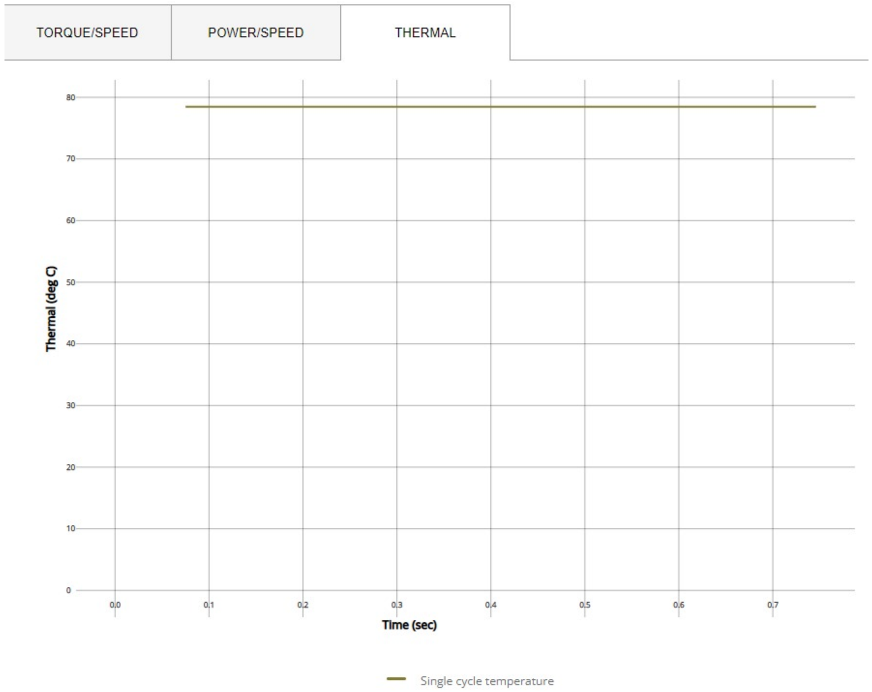

Figure 5 refer to the characteristics of the setup motor and gearbox. For the torque and power speeds the red curve refers to the peak characteristic and the green curve refers to the continuous characteristic of the setup. The shown points represent the critical points of the application.

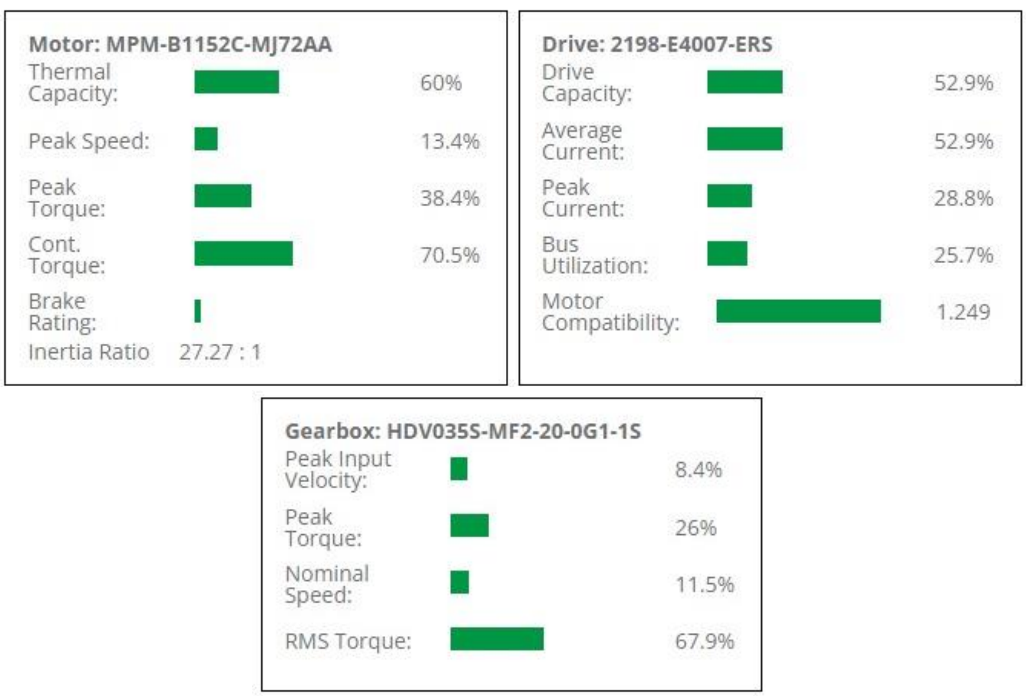

Figure 6: Summary of the usage of the capacities of the setup

Figure 6 shows how much the applications takes from several key features of the setup. A very important point of attention in motor sizing is the inertia ratio.

Conveyor Belt:

Motor, gearbox, and drive:

Since we have a very dynamic conveyor that needs a lot of start/stopping, and from the size we can consider two full pallets need to be accelerated.

Mass to be accelerated = 200kg

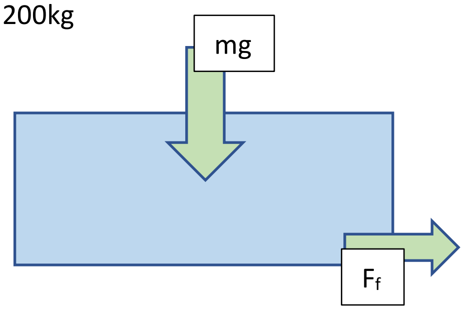

Figure 7: Free body diagram of a virtual mass representing the two pallets that need to be accelerated

An acceleration of 4.33m/s^2 is chosen.

$$F = m \cdot a = 200 \cdot 4.33 = 866N$$

Considering a friction coefficient common for the type of drum and belt we have: μ = 0.8. Therefore the force on the drum:

$$F_{drum} = \frac{866}{0.8} = 1083N$$

This is the force seen by the drum, so the torque, considering the radius which is 30mm:

$$T = F_{drum} \cdot r = 0.03 \cdot 1083 = 32.5N \cdot m$$

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This is a value very close to the peak torque given by the sizing tool we used for the motor, and it's below the maximum capacity of the gearbox, that is 40Nm.

Looking at the torque that has to be delivered by the motor, since our gear ratio is 5, the maximum torque that needs to be delivered by the motor is 6.45Nm, that is a lot lower than the value of 26.3Nm, its maximum. Besides the maximum value might appear as oversized, the motor was still chosen to meet inertia ratio recommendations from the manufacturer, that advises a value close to 10, other smaller motors had a much larger value.

To validate the calculations and also provide options of components the sizing tool Motion Analyzer was used, using the conveyor type of motion. The motion profile is described as shown in Figure 8.

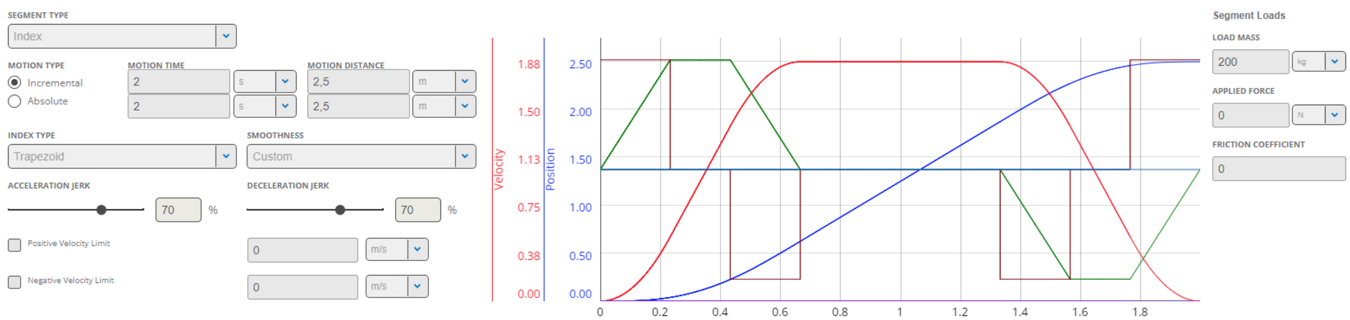

Figure 8: Motion profile conveyor

As a result, we have a list of motors that are suitable, after choosing further the analysis results are shown in Figure 9, Figure 10 and Figure 11:

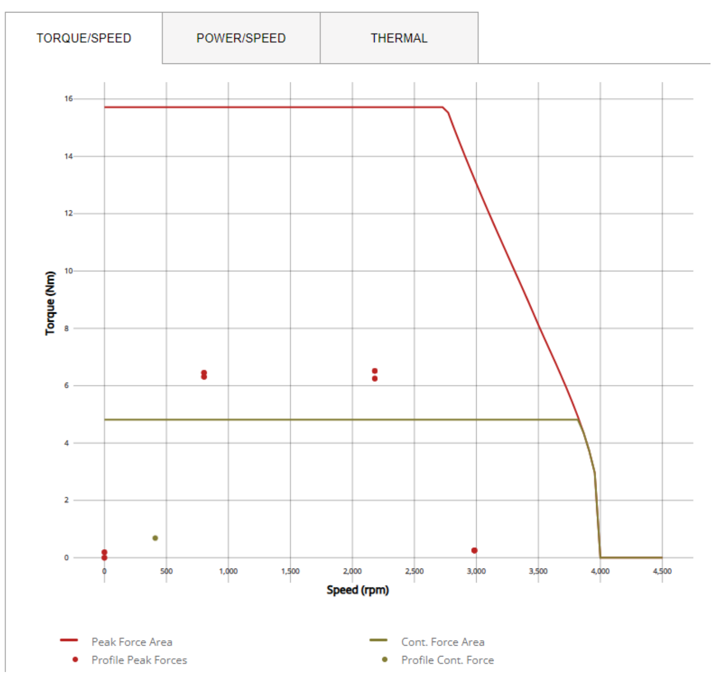

Figure 9: Torque speed characteristic, peak and continuous

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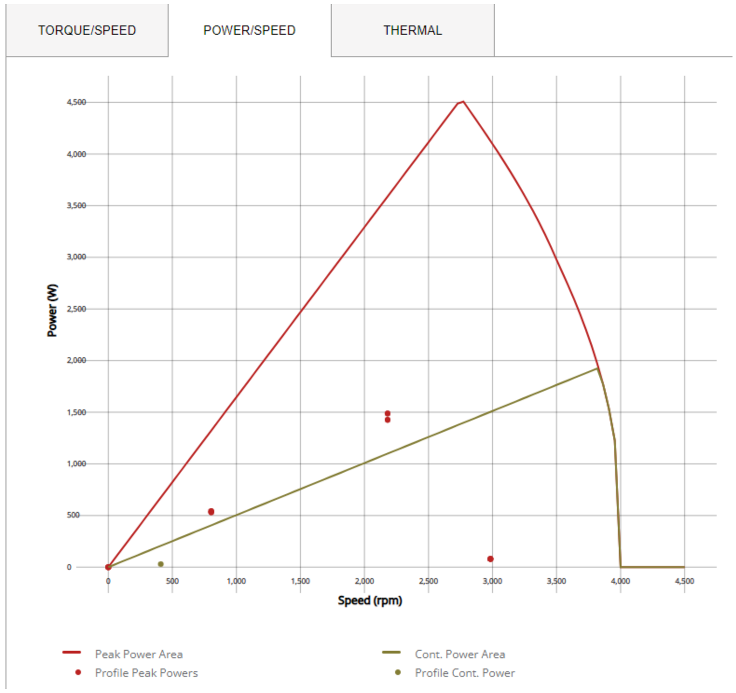

Figure 10: Power speed characteristic, peak and continuous

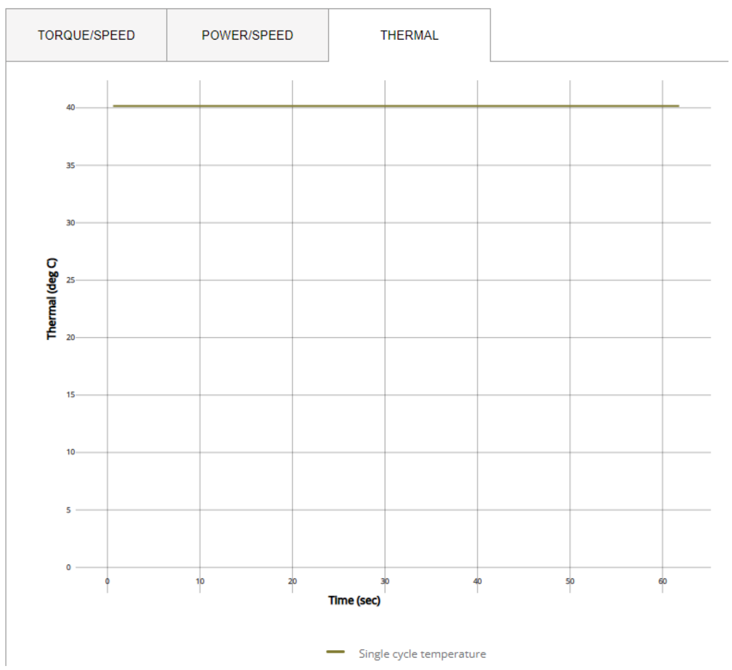

Figure 11: Thermal behavior of the setup

Figure 9, Figure 10 and Figure 11 refer to the characteristics of the setup motor and gearbox. For the torque and power speeds the red curve refers to the peak characteristic and the green curve refers to the continuous characteristic of the setup. The shown points represent the critical points of the application.

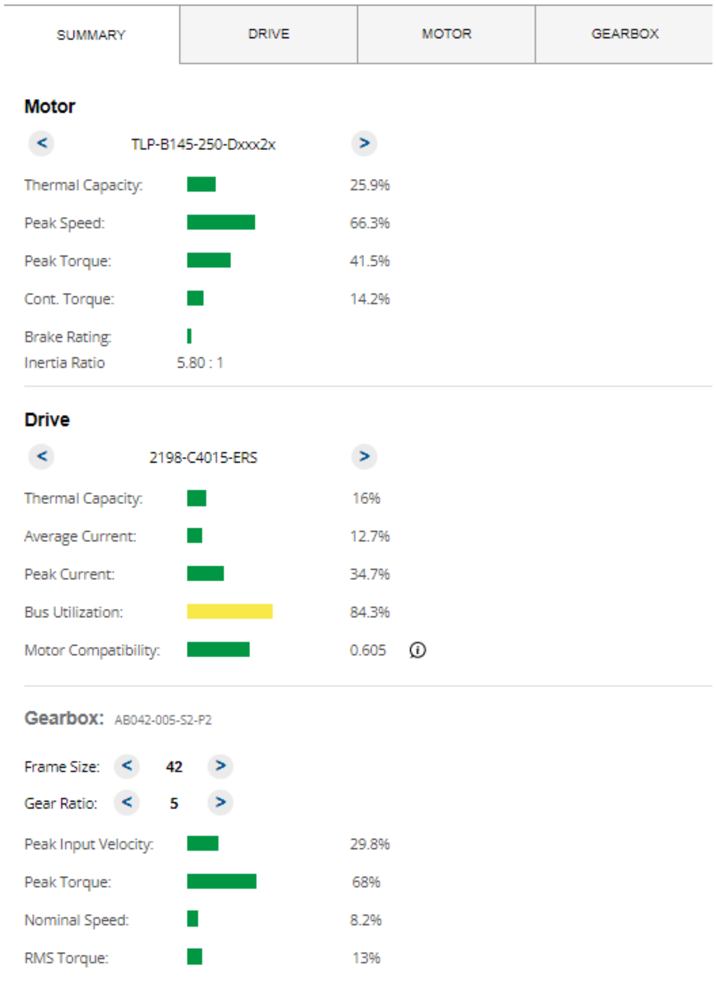

Figure 12: Overview of the application usage of the capacities of the motor

This setup is a very dynamic conveyor system: starting and stopping happen very often in this application. Therefore, a very important quantity in motor sizing is the inertia ratio. According to the manufacturer's recommendations the inertia ratio should be around or below 10, as seen in Figure 12 this is satisfied.

Sensors:

The sensors chosen were three distance sensors so that the position of the pallet can be solved for. This helps with the cost (no cameras are needed) but increases engineering time in PLC programmed.

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SEE and electrical scheme.

The electrical design of the installation revolved strongly around the selection of the drives and motors done in the previous section. As for the arms it was concluded that to match the power and speed requirements of the motor a Kinetix 5700 drive would suit our needs. Coincidentally a 2-axis servo drive with advanced safety options namely 2198-d006-ers4 matches all our requirements and allows us to integrate safety functions such as SS1 and SOS as was recommended from the Rockwell motion analyzer. By selecting such a drive, we had to additionally select a power supply. The Kinetix 5700 series requires a setup to have both an inverter (servo drive) and a DC converter (a DC bus supply) to supply power through a DC bus so after choosing our inverter we selected an appropriate supply namely 2198-P031. The same procedure was done for the selection of the servo drive for the conveyor belt, resulting in a Kinetix 5300 series servo drive namely 2198-C4015-ERS for which fewer safety options were required and could be used standalone without the need for a DC bus supply. These drives were then wired in the appropriate ways to their respective motors using shielded cables and their encoder cables.

Having selected our drives the next aspect of this design that was tackled was the safety. Thanks to the choice of the prior selected drives, it is possible to integrate a fail-safe plc, namely an S7-1516-F with AI, DI, DQ, and fail-safe DI input and output cards, which allows us to use the safety functions of the drives. To add an extra layer of security it was chosen to also use a safety relay in parallel. The goal of having 2-layer security as in this case is that we can allow selectivity in what devices stay powered on depending on the emergency situation. Thanks to the drives always being powered on through the 24V supply what we are able to do is that safety features of the drives can be triggered at any instance without repercussions on the whole installation while when the safety relay is triggered because of e-stops, not only is the 24VSV supply to all unnecessary devices removed but we also communicate to the PLC via DI, that the 24VSV line has been cut of allowing the S71516-F to trigger the safety modes of the drives. This allows for a situation for example where, the safety switches at the doors of the fence get triggered, and we immediately initiate a safety mode for the conveyor and arm servo drives such as safe limited speed, all the while all other devices continue normal operation as the 24VSV has not been interrupted. In case of a serious emergency on the other hand, the emergency stops trigger the safety relay, interrupting the 24VSV line on one hand stopping operation of all sensors and devices but keeping the drives powered on (because of the 24V line) and initiating different safety operations such as a SOS. Furthermore, providing a constant 24V supply is also an added advantage to the stepper drive which allows it to have a constant holding torque even during faulty operation.

Ultimately, the goal of this setup was not only to provide a 2-layer safety system and make the best use of the safety options of the drives but to also use devices that allow easy modifications to the setup and accommodate for a change in motor drives the addition of other sensors and other modifications.

After having selected the safety procedures of our installation we selected all remaining devices that were required to make the installation possible. First of all, an Ethernet switch, namely a SCALANCE XC206-2, was chosen to accommodate for all the ethernet connections that were required to the PLC, additionally an HMI was chosen from which the installation can be controlled. Next up, because of the chosen distance sensors for the positioning of the pallet, M12 5pin connections had to be made to the plc and the same was repeated to accommodate for the M12 5pin connections of the pair of light curtains (sender and receiver) that were chosen namely a Sick deTec / deTec4 pair of light curtains. The vacuum generator also has to be controlled via the PLC, therefore two H3 plug connections are made with the DQ card and a connection to a pressure sensor is made in the AI card. Ideally these connections should have been made on fail safe cards because the vacuum is one of the critical components, but due to the already chosen safety features, we decided that leaving the connection on normal AI cards was also fine. Reed switches to track the positioning of the double acting piston were also chosen and connected appropriately, the same was done with start and soft stop buttons furthermore electrical connections to a 5/2 valve for the double acting cylinder were also made on the DQ card. Lastly, we included a fail-safe digital input card in which we included our safety switches for the fence doors that lead to the installations, these were included in this manner as they are a key component to the triggering of safety functions of the installation.

Ultimately thanks to these devices, we are able to implement safety system where a safe limited speed is started when the safety switches are triggered because of the opening of the door, on the side of the fence where the SCARA robot does not reach, while a safe operating stop can be used when the safety switch is triggered when an operator opens the opposite door to be in close proximity to the arms of the robot. On top of these systems, the safety stops scattered around the installation further prove to be an extra layer of security in addition to the light curtains which detect whether a human or a pallet traverses into the work zone.

While improvements can continued to be made to the installation, through the addition of more safety devices, different connections to safety plc cards and perhaps changes in the operation of the safety relay, the current setup in our option already allows for very secure, reliable, and efficient operation thanks to the two-layer safety system with the parallel operation of the safety relay and fail-safe plc.

The final list of components used for the electrical design is the following:

Electrical / Pneumatic Components					
Number	**Name**	**Product**	**Location**	**Notes**	**Amount**
1	IT- Stepper Motor	Nema 23 Stepper Motor	Indexing Table	https://www.omc-stepperonline.com/p-series-nema-23-bipolar-3nm-425oz-in-4-2a-57x57x114mm-4-wires-stepper-motor-cnc-23hp45-4204s	1
2	IT - Stepper Motor Driver	ISD08	Cabinet A1	https://www.omc-stepperonline.com/integrated-stepper-motor-driver-	1

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				3-8a-10-40vdc-for-nema-23-24-34-stepper-motor-isd08	
3	CB - Asynchronous Motor	TLP Multi-Purpose Servo Motor TLP-B145-250-DJMC2A	Conveyer belt	https://motionanalyzer.rockwellautomation.com/Products/Motors/2005?mid=1	1
4	CB - Gearbox	High Precision Inline AB042-055-S2-P2	Conveyer belt	https://motionanalyzer.rockwellautomation.com/Products/Gearboxes	1
5	CB - Drive	Kinetix 5300 Servo Drive 2198-C4015-ERS	Cabinet A1	https://motionanalyzer.rockwellautomation.com/Products/Drives/2229?mid=1	1
6	CB - Sensors	Mid-range distance sensor Dx35 / DS35	Conveyer belt	https://www.sick.com/ag/en/distance-sensors/mid-range-distance-sensors/dx35/ds35-b15221/p/p309056?ff_data=JmZmX2lkPXAzMDkwNTYmZmZfbWFzdGVySWQ9cDMwOTA1NiZmZl90aXRsZT1EUzM1LUIxNTIyMSZmZl9xdWVyeT0mZmZfcG9zPTMmZmZfb3JpZ1Bvcz0yNCZmZl9wYWdlPTEmZmZfcGFnZVNpemU9OCZmZl9vcmlnUG	3

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				FnZVNpemU9OCZmZl9zaW1pPTk0LjA=&ff_data=JmZmX2lkPXAzMDkwNTYmZmZfbWFzdGVySWQ9cDMwOTA1NiZmZl90aXRsZT1EUzM1LUIxNTIyMSZmZl9xdWVyeT0mZmZfcG9zPTMmZmZfb3JpZ1Bvcz0yNCZmZl9wYWdlPTEmZmZfcGFnZVNpemU9OCZmZl9vcmlnUGFnZVNpemU9OCZmZl9zaW1pPTk0LjA=	
7	Base - Servo motor	MPM-B1152C-MJ72AA	SCARA base	https://www.rockwellautomation.com/	2
8	Base - Planetary gearbox	HDV035S-MF2-20-0G1-1S	SCARA base	https://alpha.wittenstein.de/en-en/	2
9	Base - Servo Drive	Kineitx 5700 2198-D006-ERS4 Dual Axis Inverter	Cabinet A1	https://www.rockwellautomation.com/it-it/products/details.2198-D006-ERS4.html	1
10	Base - DC Bus Supply	Kinetix 5700 DC Bus Suply 2198-P031	Cabinet A1	https://www.rockwellautomation.com/it-it/products/details.2198-P031.html	1
11	Other - Light Curtains	Safety light curtains deTec / deTec4 / Pair	Fence	https://www.sick.com/pl/en/safety-light-curtains/safety-light-curtains/detec	1

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12	Other - Vacuum generator	OVEL-5-H-10-PQ-VQ4-UA-C-A-V1PNLK-H3 -	Cabinet A1	https://www.festo.com/us/en/a/8049052/?q=vacuum~:sortByCoreRangeAndSp2020~:CC_Supply_air_connection_FoX_MYCH_3088_C_FP_GLOBAL~:CC_Supply_air_connection_FoX_MYCH_3088.Q04~:CC_Ejector_characteristics_C_FP_GLOBAL~:CC_Ejector_characteristics.H~:CC_Vacu	1

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13	Other - Pressure Snesor	SPAE-V1R-PC10-PNLK-2.5K	Cabinet A1	https://www.festo.com/us/en/a/8025978/	1
14	Other - Safety Door Switch	Non-contact safety switches RE2 / Magnetic safety switch (1059510)	Fence	https://www.sick.com/pl/en/safety-switches/non-contact-safety-switches/re2/re27-sa05l/p/p315675	2
15	Other - Reed Switches	Proximity sensor - SMT-8M-A-PS-24V-E-0,3-M8D	SCARA Robot	https://www.festo.com/tw/en/a/574334/	2
16	Other-Bistable 5/2 valve	VUVG-LK10-B52-T-M5-1R8L-S	Cabinet A1	https://www.festo.com/us/en/a/8042544/?q=valves~:sortByCoreRangeAndSp2020~:CC_Valve_function_C_FP_GLOBAL~:CC_Valve_function.B52~:CC_PRESEL_EBVENT_MYCHAR_5655_03_C_FP_GLOBA	1

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				L~:CC_PRESEL_EBVENT_MYCHAR_5655_03.24V%2520DC~:CC_Pneumatic_connection_C_FP_GLOBAL~:CC_Pneumatic_connection.M5	
17	Other - PNOZ X3.2	PNOZ X3.2 Safety Relay	Cabinet A1	https://it.rs-online.com/web/p/rele-di-sicurezza/2391061	1
18	Other - Ethernet Switch	SCALANCE XC206-2 , 6GK5206-2BB00-2AC2	Cabinet A1	https://mall.industry.siemens.com/mall/it/it/Catalog/Product/6GK5206-2BB00-2AC2	1
19	Other - HMI KPT700 PN	SIMATIC HMI, KTP700 Basic, 6AV2123-2GB03-0AX0	Cabinet A1	https://mall.industry.siemens.com/mall/en/it/Catalog/Product/6AV2123-2GB03-0AX0	1
20	Other - PLC power Supply	SIMATIC PM 1507, 6EP1333-4BA00	Cabinet A1	https://mall.industry.siemens.com/mall/it/it/Catalog/Product/6EP1333-4BA00	1
21	Other - PLC CPU	SIMATIC CPU 1516F-3 PN/DP, 6ES7516-3FN02-0AB0	Cabinet A1	https://mall.industry.siemens.com/mall/en/WW/Catalog/Product/6ES7516-3FN02-0AB0	1
22	Other - PLC DI	SIMATIC DI 32x24 V DC HF, 6ES7521-1BL00-0AB0	Cabinet A1	https://mall.industry.siemens.com/mall/en/it/Catalog/Product/6ES7521-1BL00-0AB0	1

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23	Other - PLC DQ	SIMATIC DQ 32xDC 24V/0,5A, 6ES7522-1BL00-0AB0	Cabinet A1	https://mall.industry.siemens.com/mall/en/WW/Catalog/Product/6ES7522-1BL00-0AB0	1
24	Other - PLC AI	SIMATIC AI 8xU/I/RTD/TC ST, 6ES7521-1BL00-0AB0	Cabinet A1	https://mall.industry.siemens.com/mall/it/it/Catalog/Product/6ES7531-7KF00-0AB0	1
25	Other - PLC F DI	SIMATIC F-DI 16x 24 V DC PROFIsafe ,6ES7526-1BH00-0AB0	Cabinet A1	https://mall.industry.siemens.com/mall/it/it/Catalog/Product/6ES7526-1BH00-0AB0	1
26			Relays, switches, lamps, terminals, cables, plugs etc. not included		

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SCARA Electrical Cabinet Setup

20/3/2022

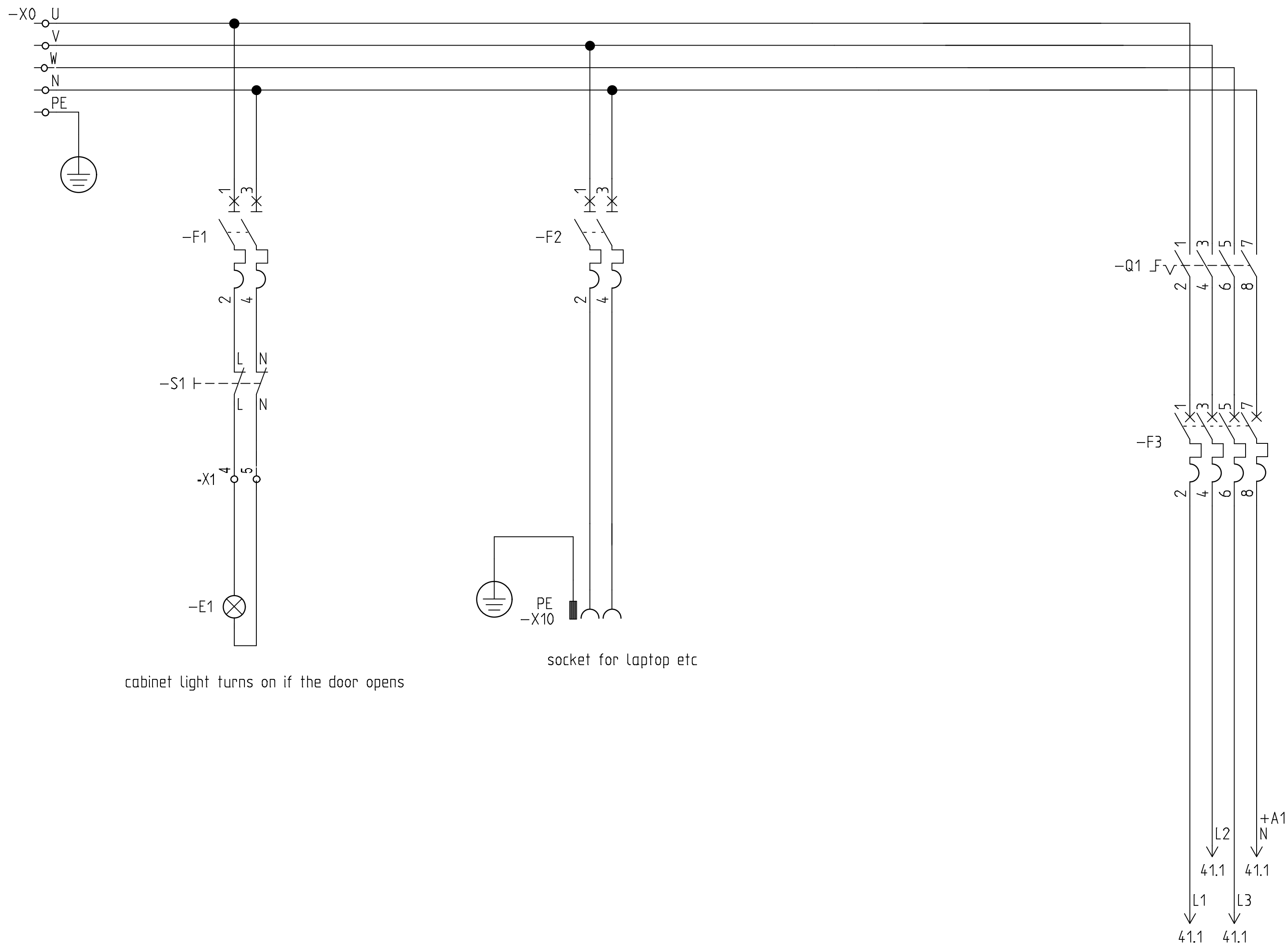
SCHOOL LICENCE

CABINET A1

SCHOOL LICENCE

Page numbers: Overview

SCHOOL LICENCE



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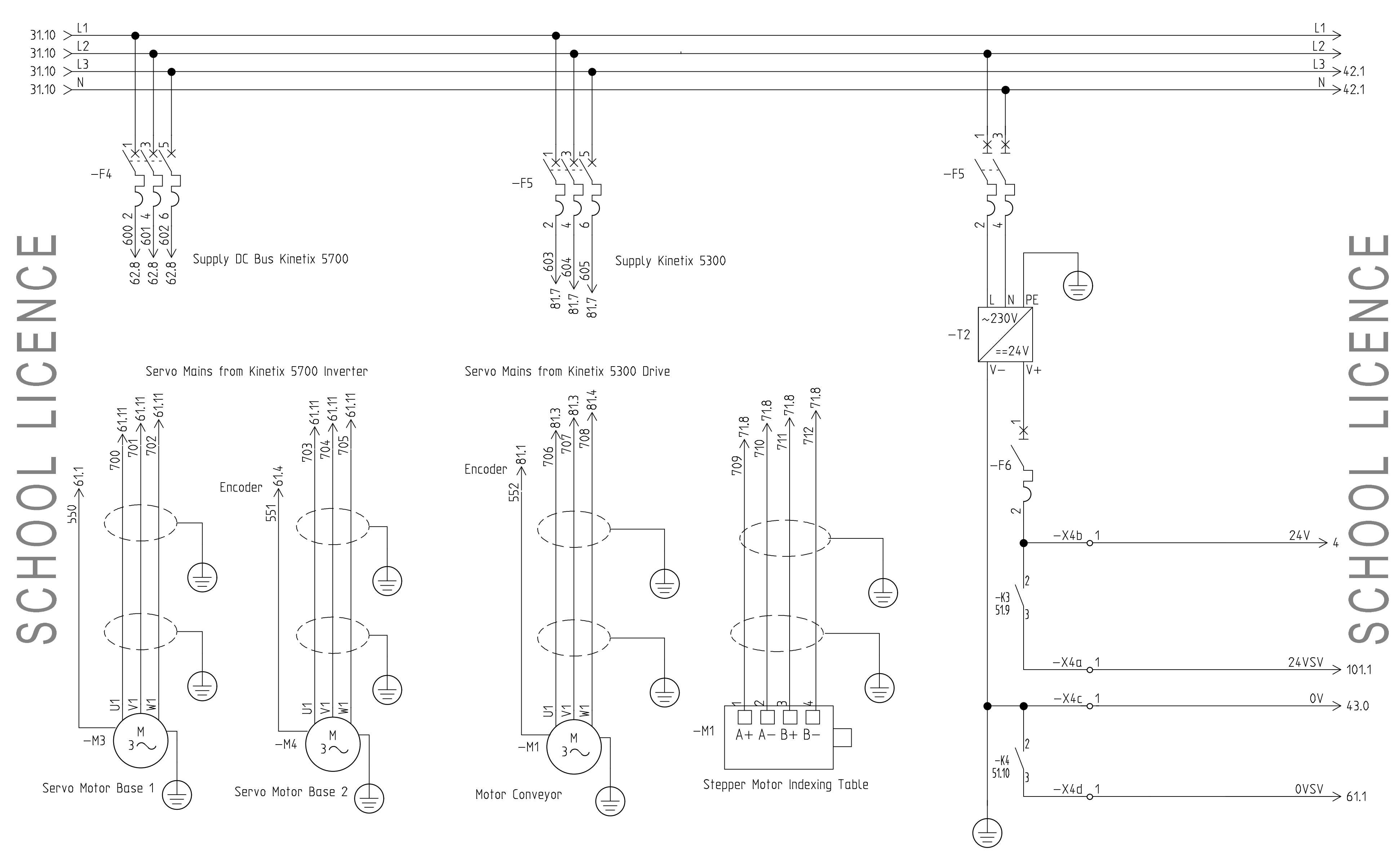

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Main circuits

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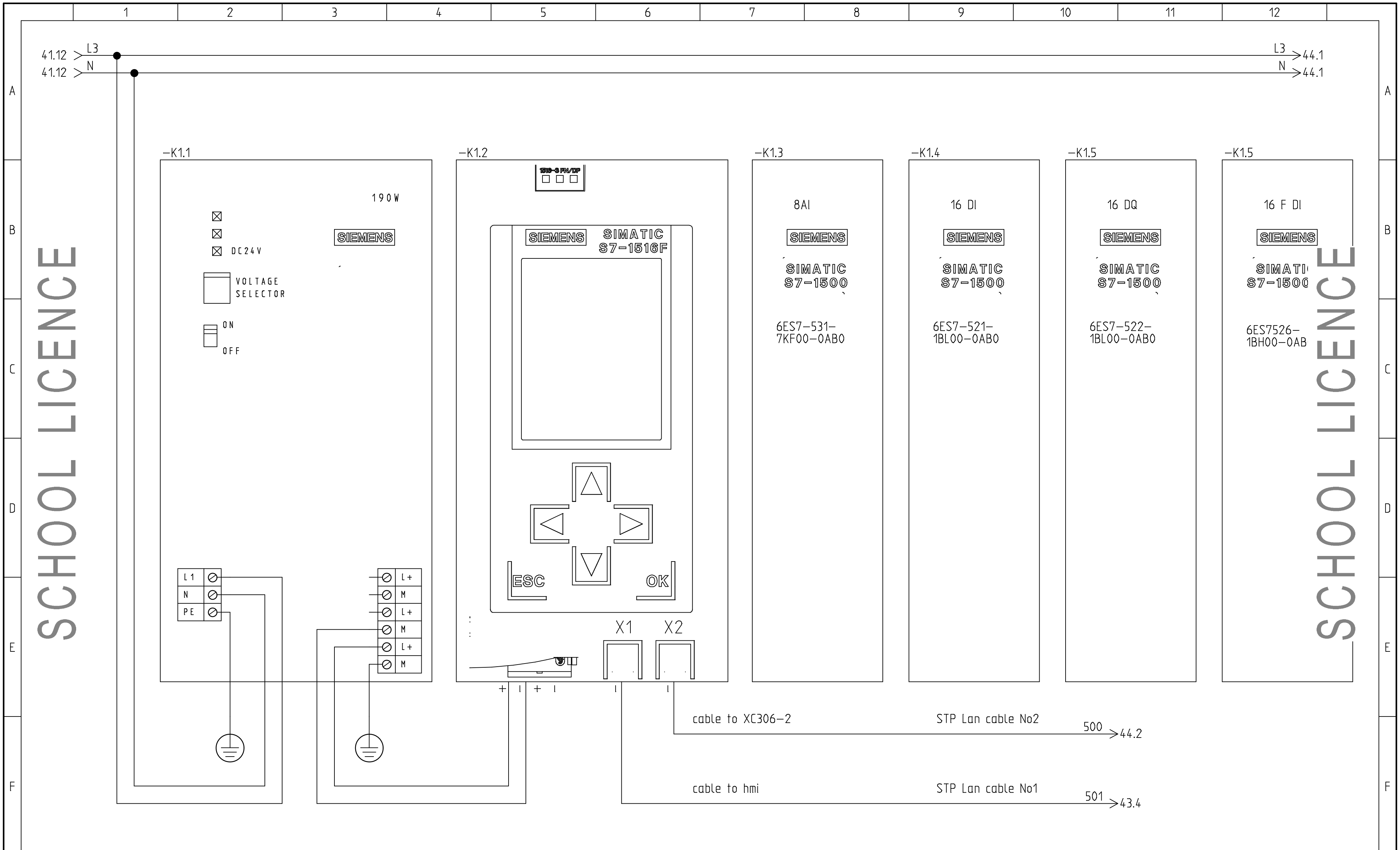

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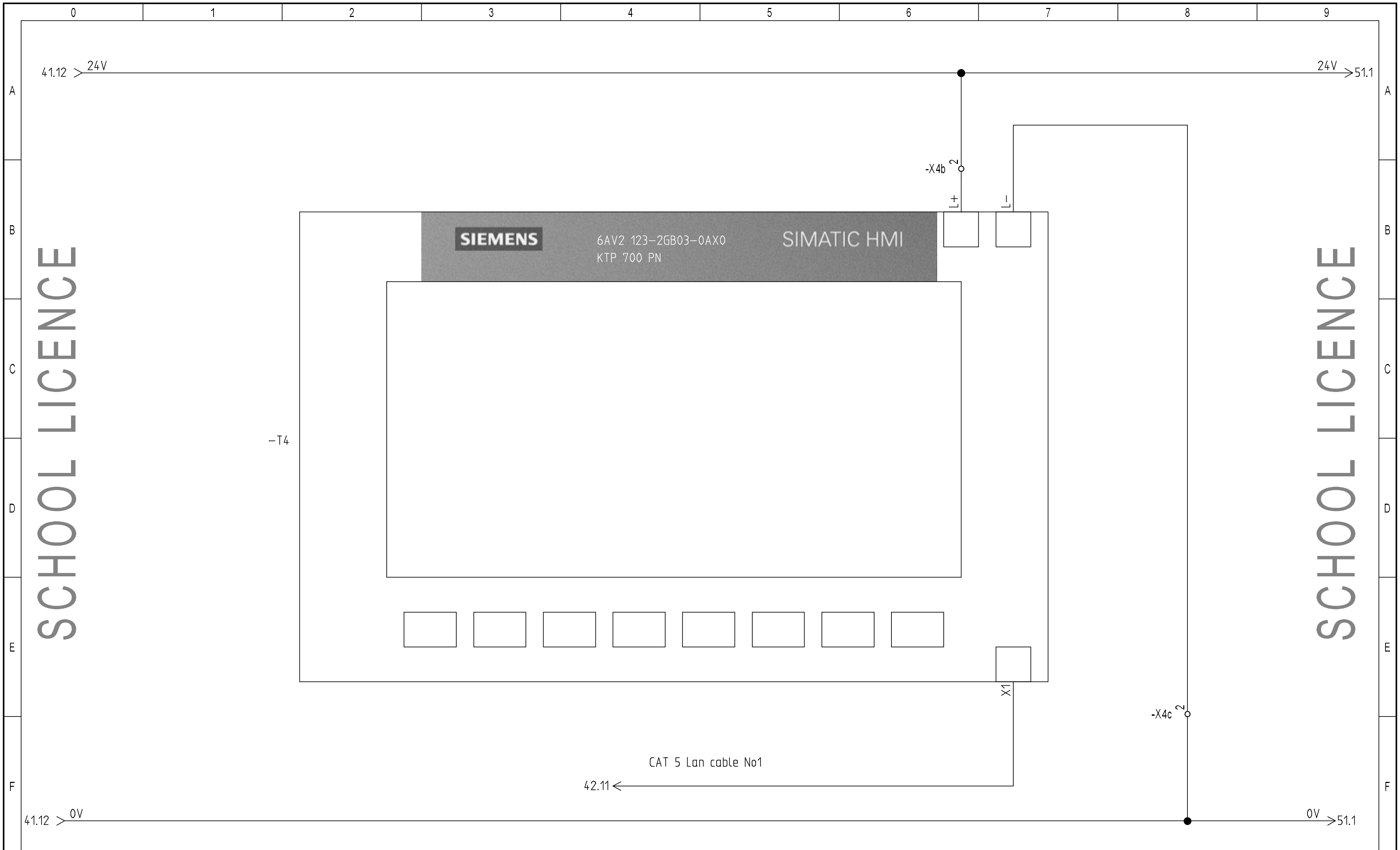

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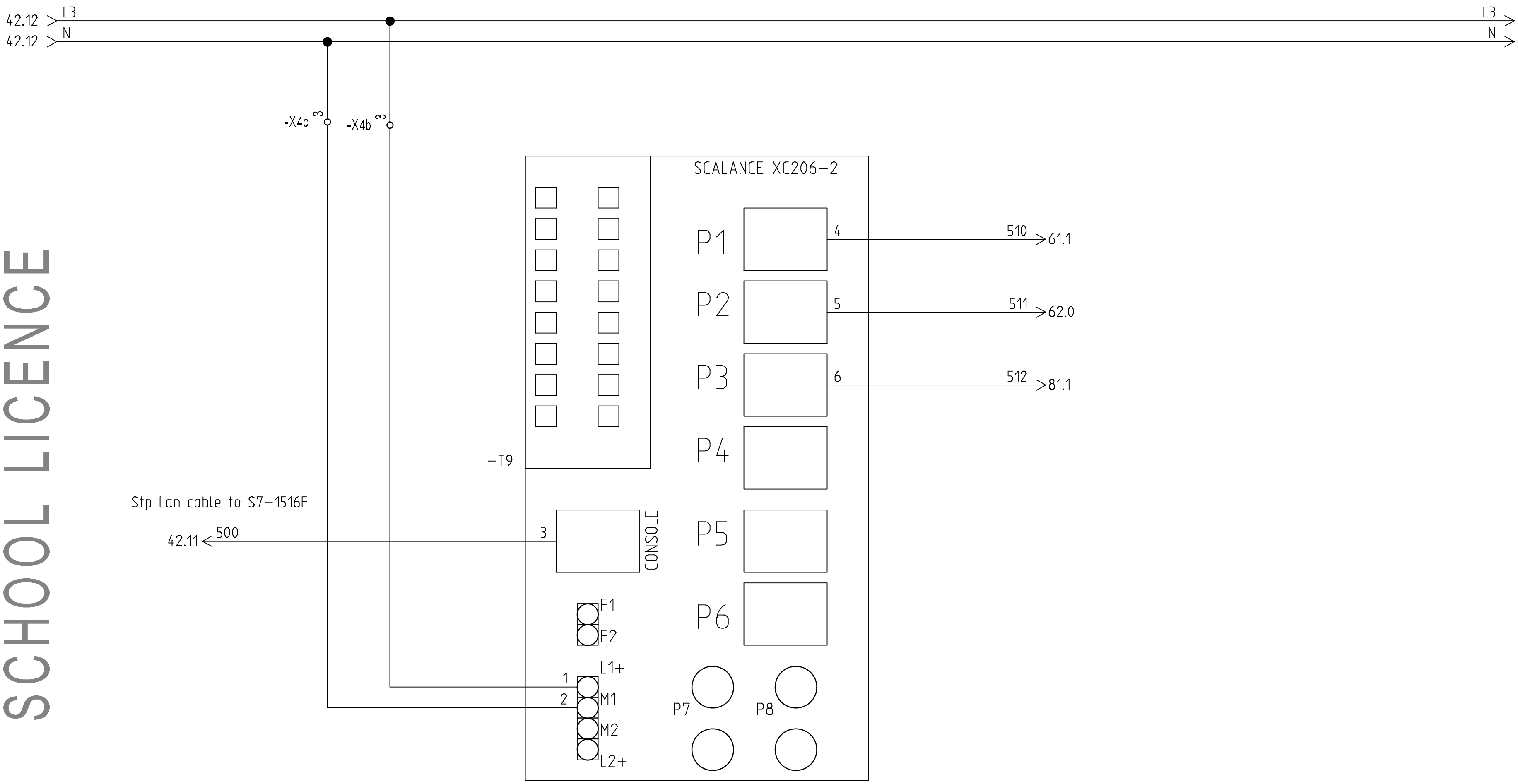

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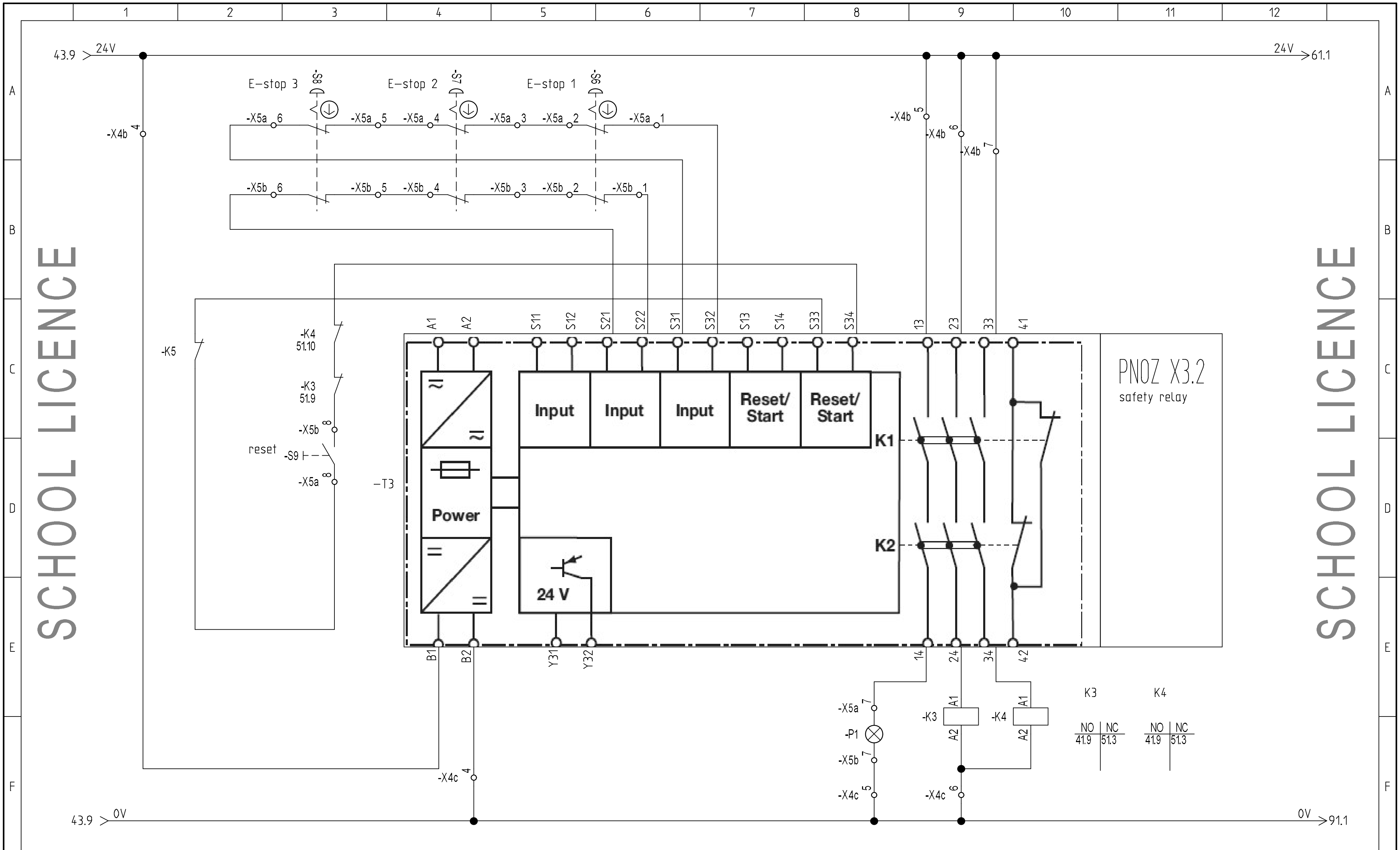

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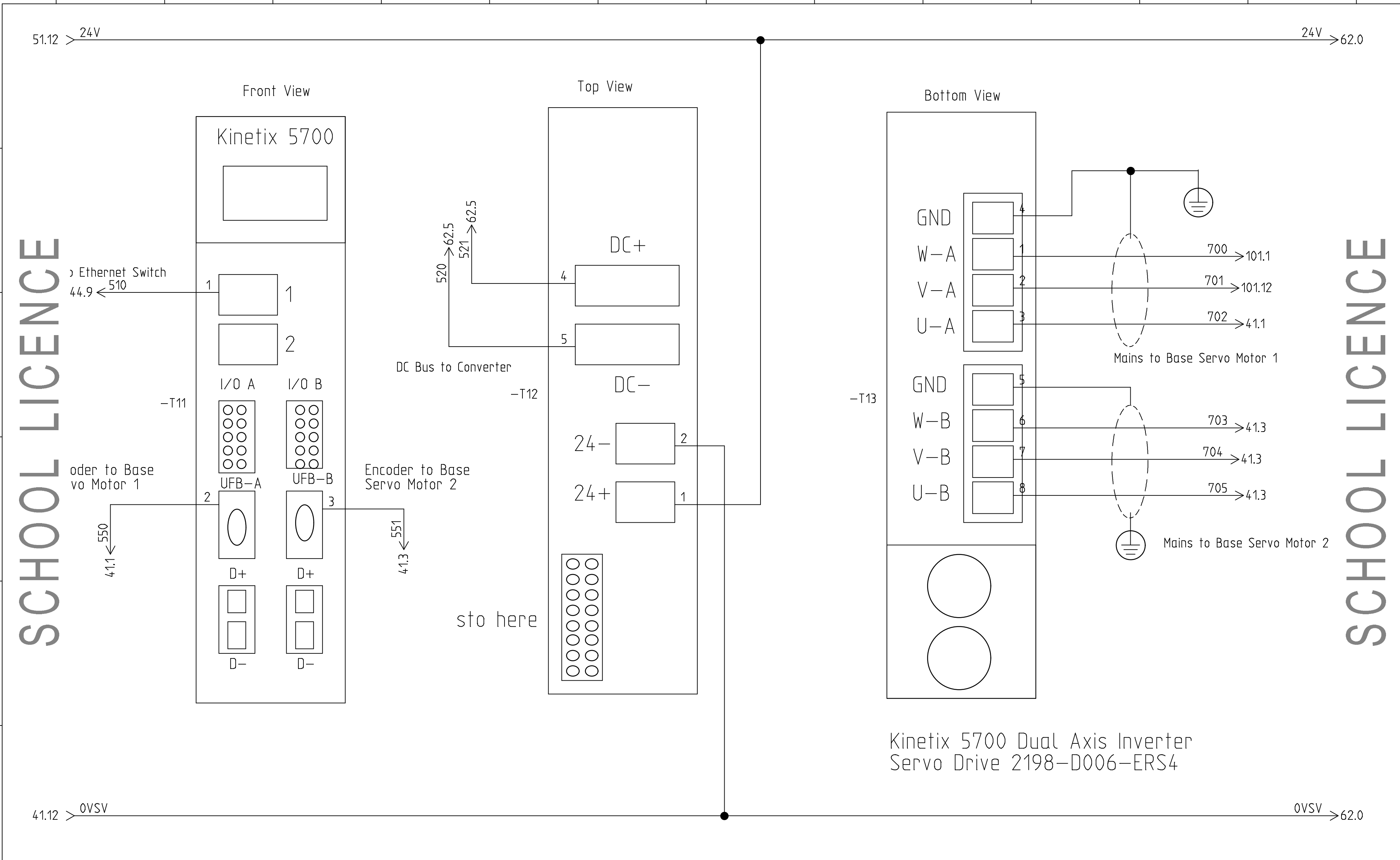

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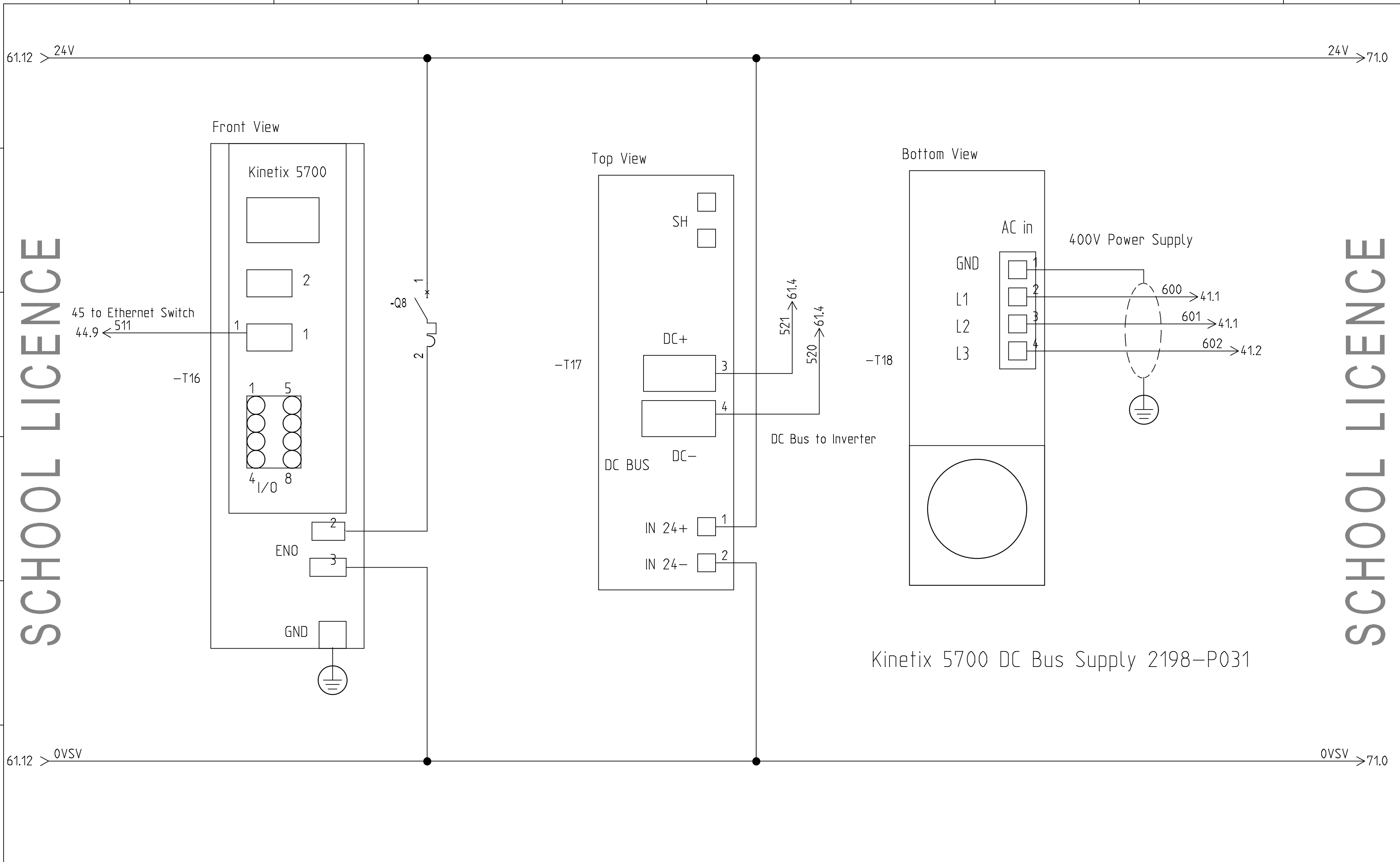

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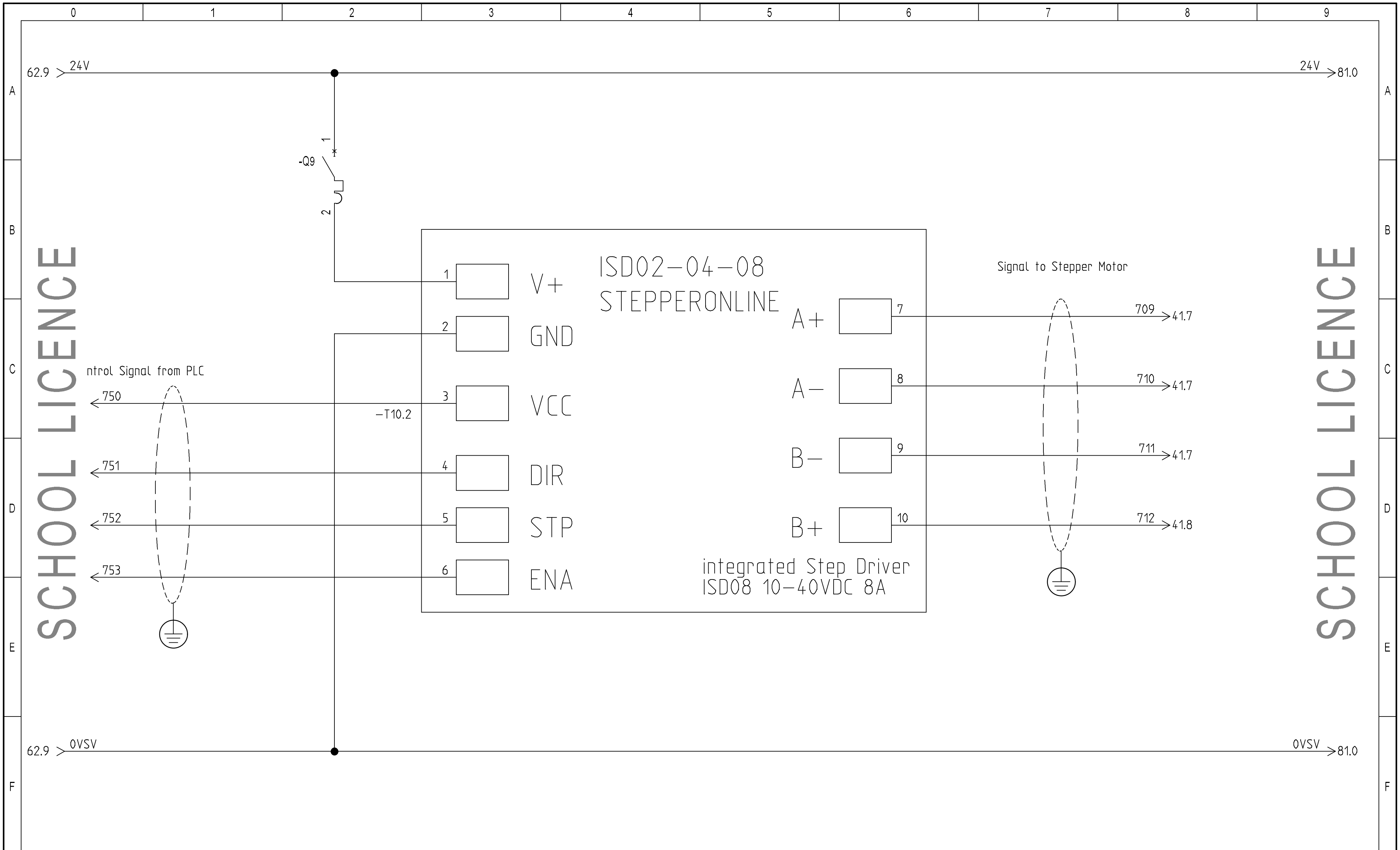

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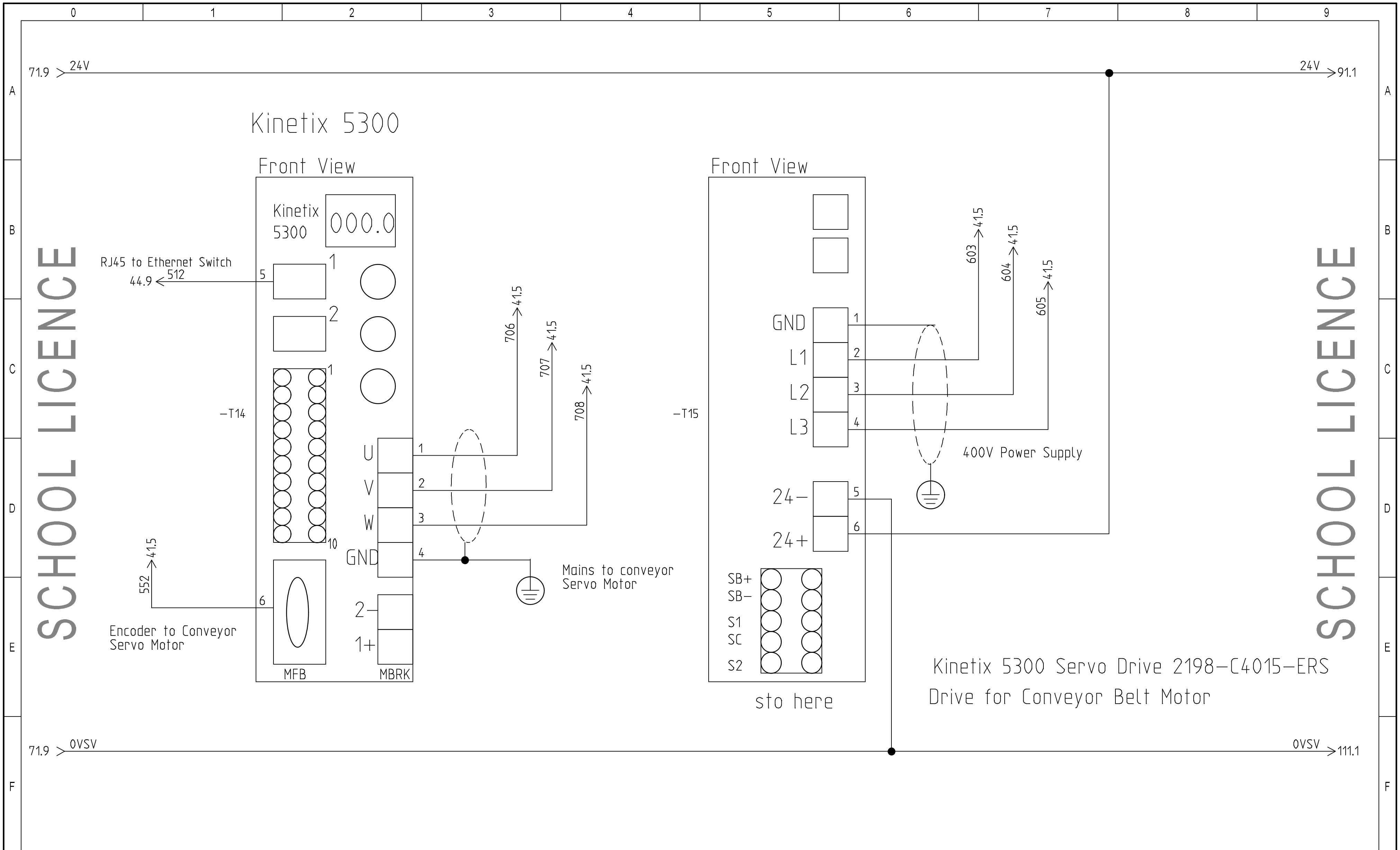

SCHOOL LICENCE

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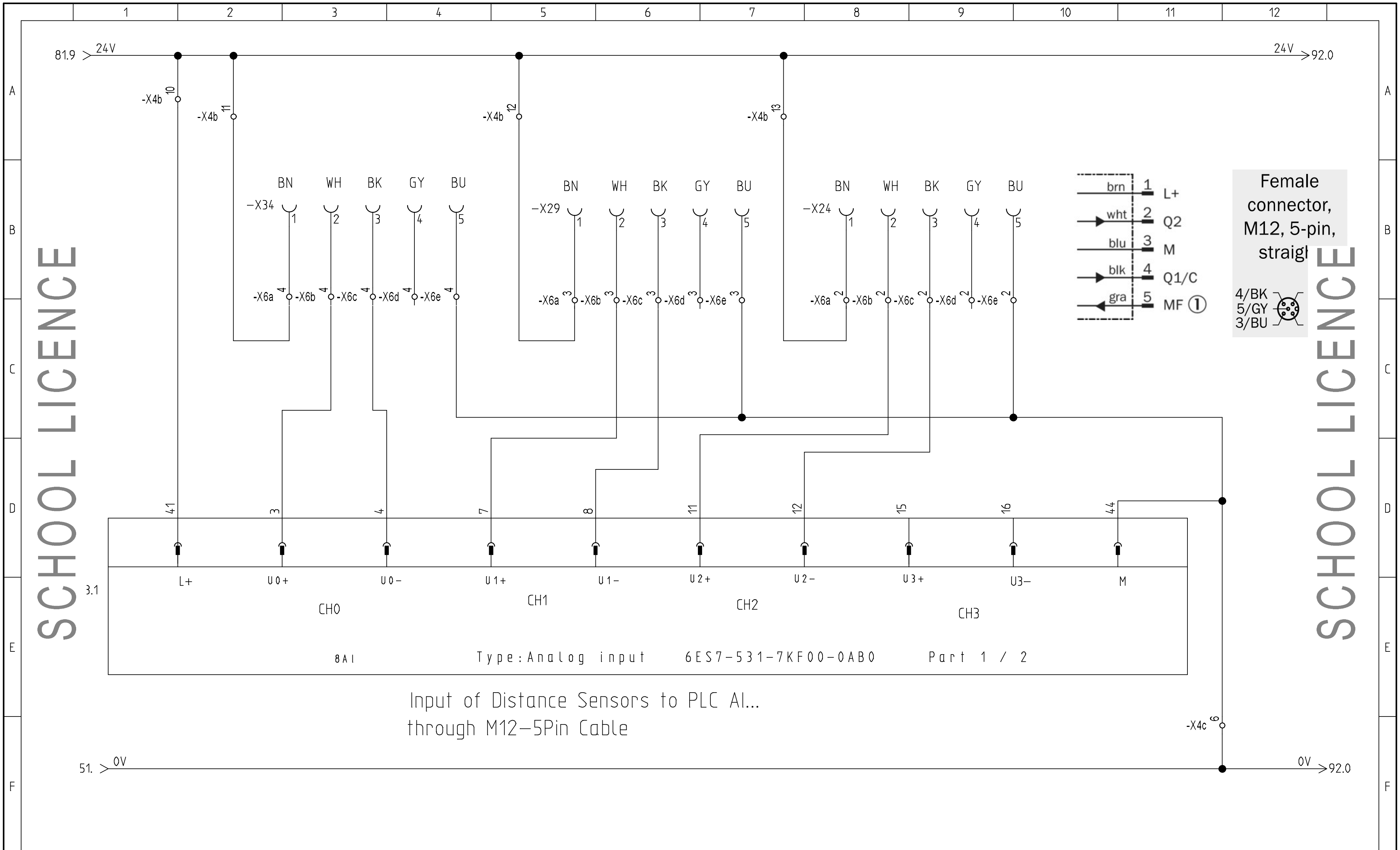

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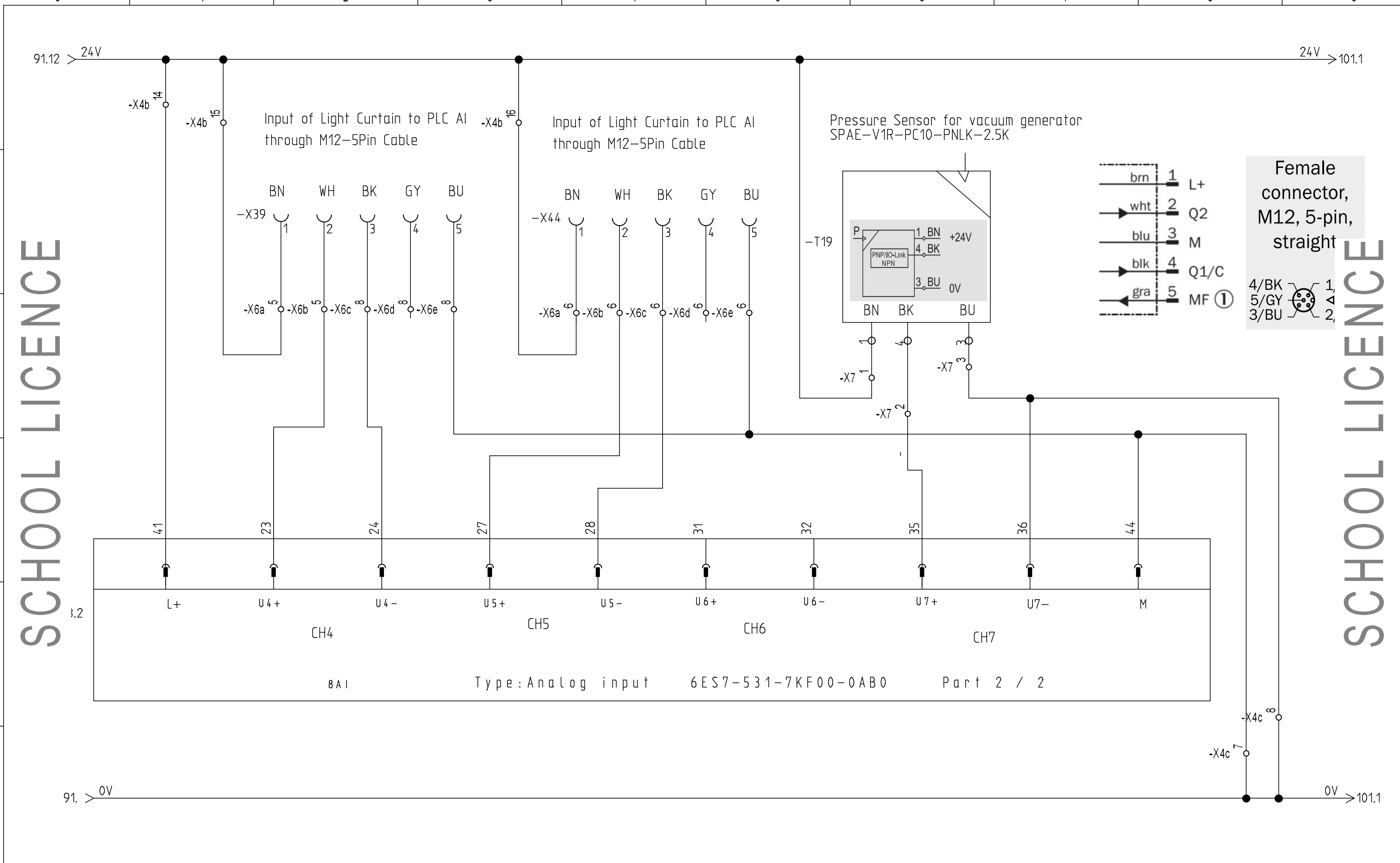

SCHOOL LICENCE

IGE+XAO

PLC AI

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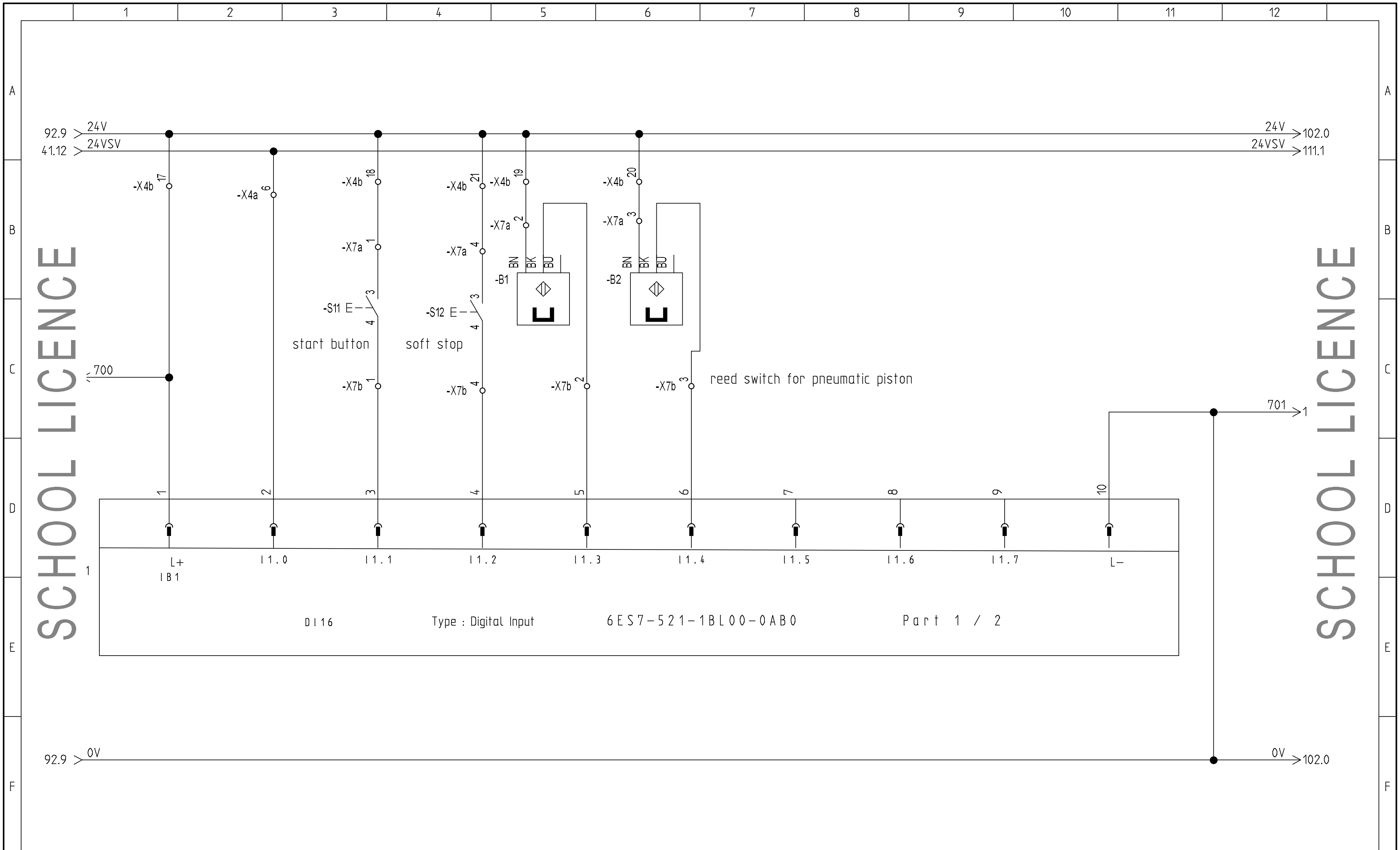

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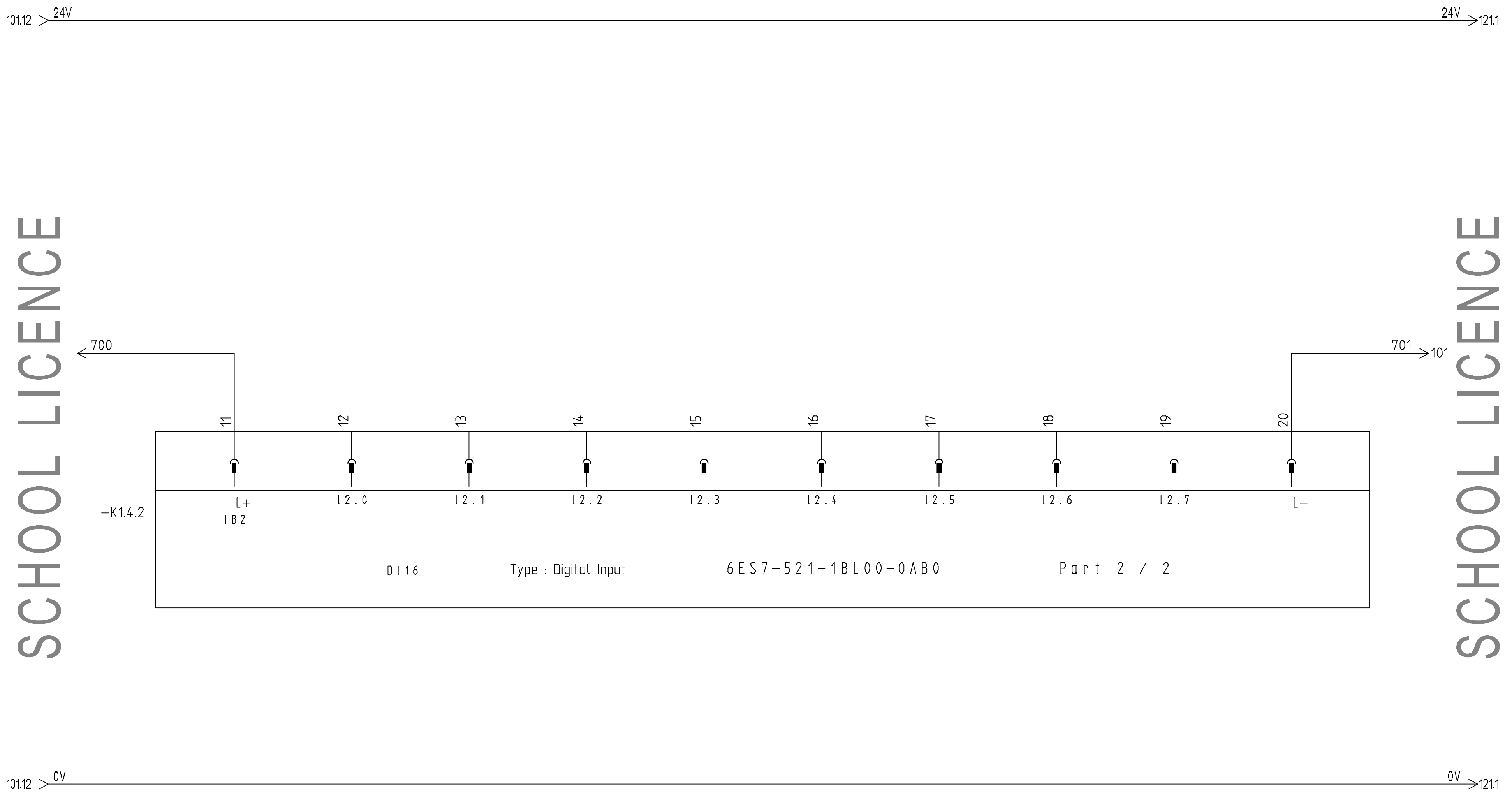

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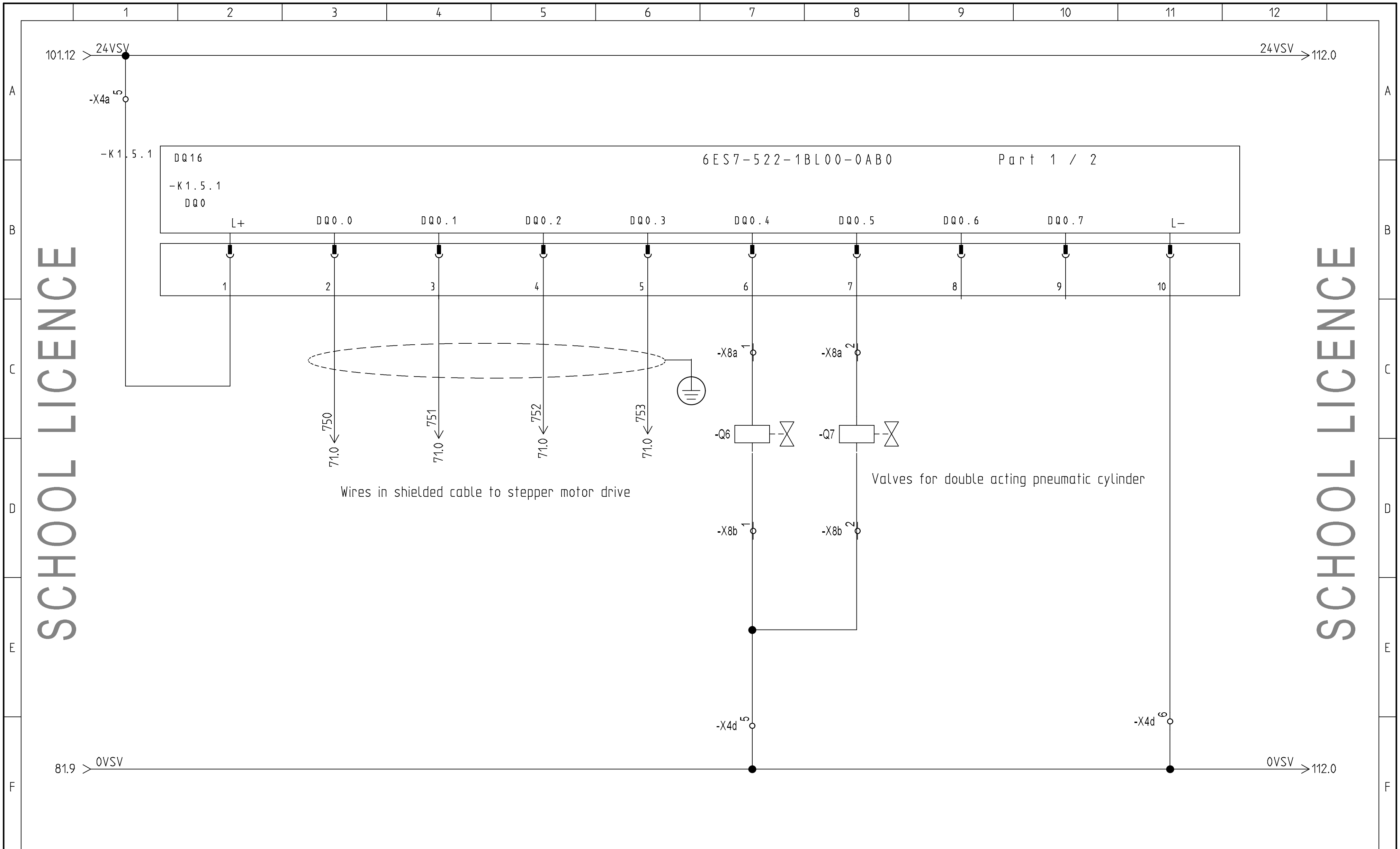

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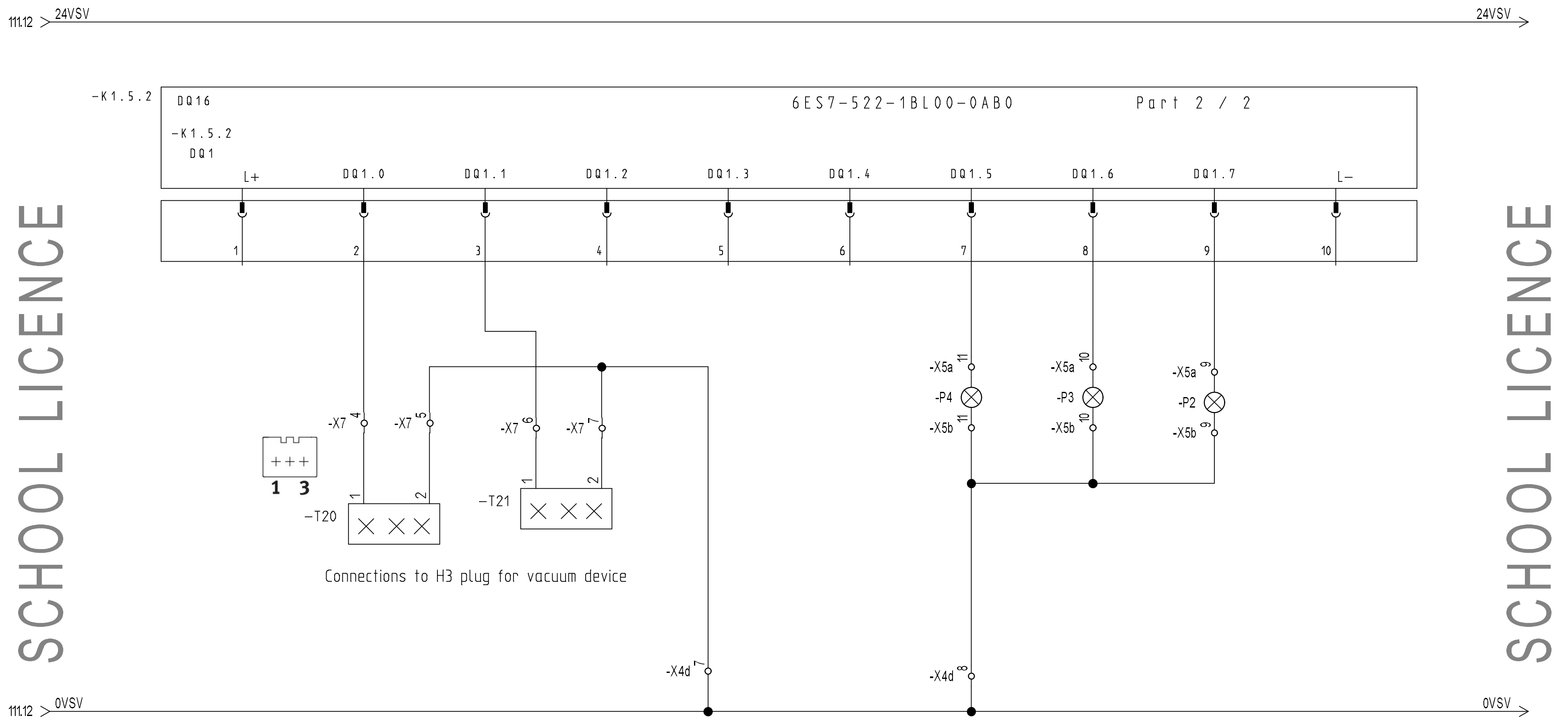

SCHOOL LICENCE

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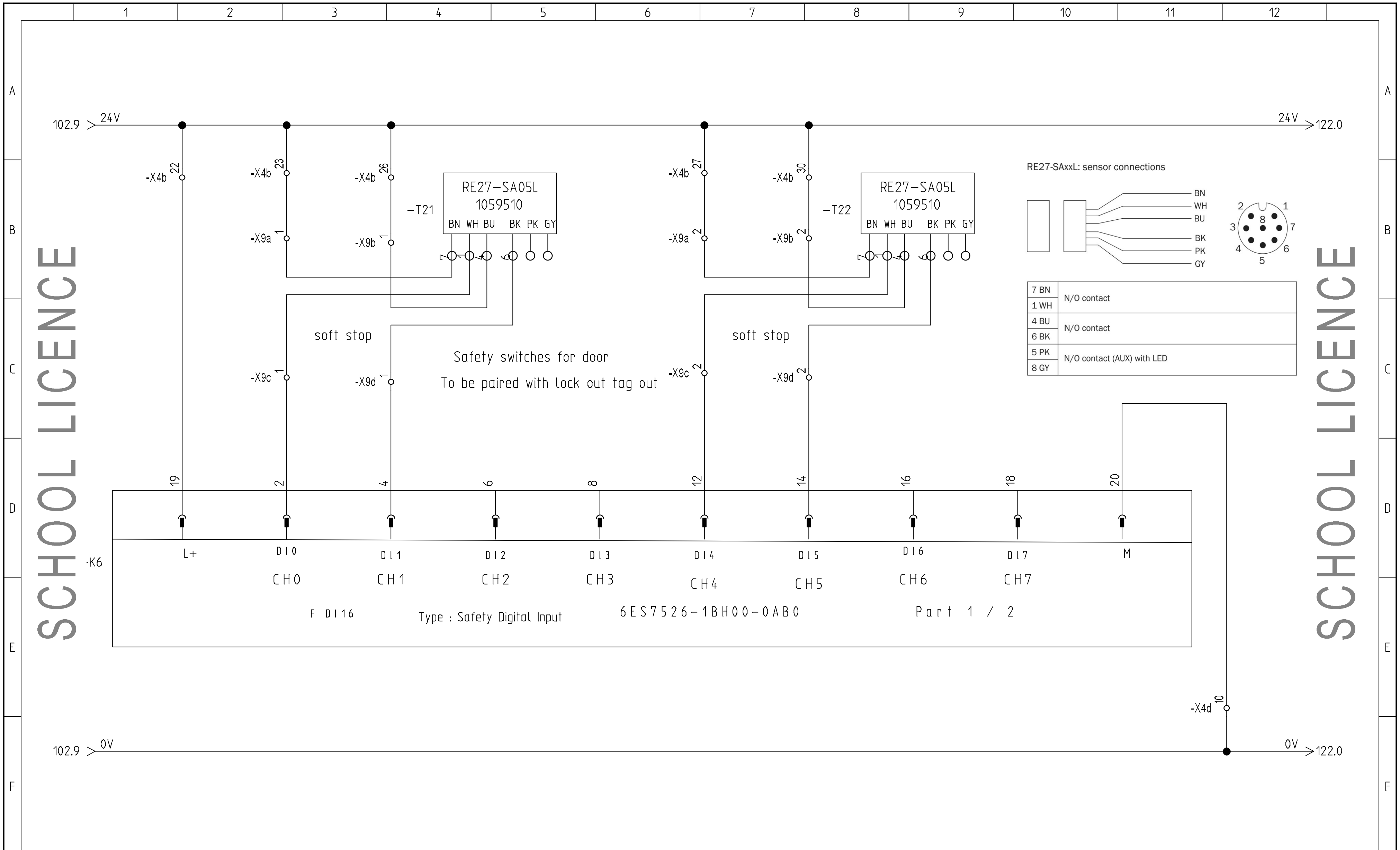

SCHOOL LICENCE

– Logo –

PLC F DI

Project: __SCARA__CTRL__Cabinet

Drawing no.:

Init.:

Rev.:

Sheet: 121

Date: 3/22/2023

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Total sheets: 21

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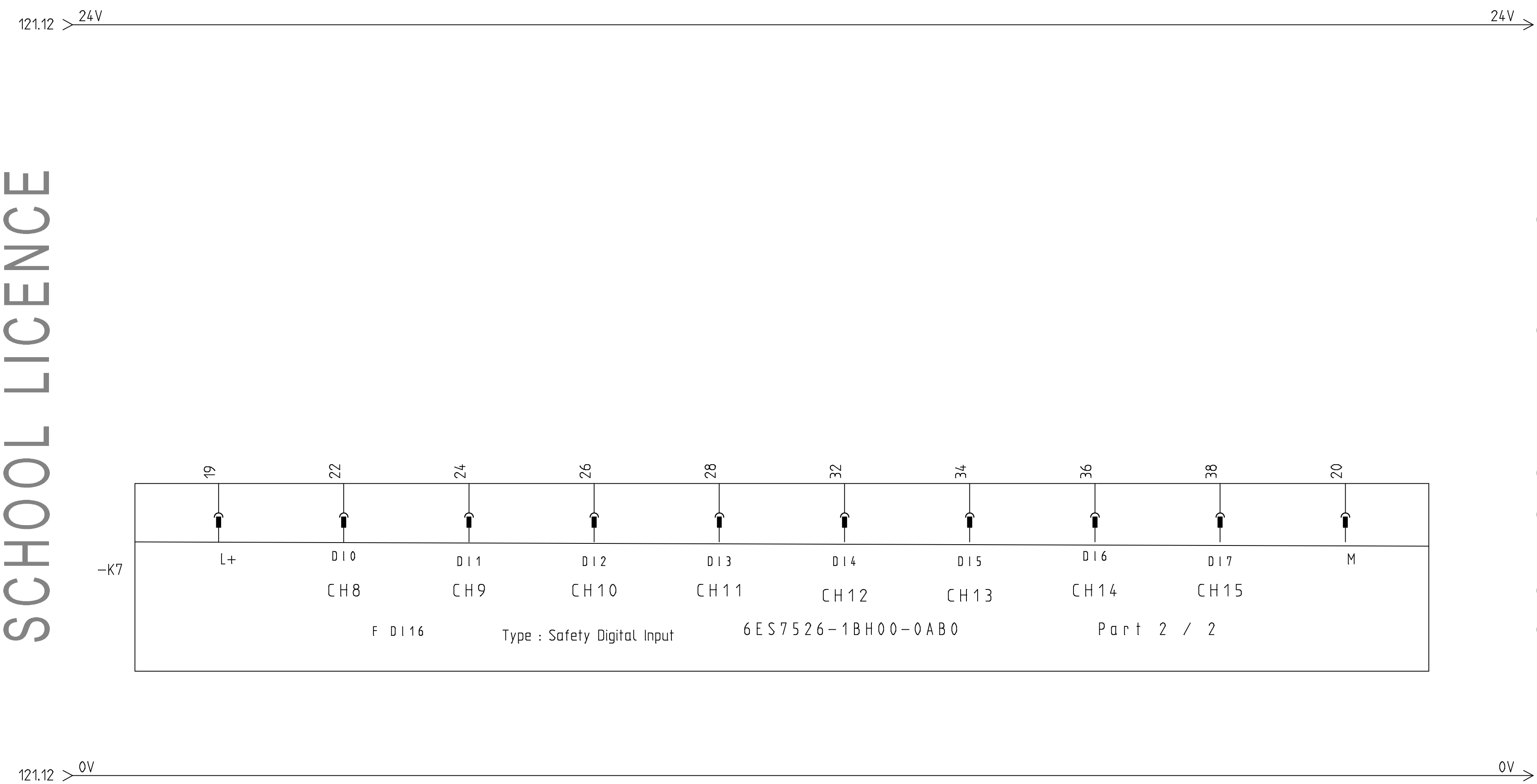

SCHOOL LICENCE

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PLC and digital twin

All of the relevant files, such as the TiA program and NX MCD model, are in the submitted zip file. It is important to mention that the goal of making a digital twin was to simplify the engineering process, such as using the MCD model to gain concrete load values within the system, as well as to verify the prototype. The goal was not to make a fully determined and an exact digital copy of the planned final robot. That means that elements like the distance sensors, or safety functions, are not programmed as those are not critical parts of the initial robot design. Rather some basic functionality is programmed to allow us to see how the arms behave in some basic scenarios which allows us to verify the overall arms design.

To run the digital twin, use PLCSIM Advanced to make a virtual PLC and make sure to name it “ParallelScara”. Afterwards, the HMI can be simulated and the simulation will run. The desired pattern can be input on the HMI. To restart the cycle, simply STOP the PLC and then RUN it again. If there are any problems, refer to the video from the first semester.

Lastly, it must be pointed out that the submitted ZIP file contains two CAD files, one used for the digital twin, which has certain standard components missing in order for the digital twin to run well, and one that has all of the components in it so the assembly is visually complete.

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Investigation Graphs

There are many aspects that could be investigated, however the most interesting one are the relation between required motor power and the loads. We can directly relate the motor power to costs as the larger the required power, the larger the costs for components that can deliver that power. The loads are then affected by three major components, the mass of the ball, the length of the arms, and speeds and accelerations. Hence it would be interesting to create a set of graphs, where each graph is for a specific cycle time, top speed and acceleration, and contains multiple curves, each curve for a specific mass of the ball. The x-axis would then be the length of the arms and the y-axis would be the required power. This way, many different combinations of reach, payload mass, and cycle time would be visualized.

Bibliography

[1] "Bearing Tolerances and Precision Levels," [Online]. Available: https://www.astbearings.com/bearing-tolerances-precision-levels.html.

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