FINAL THESIS (TFE)

Bachelor's degree in Industrial Electronics and Automatic Control Engineering

MACHINE PROGRAMMING AND DATA MONITORING

Thesis and Annexes

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Summons: June 202

Abstract

The rotary knife machine is commonly used in the industrial sector to cut or seal different type of products such as, for example, containers or cardboard boxes on a production line. For the correct operation of these machines, it's necessary to synchronize the slave axis (rotary knife) with the master axis (conveyor with products) so that the cutting or sealing is done at the right time.

In this thesis, the programming of a rotary knife machine is described and the correct operation is verified using a compact demo case. A library created by Omron called 'RK_SyncRotary' has been used. The following two operation modes have been demonstrated on the rotary knife machine: continuous mode and mark to mark mode. For the machine control, a Human Machine Interface device has been used. The reset and emergency stop buttons from the machine have been configured through the Safety controller. The production data of the machine are shared in JSON format with a web application using the MQTT protocol. The efficiency of the machine is displayed on a dashboard which is also accessible from a Smartphone or a Tablet via QR code.

Resumen

Las máquinas con cuchillas rotativas son ampliamente utilizadas en el sector industrial para cortar o sellar diferentes tipos de productos como pueden ser, por ejemplo, envases o cajas de cartón en una línea de producción. Para su correcto funcionamiento es necesario sincronizar el eje esclavo (cuchilla rotativa) con el eje maestro (cinta con productos) para que el corte o sellado se haga en el momento adecuado.

En esta tesis, se describe la programación de una máquina con cuchillas rotativas y se comprueba su correcto funcionamiento mediante el uso de una demo compacta. Se ha utilizado una librería llamada 'RK_SyncRotary' creada por Omron. Se demuestran dos modos de funcionamiento en la máquina de corte: modo continuo y modo corte por marcas. Para el control de la máquina se utiliza una interfaz gráfica para pantalla táctil. Los botones de reset y emergency stop de la máquina están configurados a través del controlador de Seguridad. Los datos de producción de la máquina son compartidos con una aplicación web en formato JSON mediante el uso del protocolo MQTT. La eficiencia de la máquina se visualiza en un tablero de datos al cual se puede también acceder desde un Smartphone o Tablet escaneando un código QR.

Resum

Les màquines amb ganivets rotatius són àmpliament utilitzades al sector industrial per tallar o segellar diferent tipus de productes com poden ser, per exemple, envasos o caixes de cartró en línies de producció. Per tal que aquest tipus de màquina funcioni correctament, cal sincronitzar l'eix esclau (ganivet rotatiu) amb l'eix mestre (cinta amb productes) per tal que el tall o segellat es faci en el moment adequat.

En aquesta tesi, es descriu la programació d'una màquina amb ganivets rotatius i se'n comprova el correcte funcionament mitjançant l'ús d'una demo compacta. S'ha fet servir la llibreria anomenada 'RK_SyncRotary' creada per Omron. Es demostren dos modes de funcionament a la màquina de tall: mode continu i mode tall per marques. Per al control de la màquina es fa servir una interfície gràfica per a pantalla tàctil. Els botons de reset i emergency stop de la màquina estan configurats a través del controlador de seguretat. Les dades de producció de la màquina són compartides en format JSON amb una aplicació web mitjançant l'ús del protocol MQTT. L'eficiència de la màquina es visualitza en un tauler de dades al qual es també possible accedir des d'un Smartphone o Tablet escanejant un codi QR.

Acknowledgements

To Jennifer, my wife, who has been by my side through good and bad times during my bachelor's degree.

Glossary

Hereunder it's described the list of acronym names used along this thesis. This section can be considered as a brief dictionary:

- E-STOP: Emergency Stop
- FB: Function Block
- HMI: Human Machine Interface
- I/O: Input/Output
- IoT: Internet of Things
- IT: Information Technologies
- PE: Protective Earth
- RK: Rotary Knife
- VAC: Voltage Altern Current
- VDC: Voltage Direct Current

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1. Introduction

1.1. Thesis objective

In recent years, all industrial packaging processes are being automated. The rotary cutting machine is part of the packaging process and is commonly used in the industrial sector to cut or seal different type of products such as, for example, plastic containers, cardboard boxes or labelling operations on a production line.

In this kind of machine, the product to be processed is delivered by the master axis (conveyor) and is cut or sealed by the slave axis (rotary knife).

The main objective of this thesis is to simulate a real rotary knife machine using a compact demo case and show the efficiency of the machine and the production data with a real-time Dashboard.

The main topics that cover this thesis are:

- Programming the machine: Motion (2 axes synchronization) and Safety (Reset, E-Stop).
- Use of the 2 different communication layers: EtherNet/IP (Factory level) and EtherCAT (Machine level).
- Control of the machine with the Human Machine Interface (HMI).
- Conversion of the NJ-series machine controller variables to JSON format for sharing them with a web application (Dashboard) using the MQTT protocol.
- OEE (Overall Equipment Effectiveness) and production data visualization with a real-time Dashboard.
- Access to the Dashboard with a Smartphone or a Tablet via QR code.

2. System setup

2.1. Hardware

The compact demo case used for the simulation of the rotary knife machine contains different hardware that has been used to program and test the application of this thesis. The most important ones are:

- Omron NJ-series is a machine controller for logic sequence, safety, and motion. The NJ has 2 different ports for communications: EtherNet/IP (Factory level) and EtherCAT (Machine level). As an option, there are models with other features: DB connection, OPC UA, Robotics and CNC.

Figure 2.1.1. Omron NJ-series machine controller (source: [1]).

- Omron NA-series HMI is the Human Machine Interface touchscreen enabling faster control and monitoring. In this thesis, the 9-inches model has been used to control the machine.

Figure 2.2.2. Omron NA-series HMI (source: [1]).

- Omron G5-series servo system comes with EtherCAT built-in communications and provides safety conforming ISO13849-1 PLd. In this thesis, 2 units of 100 W servo system with incremental encoder have been used for the control of the 2 axes: master axis (conveyor) and slave axis (rotary knife).

Figure 2.3.3. Omron G5-series servo system (source: [1]).

- Omron NX-series is a remote I/O system synchronized with the Distributed Clock of the EtherCAT network (Machine level). The Safety CPU allows safety connection using Safety over EtherCAT (FSoE) protocol.

Figure 2.4.4. Omron NX-series I/O and safety (source: [1]).

- Westermo MRD-305-DIN is an industrial router that uses the Internet to inter-connect systems, allowing HMI, PLCs, sensors, etc.… to communicate with each other.

Figure 2.5.5. Westermo MRD-305-DIN industrial router (source: [3]).

The ubication of the different devices in the demo case is shown in the following picture:

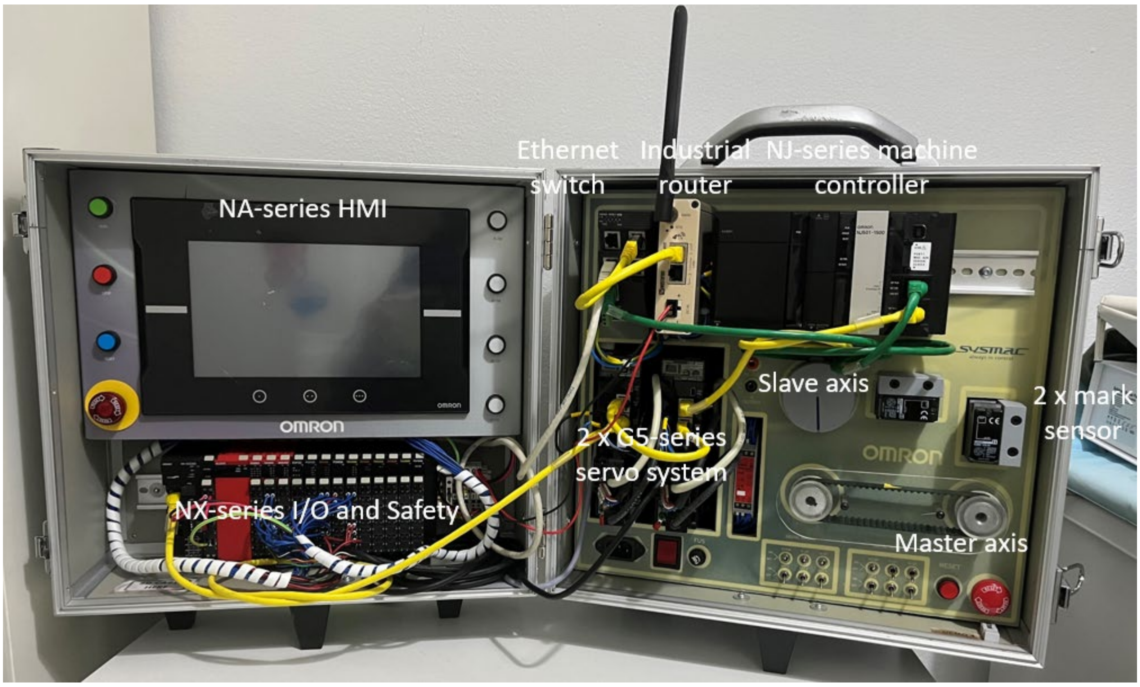

Figure 2.6.6. Demo case used in the thesis (source: own).

2.2. Software

The Sysmac Studio tool is the software used in this thesis. It provides an Integrated Development Environment (IDE) integrating Logic, Motion, Robotics, HMI, Vision, Sensing, Safety and 3D simulation in one single software platform to setup, program, debug and maintain Omron NX/NJ machine controllers. Sysmac Studio is fully compliant with the open standard IEC 61131-3 and supports Ladder, Structured Text (ST), and Function Block programming.

The software version used in this thesis is the Sysmac Studio v1.47.

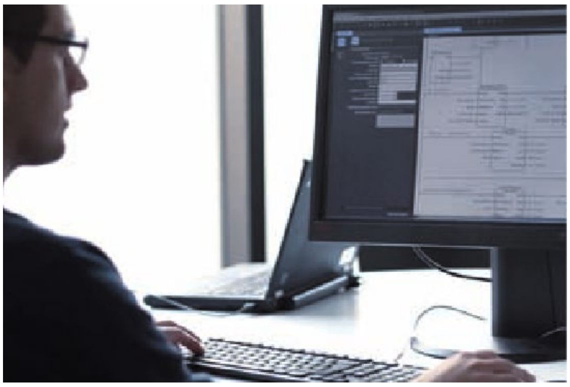

Figure 2.2. Sysmac Studio software tool (source: [1]).

2.3. Communications architecture and electrical connections

The communication between the machine controller, the servo system and the remote I/O terminal is through the EtherCAT Fieldbus (Machine level). For the communication between the machine controller, the HMI and the industrial router, the EtherNet/IP Fieldbus has been used (Factory level). The NJ-series machine controller has 2 different communication ports and is the responsible for handling the two-communication Fieldbus (EtherCAT and EtherNet/IP).

Ethernet and EtherCAT cables are category 6 (Cat 6), standardized twisted pair cable achieving 250 MHz.

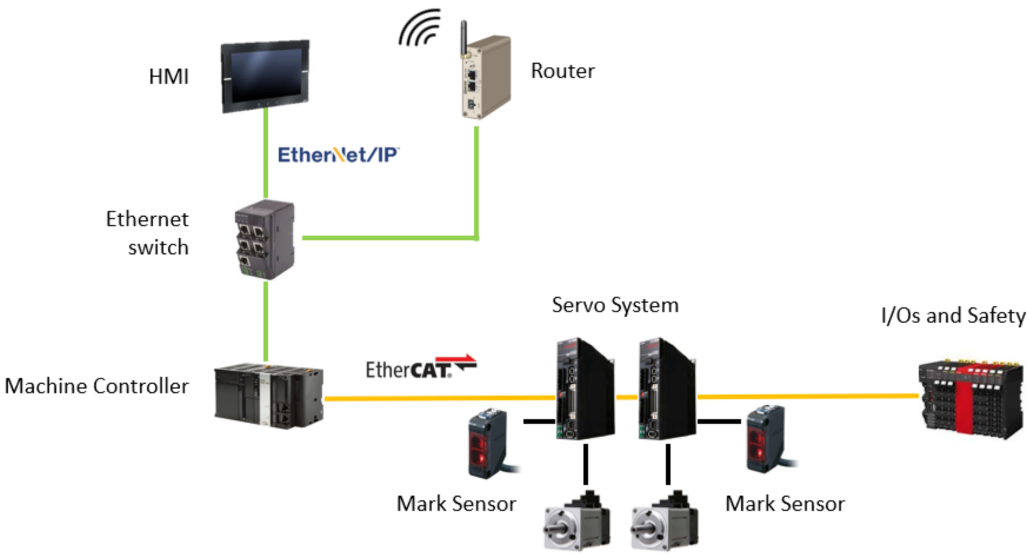

Figure 2.3. Communications architecture based on EtherCAT and EtherNet/IP (source: own).

The machine controller, servo drives and 24 VDC power supply are powered with 230 VAC. The HMI, Ethernet switch, remote I/O terminal and servo drives (CN1 terminal for I/O signals) are connected to the 24 VDC power supply.

The mark sensors are connected to the servo drives.

Refer to the 'Annex C: Wiring Diagrams' to see the detailed connections of the demo case.

2.4. Simulation with the demo case

A compact demo case is used to simulate a real rotary knife machine. In this kind of machines is necessary to synchronize the slave axis with the master axis so that the cutting or sealing is done at the right time. The demo case includes 2 axes for it, the slave axis (rotary knife with one blade) and the master axis (conveyor with marks to cut). In the conveyor there are some marks to simulate the products.

Each axis has its own mark sensor:

- **Slave axis (rotary knife):** The mark sensor is used for the Homing operation (cutting position) of the servo motor.
- **Master axis (conveyor):** The mark sensor is used to detect the products when the 'Mark to mark' working mode is selected.

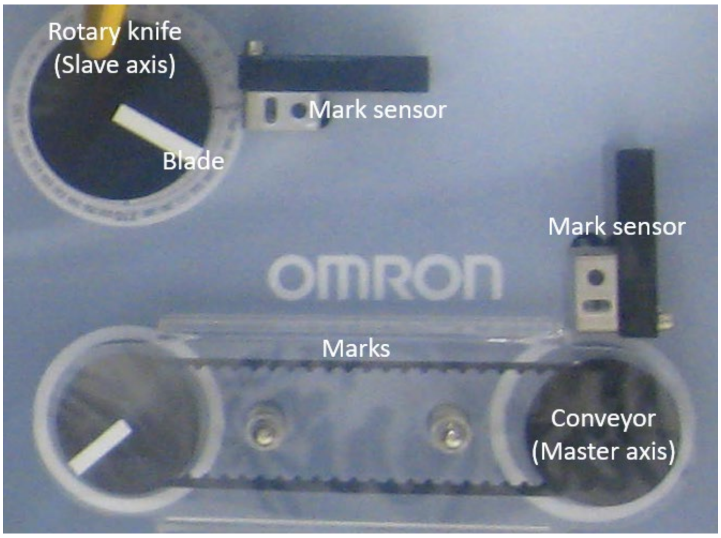

Figure 2.4.1. Details of demo case used in the thesis (source: own).

The rotating direction of the servo motors is as follows to ensure the product is correctly cut:

- **Slave axis (rotary knife):** Clockwise (CW) direction.
- **Master axis (conveyor):** Counterclockwise (CCW) direction.

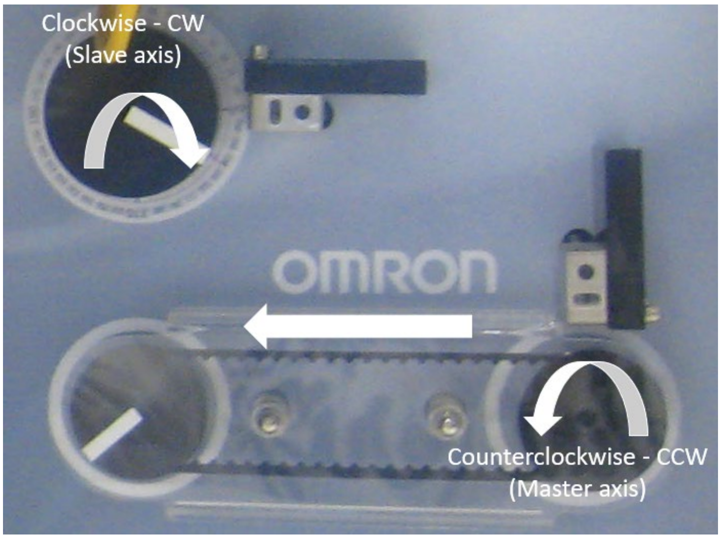

Figure 2.4.2. Rotating direction of the servo motors (source: own).

3. Sysmac Studio configuration

3.1. EtherCAT network

The EtherCAT network (Machine level) used in the demo case has been configured in the Sysmac Studio software tool:

- **Node 1:** G5 servo drive 1 (slave axis – rotary knife)
- **Node 2:** G5 servo drive 2 (master axis – conveyor)
- **Node 3:** NX-series EtherCAT communication coupler

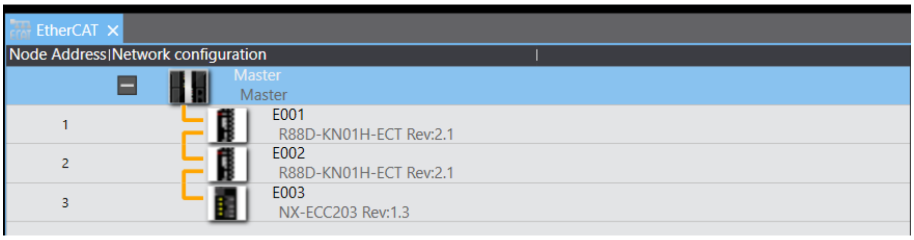

Figure 3.1. EtherCAT configuration (source: own).

3.2. Ethernet network

The IP address of the demo case devices connected to Ethernet (Factory level) has been defined in the Sysmac Studio software tool:

- **NJ-series machine controller IP address:** 192.168.250.1
- **Gateway:** 192.168.250.3 (industrial router IP address)

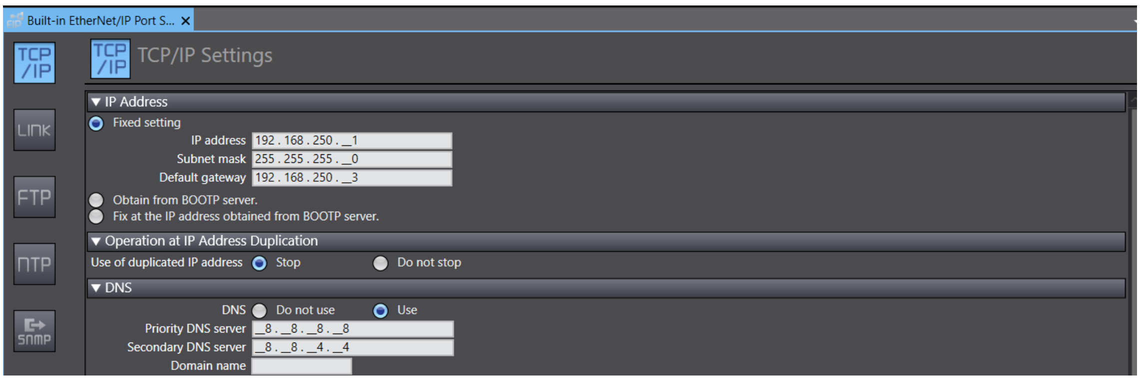

Figure 3.2.1. Details of the NJ-series machine controller IP address (source: own).

- **NA-series HMI IP address:** 192.168.250.2

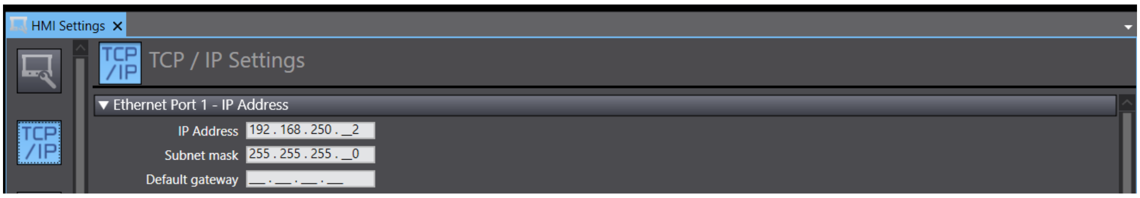

Figure 3.2.2. Details of the NA-series HMI IP address (source: own).

- **PC (Laptop) IP address:** 192.168.250.5

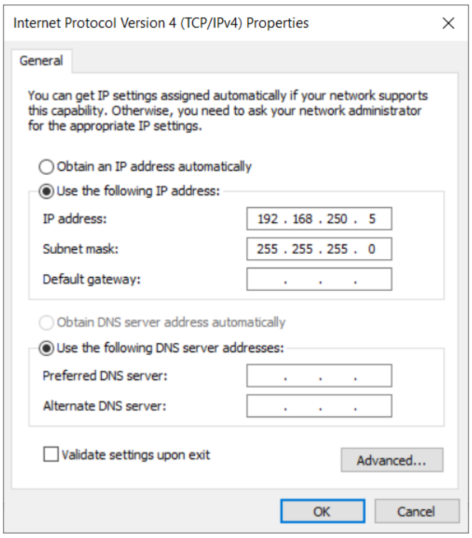

Figure 3.2.3. Details of the PC (Laptop) IP address (source: own).

IP	Device	Picture
192.168.250.1	NJ5 machine controller	
192.168.250.2	NA HMI	
192.168.250.3	Westermo MRD-405 router	
192.168.250.5	PC (Laptop)	

Table 3.2. Summary of IP addresses.

3.3. Servo drives

3.3.1. G5 servo drive 1

The G5 servo drive 1 (EtherCAT node 1) is connected to the slave axis (rotary knife). As defined in the section '2.4. Simulation with the demo case', the rotation direction of the rotary knife is Clockwise (CW). It is specified in the servo drive parameters.

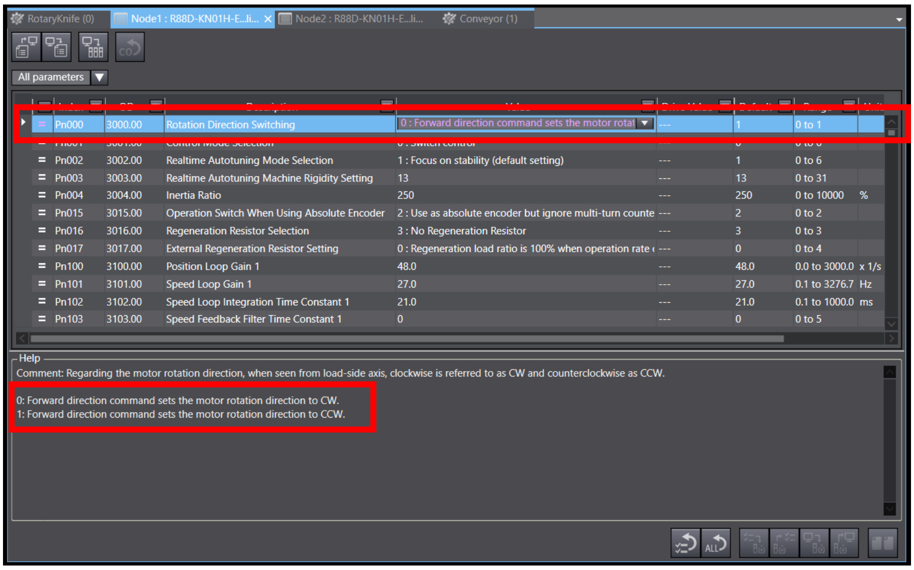

Figure 3.3.1. Details of the rotation direction of the rotary knife (source: own).

3.3.2. G5 servo drive 2

The G5 servo drive 2 (EtherCAT node 2) is connected to the master axis (conveyor). As defined in the section '2.4. Simulation with the demo case', the rotation direction of the conveyor is Counterclockwise (CCW). It is specified in the servo drive parameters.

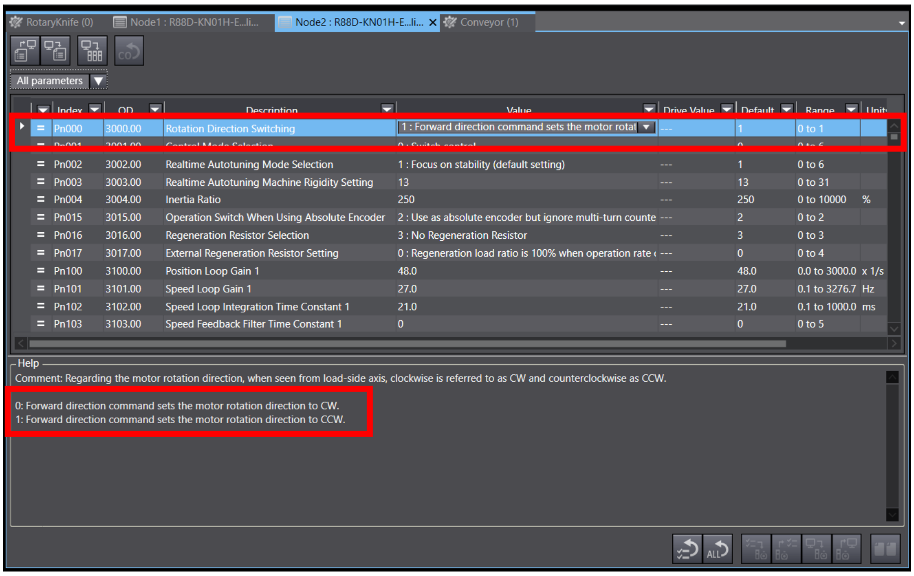

Figure 3.3.2. Details of the rotation direction of the conveyor (source: own).

3.4. Axis

3.4.1. Slave axis (rotary knife)

Axis basic settings: The following settings have been defined in Sysmac Studio:

- **Axis number:** 0
- **Axis type:** Servo axis
- **Output device:** G5 servo drive 1 (EtherCAT node 1)

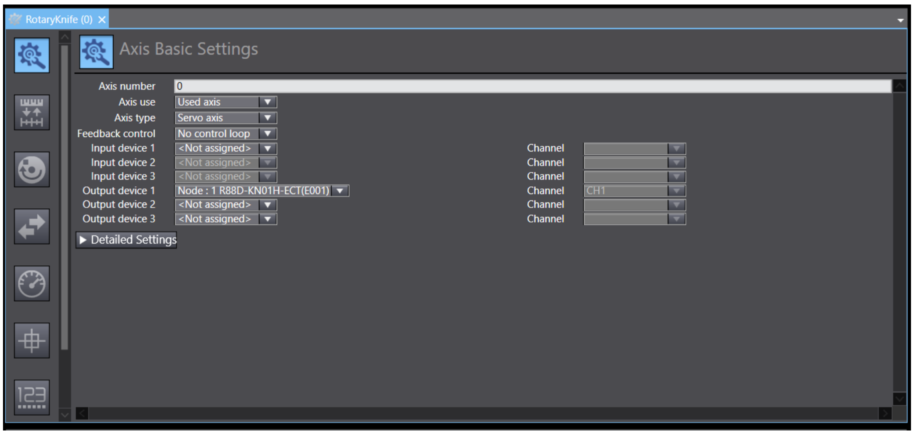

Figure 3.4.1.1. Details of the axis basic settings (source: own).

Unit conversion settings: The following settings have been defined in Sysmac Studio:

- **Unit:** mm
- Without gearbox
- **Command pulse count per motor rotation:** 1,048,576 pulse/rev[*1]
- **Work travel distance per motor rotation:** 188.4 mm/rev[*2]

[*1] 20-bit incremental encoder: 2^20 = 1,048,576 pulse/rev.

[*2] Perimeter of the rotary knife: 60 mm * π = 188.4 mm.

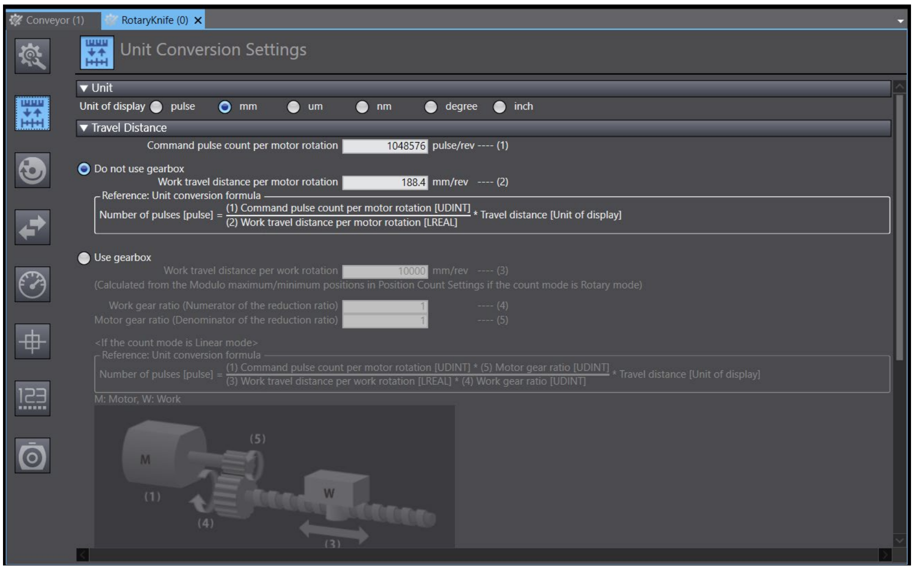

Figure 3.4.1.2. Details of the unit conversion settings (source: own).

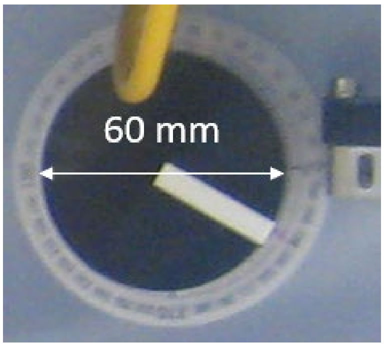

Figure 3.4.1.3. Details of the rotary knife perimeter (source: own).

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Home settings: The following settings have been defined in Sysmac Studio:

- **Home input signal:** Use external home input*1
- **Homing velocity:** 500 mm/s
- **Homing compensation value:** 45 mm*2

*1 The motor will use the mark sensor position for the homing operation.

*2 Distance between the mark sensor and cutting position of the rotary knife in mm.

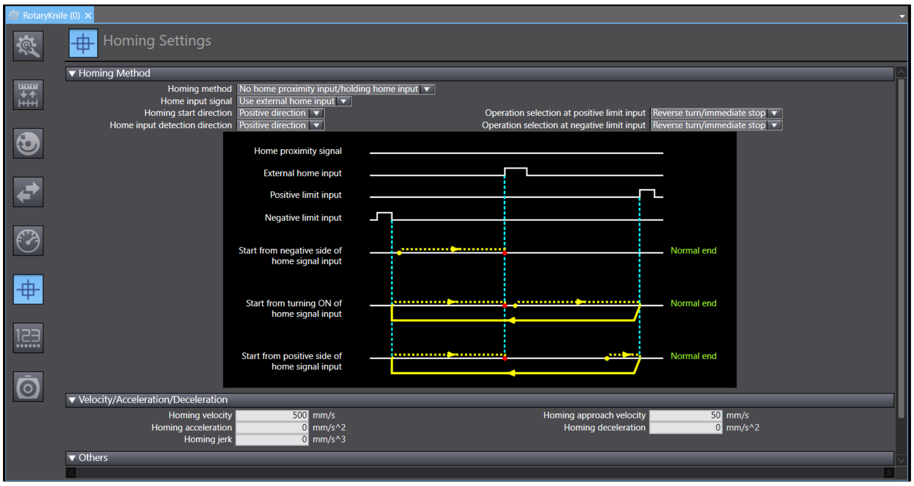

Figure 3.4.1.4. Details of the homing settings I/II (source: own).

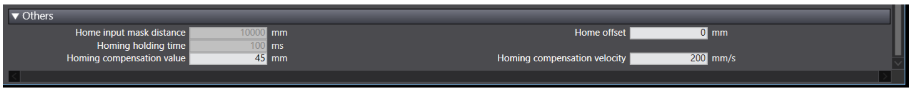

Figure 3.4.1.5. Details of the homing settings II/II (source: own).

Position count settings: The following settings have been defined in Sysmac Studio:

- **Modulo maximum position setting value:** 188.4 mm *1

*1 188.4 mm is the perimeter of the rotary knife, so in each motor revolution the counter will be cleared.

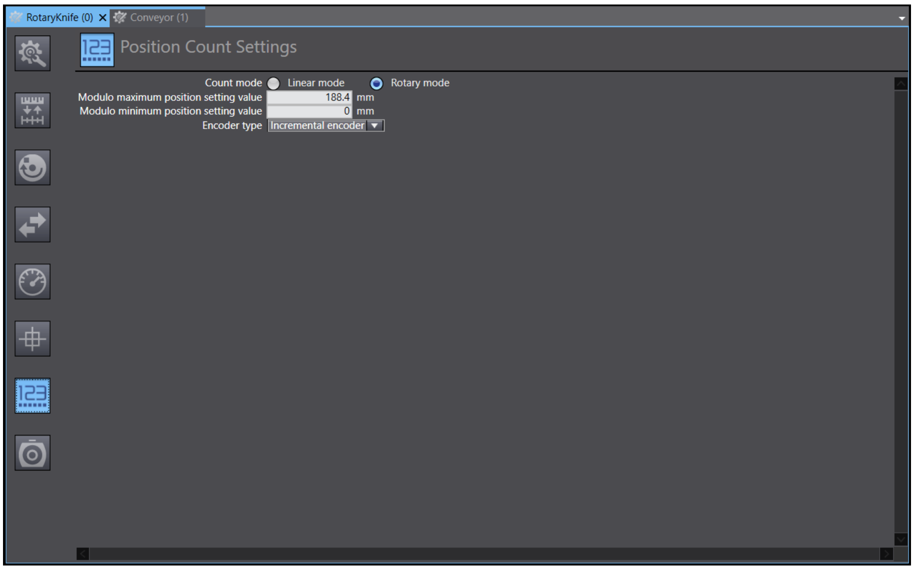

Figure 3.4.1.6. Details of the position count settings (source: own).

3.4.2. Master axis (conveyor)

Axis basic settings: The following settings have been defined in Sysmac Studio:

- **Axis number:** 1
- **Axis type:** Servo axis
- **Output device:** G5 servo drive 2 (EtherCAT node 2)

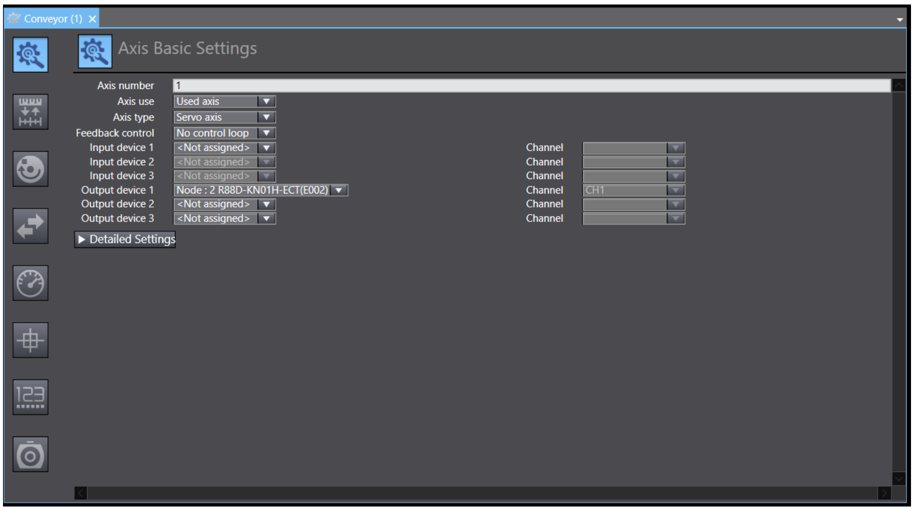

Figure 3.4.2.1. Details of the axis basic settings (source: own).

Unit conversion settings: The following settings have been defined in Sysmac Studio:

- **Unit:** mm
- Without gearbox
- **Command pulse count per motor rotation:** 1,048,576 pulse/rev[*1]
- **Work travel distance per motor rotation:** 100 mm/rev[*2]

[*1] 20-bit incremental encoder: 2^20 = 1,048,576 pulse/rev.

[*2] Perimeter of the motor conveyor = 100 mm.

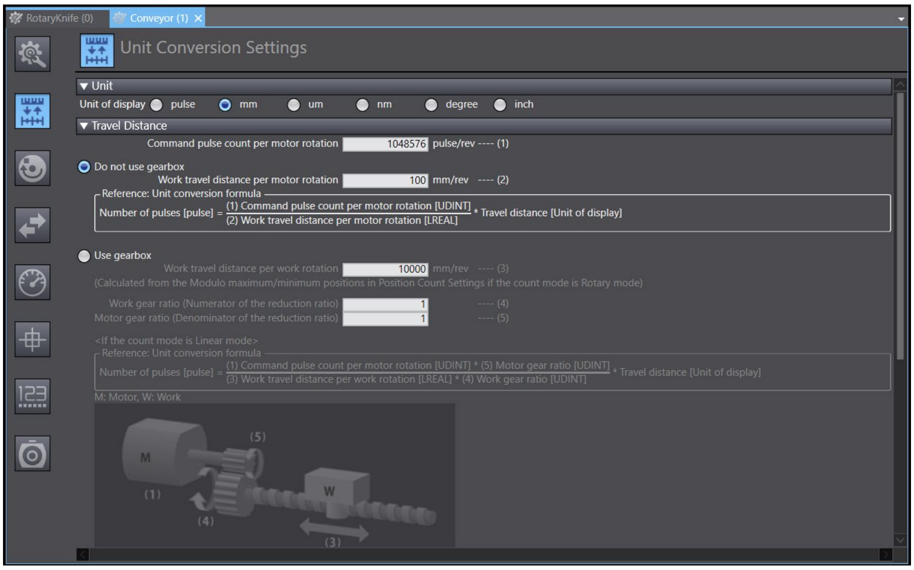

Figure 3.4.2.2. Details of the unit conversion settings (source: own).

Home settings: The following settings have been defined in Sysmac Studio:

- **Home method:** Zero position preset*1

*1 The motor will use the current position as homing position (position 0).

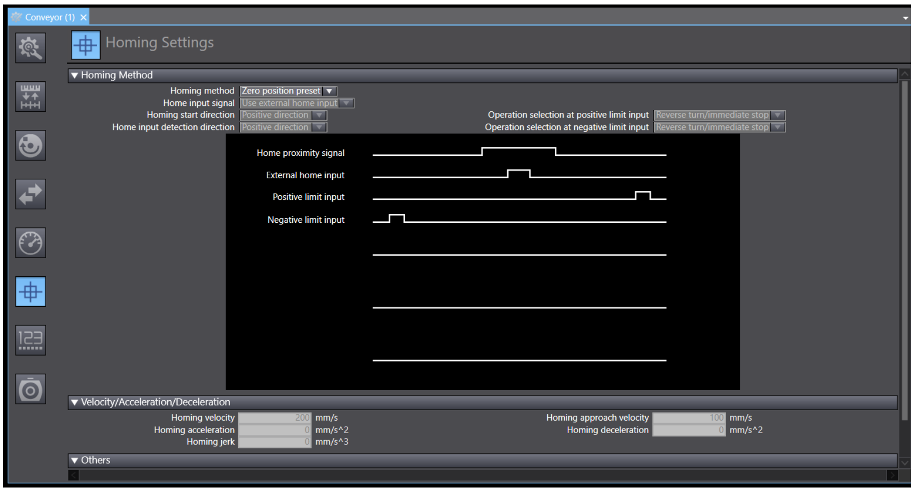

Figure 3.4.2.3. Details of the homing settings (source: own).

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Position count settings: The following settings have been defined in Sysmac Studio:

- **Modulo maximum position setting value:** 500 mm [*1]

[*1] Every 500 mm the counter will be cleared.

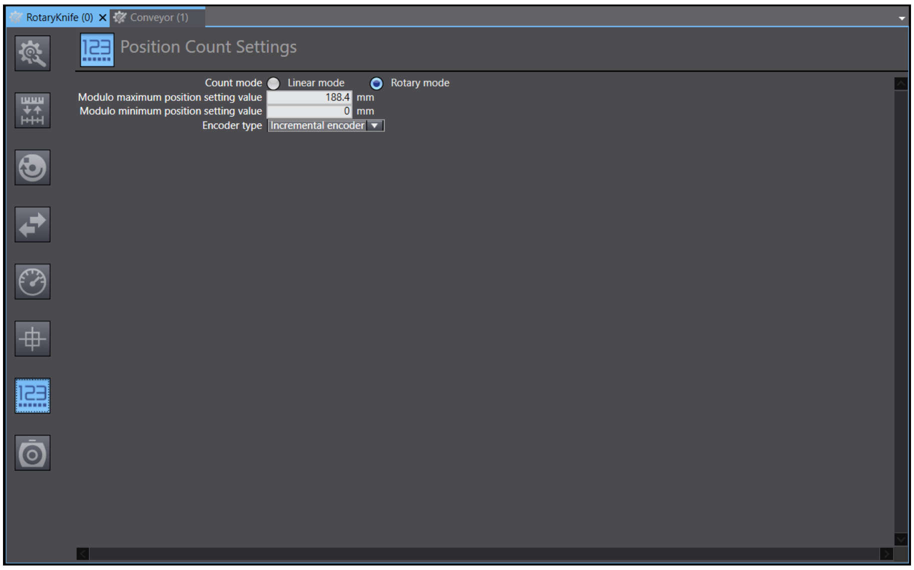


Figure 3.4.2.4. Details of the position count settings (source: own).

3.5. I/O Map

3.5.1. Controller

The following variables have been assigned to the I/O ports. Refer to the 'Annex C: Wiring Diagrams' to see the devices connected to the I/O units.

The 3 variables assigned to the NX Safety CPU unit are the buttons connected to the safety system (Reset and E-Stop buttons) and the variable for checking the safety conditions are met before starting the main program. These are the exposed Safety CPU variables to the Controller program.

Unit1	▼ NX-SL3300						
	▶ Safety CPU Status	Status of Safety CPU Unit fo	R	UINT			
	Start_OK	StartOK	R	BOOL	Start_OK		Global Variables
	Reset_Button	Reset_Button	R	BOOL	Reset_Button		Global Variables
	EmergencyStop_Button	EmergencyStop_Button	R	BOOL	EmergencyStop_Button		Global Variables

Figure 3.5.1.1. I/O Map for the NX-SL3300 Safety CPU (source: own).

The 3 variables assigned to the NX-ID4442 digital input unit are the Run and Stop buttons and a button to simulate bad products in the production line.

Unit7	▼ NX-ID4442						
	▼ Input Bit 8 bits	Input bit (8 bits)	R	BYTE			
	Input Bit 00	Input Bit 00	R	BOOL	Simulation_BadProduct		Global Variables
	Input Bit 01	Input Bit 01	R	BOOL			
	Input Bit 02	Input Bit 02	R	BOOL			
	Input Bit 03	Input Bit 03	R	BOOL			
	Input Bit 04	Input Bit 04	R	BOOL	Run_Button		Global Variables
	Input Bit 05	Input Bit 05	R	BOOL	Stop_Button		Global Variables
	Input Bit 06	Input Bit 06	R	BOOL			
	Input Bit 07	Input Bit 07	R	BOOL			

Figure 3.5.1.2. I/O Map for the NX-ID4442 digital input unit (source: own).

The 4 variables assigned to the NX-OD4256 digital output unit are the lamps for the Run, Stop, Reset and E-Stop buttons.

Unit9	▼ NX-OD4256						
	▼ Output Bit 8 bits	Output Bit (8 bits)	W	BYTE			
	Output Bit 00	Output Bit 00	W	BOOL			
	Output Bit 01	Output Bit 01	W	BOOL			
	Output Bit 02	Output Bit 02	W	BOOL			
	Output Bit 03	Output Bit 03	W	BOOL			
	Output Bit 04	Output Bit 04	W	BOOL	LED_Run		Global Variables
	Output Bit 05	Output Bit 05	W	BOOL	LED_Stop		Global Variables
	Output Bit 06	Output Bit 06	W	BOOL	LED_EmergencyStop		Global Variables
	Output Bit 07	Output Bit 07	W	BOOL	LED_Reset		Global Variables

Figure 3.5.1.3. I/O Map for the NX-OD4256 digital output unit (source: own).

3.5.2. Safety CPU

The following variables have been assigned to the safety I/O ports. Refer to the 'Annex C: Wiring Diagrams' to see the devices connected to the I/O units.

The variable assigned to the NX-SID800 safety digital input unit is the Reset button.

Node3/Unit2	▼ NX-SID800					
	▼ Safety Inputs					
	Si00 Logical Value	R	SAFEBOOL			
	Si01 Logical Value	R	SAFEBOOL			
	Si02 Logical Value	R	SAFEBOOL			
	Si03 Logical Value	R	SAFEBOOL	SI_Reset	SI_Reset	Global Variables
	Si04 Logical Value	R	SAFEBOOL			
	Si05 Logical Value	R	SAFEBOOL			
	Si06 Logical Value	R	SAFEBOOL			
	Si07 Logical Value	R	SAFEBOOL			

Figure 3.5.2.1. I/O Map for the NX-SID800 safety digital input unit (source: own).

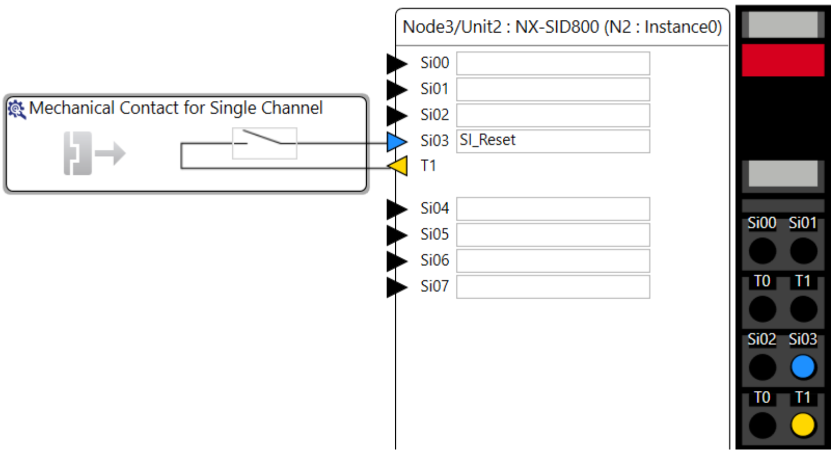


Figure 3.5.2.2. Details of the wired devices to the NX-SID800 safety digital input unit (source: own).

The variables assigned to the NX-SIH400 safety digital input unit are the 2 channels of the E-Stop button and the signal for detecting safety failures in the rotary knife servo drive.

Node3/Unit3	▼ NX-SIH400					
	▼ Safety Inputs and Status					
	Si00 Logical Value	R	SAFEBOOL	SI_EmergencyStop1	SI_Emergency Stop CH1	Global Variables
	Si01 Logical Value	R	SAFEBOOL		SI_Emergency Stop CH2	
	Si02 Logical Value	R	SAFEBOOL			
	Si03 Logical Value	R	SAFEBOOL	EDM_RotaryKnife	SI_EDM_RotaryKnife	Global Variables
	Safety Connection Status	R	SAFEBOOL			
	Safety Input Terminal Status	R	SAFEBOOL			

Figure 3.5.2.3. I/O Map for the NX-SIH400 safety digital input unit (source: own).

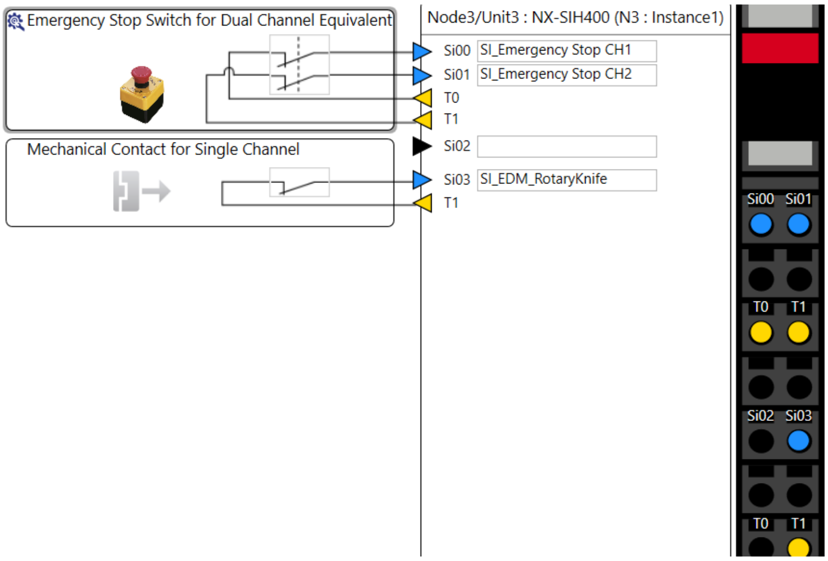


Figure 3.5.2.4. Details of the wired devices to the NX-SIH400 safety digital input unit (source: own).

The variables assigned to the NX-SOD400 safety digital output unit are the 2 rotary knife servo drive safety inputs.

Node3/Unit4	▼ NX-SOD400					
	▶ Status					
	▼ Safety Outputs					
	So00 Output Value	W	SAFEBOOL			
	So01 Output Value	W	SAFEBOOL			
	So02 Output Value	W	SAFEBOOL	STO1_RotaryKnife	STO_RotaryKnife CH1	Global Variables
	So03 Output Value	W	SAFEBOOL		STO_RotaryKnife CH2	

Figure 3.5.2.5. I/O Map for the NX-SOD400 safety digital output unit (source: own).

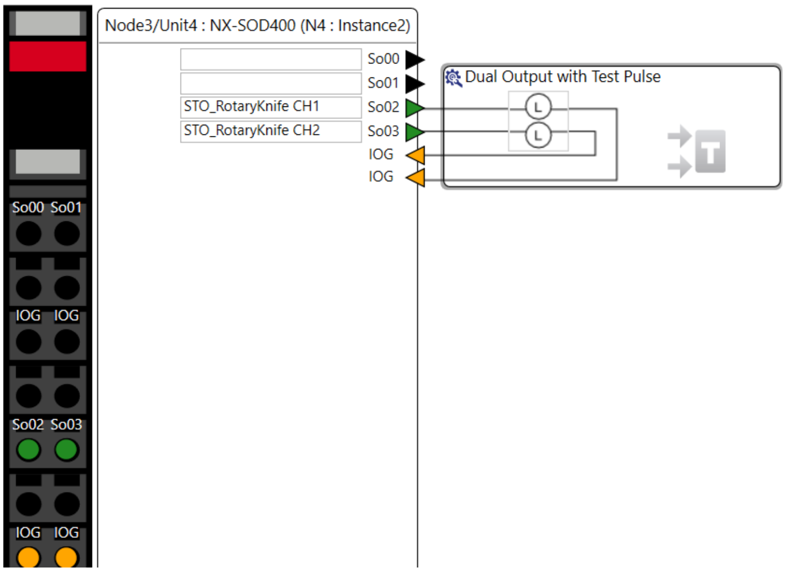


Figure 3.5.2.6. Details of the wired devices to the NX-SOD400 safety digital output unit (source: own).

The CN8 connector from the rotary knife servo drive is wired to use the STO function (Safe Torque OFF according to IEC 61800-5-2) to cut off the motor current and stop the motor through the input signals from the Safety CPU unit.

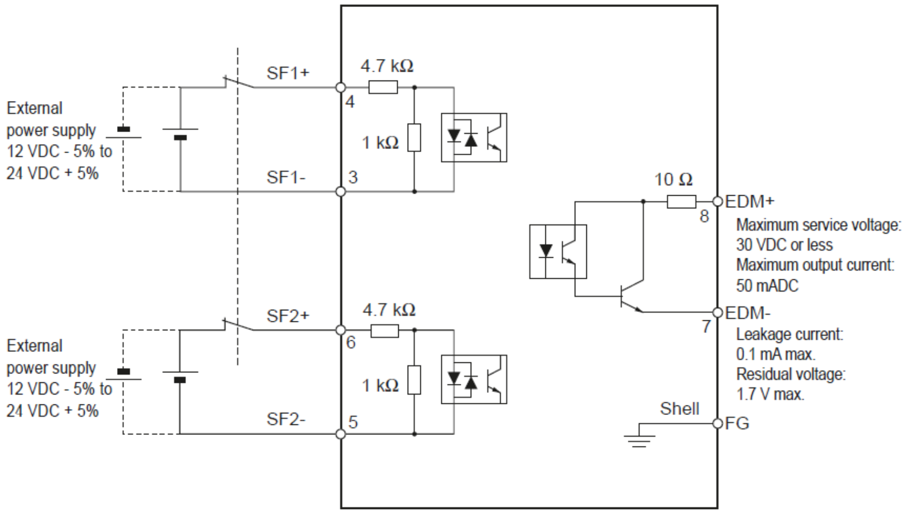


Figure 3.5.2.7. Safety I/O signals - CN8 connector (source: [8]).

The variables assigned to the CN8 connector are the EDM_RotaryKnife and the STO_RotaryKnife:

- The EDM_ RotaryKnife is a monitor signal for detecting safety failures in the servo drive.
- The STO_RotaryKnife are the 2 the safety inputs for operating the STO function in the servo drive. This input turns OFF the power transistor drive signals in the servo drive to cut off the current output to the motor.

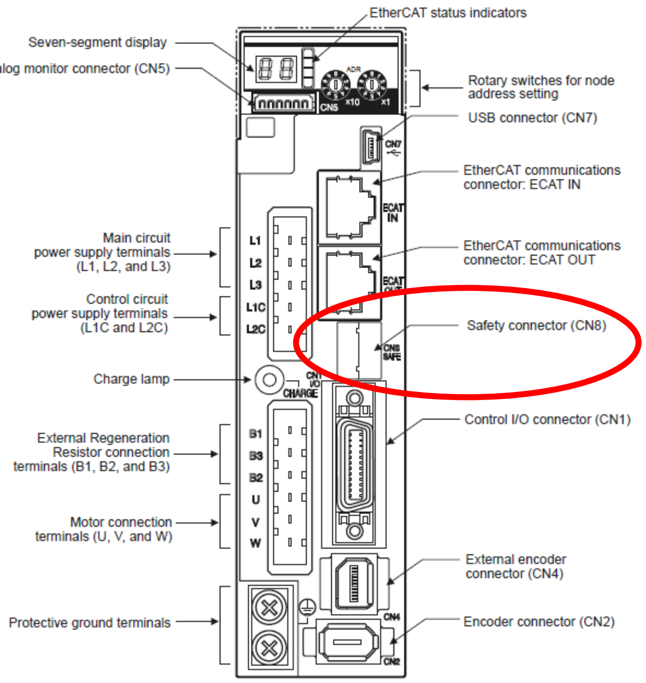


Figure 3.5.2.8. Detail of the CN8 connector (source: [8]).

4. Rotary Knife library

4.1. RK_SyncRotary Function Block

The Rotary Knife library version 1.1.3 from Omron has been used to synchronize the master axis and slave axis in this thesis.

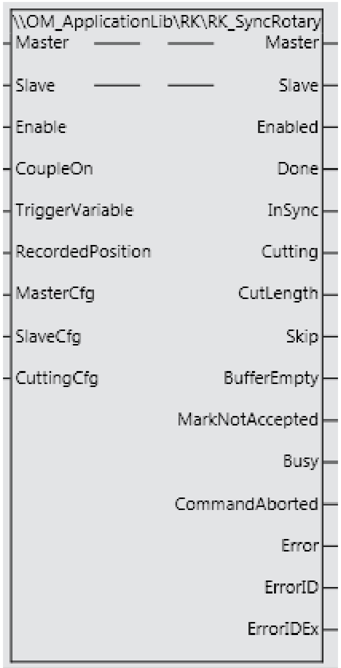


Figure 4.1. Omron RK_SyncRotary Function Block (source: [13]).

4.2. Variables

4.2.1. Overview

In this thesis, the conveying products are cut at certain intervals. The product is conveyed by the master axis and is cut by the rotary knife (slave axis) in the cutting position. The mark sensor detects the mark on the product to be cut. The master axis and slave axis are synchronized during the InSyncPhase zone.

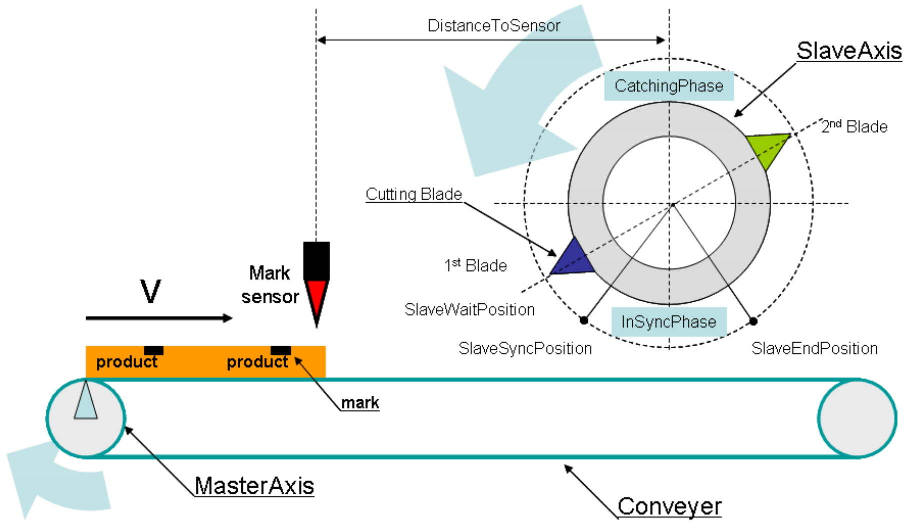


Figure 4.2.1. Overview of Rotary Knife library parameters (source: [13]).

- **MasterAxis:** It is the main axis of the system. This axis drives the conveyor to feed products.
- **SlaveAxis:** It is the slave axis of the system. This axis drives the rotary knife.
- **Product:** The product to be processed.
- **Mark:** The mark which is printed on the product and used for determining the cutting position.
- **Mark sensor:** A sensor for detecting a mark printed on the product.
- **DistanceToSensor:** Distance between the mark sensor and cutting positions. This distance must be longer than the distance between the marks.
- **CuttingBlade:** The blade that is mounted on the rotary knife to cut the product. One or two blades are possible with the Rotary Knife library. In this project, just one blade is used.
- **CuttingPosition:** This is the cutting position of the rotary knife. It is the homing position of the servo motor.
- **SlaveWaitPosition:** Waiting position of the SlaveAxis.
- **InSyncPhase:** Synchronizing section.
- **SlaveSyncPosition:** Start position of InSyncPhase.
- **SlaveEndPosition:** End position of InSyncPhase.
- **CatchingPhase:** Outside of Synchronization section.

4.2.2. Input variables

Variable	Data type	Initial value	Valid range	Change during execution
Enable	BOOL	FALSE	True/False	-
CoupleOn	BOOL	FALSE	True/False	When enabled
MasterCnfg	sMASTER_CNFG	-		Not possible
SlaveCnfg	sSLAVE_CNFG	-		-
CuttingCnfg	sSLAVE_CNFG	-		-

Table 4.2.2.1. RK_SyncRotary FB input variables.

Enable

- When [Enable] is executed, the RK_SyncRotary Function Block is operative.
- After [Enable], the rotary knife goes to the [SlaveWaitPosition] waiting for a [CoupleOn] signal.

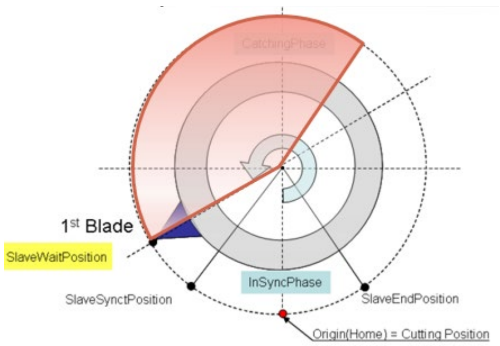


Figure 4.2.2.1. Details of the Enable variable (source: [13]).

CoupleOn

- When [CoupleOn] is executed, the synchronization function is enabled, so the rotary knife is ready to be synced with the product.

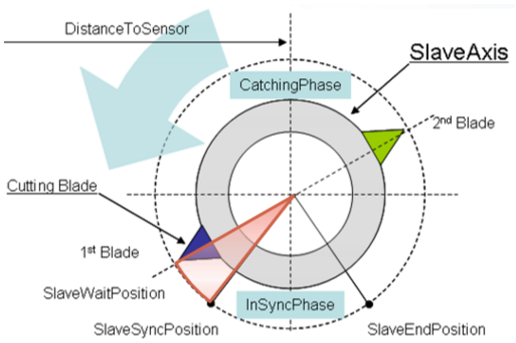


Figure 4.2.2.2. Details of the CoupleOn variable (source: [13]).

MasterCnfg (Master axis configuration)

- This group of parameters is to configure the master axis (conveyor).

MasterCnfg.CountCnfg	Data type	Initial value	Valid range	Change during execution
.ModuloMaxPos	LREAL	0.0	Same as Master Axis	Not possible
.ModuloMinPos	LREAL	0.0	0.0	Not possible

Table 4.2.2.2. Max./Min. master modulo variables for master axis.

MasterCnfg.TriggerInput	Data type	Valid range	Change during execution
.Mode	_eMC_TRIGGER_MODE	_mcDrive _mcController	Not possible
.LatchID	_eMC_TRIGGER_LATCHID	_mcLatch1 _mcLatch2	Not possible
.InputDrive	_eMC_TRIGGER_INPUT_DRIVE	_mcEXT	Not possible

Table 4.2.2.3. Trigger input variables for master axis.

- Use the TriggerInput settings in [CuttingCnfg.Mode = 1] (Mark to mark) to define the internal latch function over the master axis.
- Up to 64 product positions can be stored in the buffer.

SlaveCnfg (Slave axis configuration)

- This group of parameters is to configure the slave axis (rotary knife).

SlaveCnfg	Data type	Initial value	Valid range	Change during execution
.SyncPos	LREAL	0.0	0 to Max. Modulo	Not possible
.EndPos	LREAL	0.0	0 to Max. Modulo	Not possible
.WaitPos	LREAL	0.0	Positive value, less than Max. Modulo	Not possible
.MaxVelocity	LREAL	0.0	>0 to Max. Axis Slave Speed	Not possible
.Acceleration[*1]	LREAL	0.0	>0 to Max. Axis Slave Acceleration	When Enabled
.Deceleration[*1]	LREAL	0.0	>0 to Max. Axis Slave Deceleration	When Enabled
.VelocityToWaitPos[*1]	LREAL	0.0	>0 to Max. Axis Slave Speed	Not possible
.BladeNum[*2]	UDINT	1	1, 2	Not possible
.ProfileType[*3]	UDINT	0	0: Trapezoidal 5: 5th order polynomial	Not possible

.VelFactor*4	UDINT	100	1 ..199 (%)	When Enabled
.ModuloMaxPos*5	LREAL	0.0	Same as Slave Axis	Not possible
.ModuloMinPos	LREAL	0.0	0.0	Not possible

1. .VelocityToWaitPos , .Acceleration and .Deceleration defines the travelling after enable to .WaitPos, or after cutting a product, the travel from .EndPos to .WaitPos (if there aren't pending cycles to be executed).
2. Define number of symmetrical blades.
3. Use .ProfileType trapezoidal or Polynomial according your torque / speed / jerk limitations.
4. .VelocityFactor can be used during the travel from .SyncPos to .EndPos if is needed to run a bit faster than the master during the cut (e.g. to keep a clearance after a cut). The setting unit is %. Set a factor as a percentage of the MasterAxis.
5. Set the circumference (perimeter of the rotary knife) on which the edge of the rotary knife traces.

Table 4.2.2.4. Input variables for slave axis.

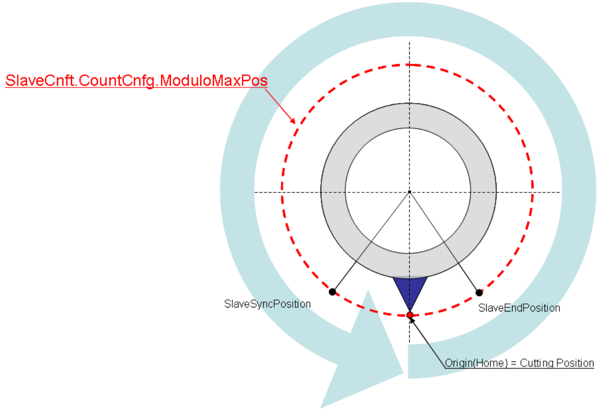


Figure 4.2.2.3. Details of ModuloMaxPos for the slave axis (source: [13]).

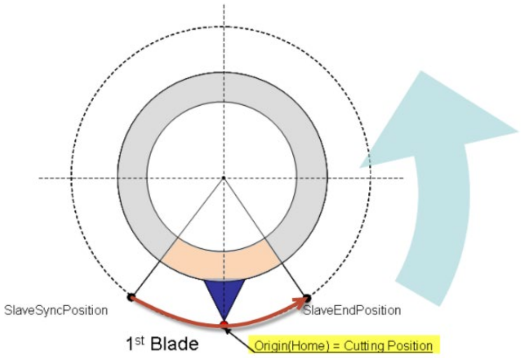


Figure 4.2.2.4. Details of the origin position for the slave axis (source: [13]).

CuttingCnfg (Cutting configuration)

CuttingCnfg	Data type	Initial value	Valid range	Change during execution
.Mode*1	UDINT	0	0: Continuous 1: Mark to Mark 2: External Mark to Mark	Not possible
.CutLength	LREAL	0.0	0 and greater	When Enabled
.MasterSyncPos	LREAL	0.0	0 and greater	Not possible
.DistanceToSensor	LREAL	0.0	0 and greater	Not possible
.Tolerance	LREAL	0.0	0 and greater	When Enabled
.OffsetFromMark	LREAL	0.0	0 to [CutLength]	When Enabled

*1 In this project just the modes 0 and 1 are used.

Table 4.2.2.5. Cutting configuration variables.

CutLength meaning (Mode 0: Continuous)

- The distance to cut is specified at the [CuttingCnfg.CutLength] parameter.
- The value can be changed during Rotary Knife library execution after a Rotary Knife cycle completion.
- The position of master axis to start the first cut after [CoupleOn] is the one specified by [MasterSyncPos].

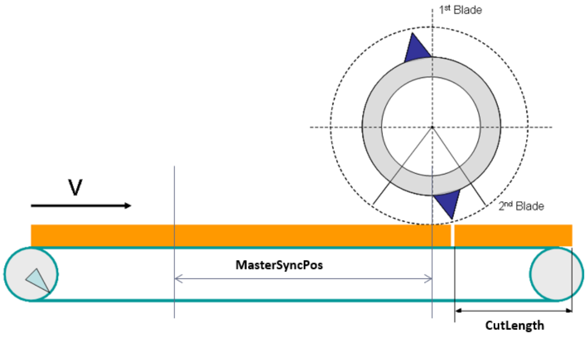


Figure 4.2.2.5. Details of the CutLength variable in continuous mode (source: [13]).

CutLength meaning (Mode 1: Mark to mark)

- The set value is the cut length in the case that mark misdetection occurs. It will prevent a machine from producing too long cut length.
- The product will be cut at the length of [CuttingCnfg.Cutlength] (constant length), because the actual mark is not detected in the area designated with [CuttingCnfg.Tolerance].
- Mark misdetection may happen in the following conditions: there are some malfunctions on the mark sensor or there is no mark or misprinting on the product to cut.

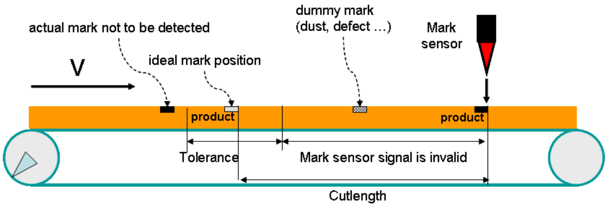


Figure 4.2.2.6. Details of the CutLength variable in mark to mark mode (source: [13]).

OffsetFromMark

- This function modifies the cutting position, adding an offset from the mark.
- This function is enabled only when [CuttingCnfg.Mode] is set to 1 and 2.
- Do not change the offset distance for a distance which is same as the distance between two marks during one-cutting-cycle, it causes an error.

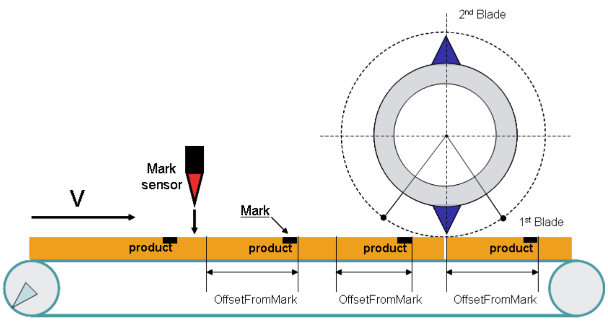


Figure 4.2.2.7. Details of the OffsetFromMark variable (source: [13]).

4.2.3. Output variables

Outputs	Data type	Meaning
Enabled	BOOL	True while the FB is executing.
Done	BOOL	TRUE while the SlaveAxis is waiting at the SlaveWaitPosition
Busy	BOOL	TRUE during execution, when the Slave goes to SlaveWaitPosition
CommandAborted	BOOL	TRUE if the execution of the instruction is aborted by other FB
Skip	BOOL	TRUE when the next operation must be skipped
InSync	BOOL	TRUE while the Slave Axis is performing a movement in the InSyncPhase
Cutting	BOOL	TRUE during one task period during cutting operation
CutLength	LREAL	Shows the length to cut • Mode 0: Current Cutlength • Mode 1, 2: Length measured from Mark to Mark
BufferEmpty	BOOL	TRUE when the next cut is unknown, because there is no buffered products to be cut. Only valid in mode 1 and 2
MarkNotAccepted	BOOL	TRUE when there is a mark detected while the Buffer empty was TRUE
Error	BOOL	TRUE if an error occurs
ErrorID	WORD	Contains the error code when an error occurs #0000 is the initial value and indicated as normal end
ErrorIDEx	DWORD	Contains the error code when an error occurs. #00000000 is the initial value and indicates a normal end

Table 4.2.3. RK_SyncRotary FB output variables.

4.2.4. Input/Output variables

The input/output variables are the 2 axes (master axis and slave axis).

Variable	Data type	Valid range	Change during execution	Meaning
Master	_SAXIS_REF	-	Not possible	Master axis
Slave	_SAXIS_REF	-	Not possible	Slave axis

Table 4.2.4. RK_SyncRotary FB input/output variables.

4.2.5. Cutting configuration modes

The cutting configuration modes 0 (continuous) and 1 (mark to mark) are the ones used in this thesis.

4.2.5.1. Continuous mode (mode 0)

- When [Enable] of input variable changes to TRUE, the rotary cutter moves to the [SlaveWaitPosition] and waits until [CoupleOn] changes to TRUE.

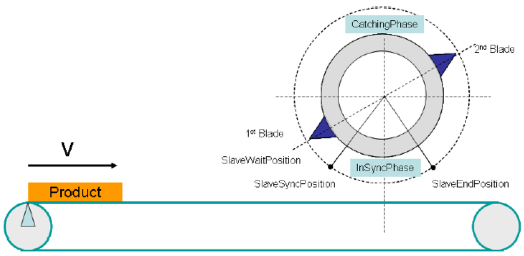


Figure 4.2.5.1.1. Detail 1 of the Continuous mode (source: [13]).

- After [CoupleON] of input variable changes to TRUE, the rotary cutter starts rotating.

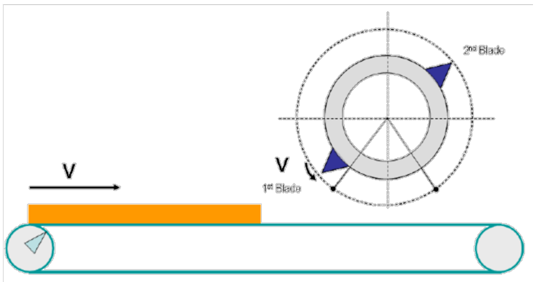


Figure 4.2.5.1.2. Detail 2 of the Continuous mode (source: [13]).

- When the master axis (conveyor) reaches the [MasterSyncPosition], the rotary cutter performs synchronization. [InSync] output changes to TRUE.

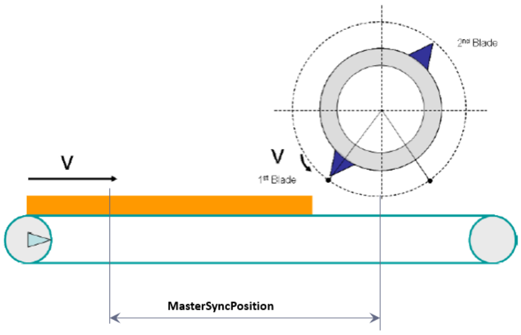


Figure 4.2.5.1.3. Detail 3 of the Continuous mode (source: [13]).

- The rotary cutter rotates and passes the cutting position. At this time, a product is cut if there is any at the cutting position. The cutting position is not defined. [Cutting] output changes to TRUE.

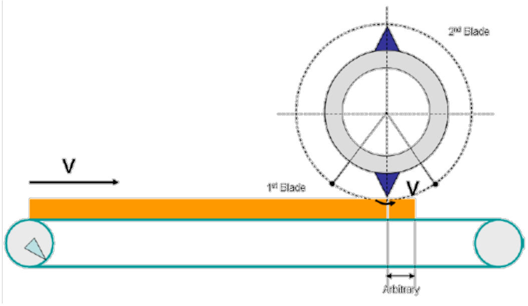


Figure 4.2.5.1.4. Detail 4 of the Continuous mode (source: [13]).

- After the first cutting, a cam profile is calculated for the next cutting. After this, the rotary cutter will operate according to this cam profile. You can change the cut length before the previous cutting operation executes.

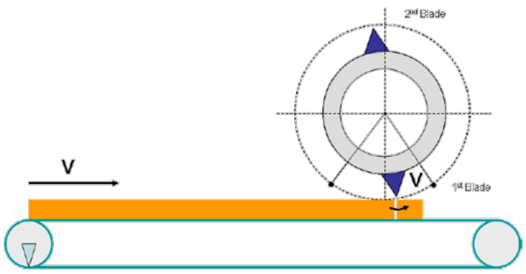


Figure 4.2.5.1.5. Detail 5 of the Continuous mode (source: [13]).

- The blade is moving in the CatchingPhase (non-synchronization section) preparing for the next cutting.

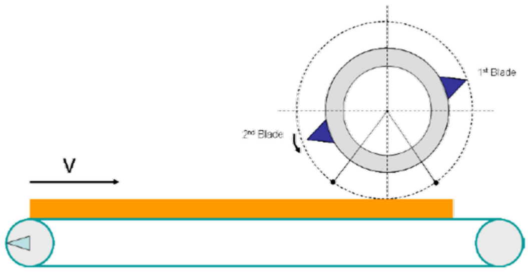


Figure 4.2.5.1.6. Detail 6 of the Continuous mode (source: [13]).

- The blade starts synchronization at the [SlaveSyncPosition].

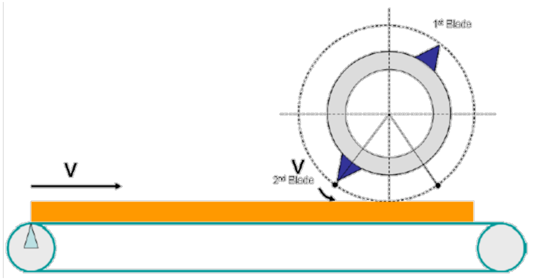


Figure 4.2.5.1.7. Detail 7 of the Continuous mode (source: [13]).

- The blade cuts a product. The cut length at this time is the value set by [CuttingCnfg.CutLength] of the input variable. During cutting operation, [Cutting] output is TRUE. You can change the cut length before the previous cutting operation is executed.

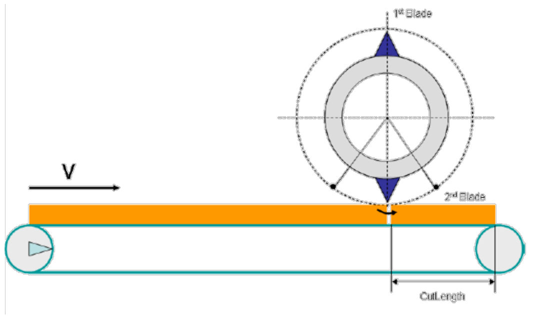


Figure 4.2.5.1.8. Detail 8 of the Continuous mode (source: [13]).

- After that, the same operation is performed repeatedly, and products are cut.

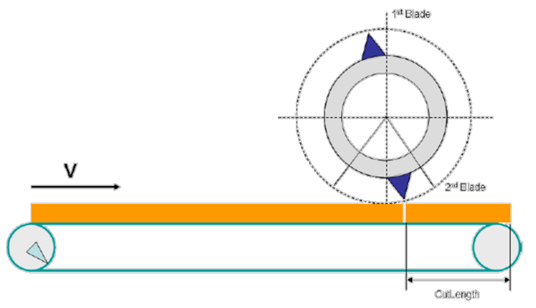


Figure 4.2.5.1.9. Detail 9 of the Continuous mode (source: [13]).

4.2.5.2. Mark to mark mode (mode 1)

- When [Enable] of input variable changes to TRUE, the blade of the rotary cutter moves to the [SlaveWaitPositon].

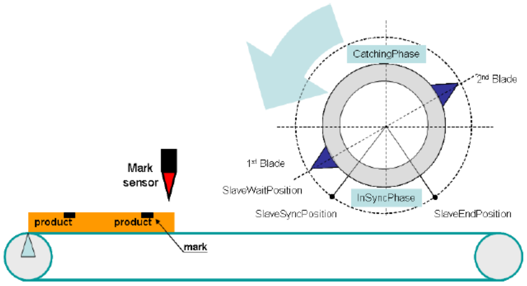


Figure 4.2.5.2.1. Detail 1 of the Mark to mark mode (source: [13]).

- After moving to the [SlaveWaitPosition] is completed, when [CoupleOn] of the input variable is TRUE and the mark on a product is detected, synchronization starts.

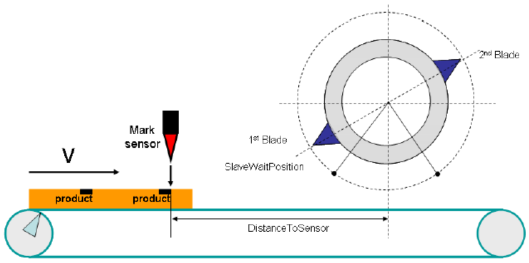


Figure 4.2.5.2.2. Detail 2 of the Mark to mark mode (source: [13]).

- When the second mark is detected, the first cut length is determined.

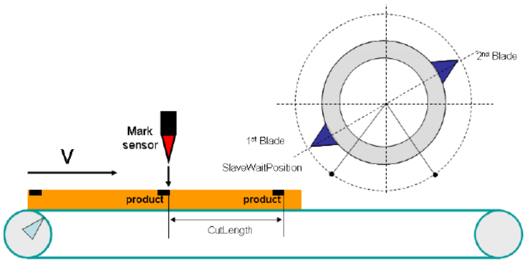


Figure 4.2.5.2.3. Detail 3 of the Mark to mark mode (source: [13]).

- The blade is synchronized with the first mark. If the [OffsetFromMark] of the input variable is set, the blade synchronizes behind the mark with the set value.

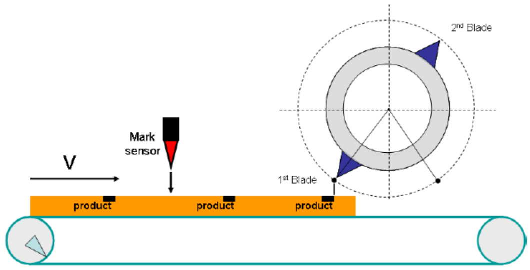


Figure 4.2.5.2.4. Detail 4 of the Mark to mark mode (source: [13]).

- The blade is in synchronization in the [InSyncPhase]. [InSync] output changes to TRUE.

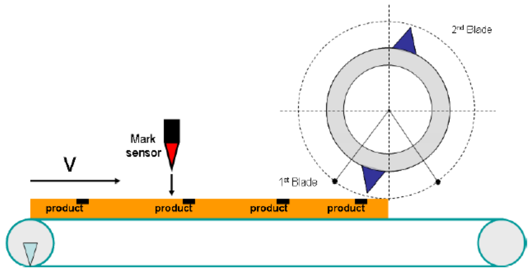


Figure 4.2.5.2.5. Detail 5 of the Mark to mark mode (source: [13]).

- The blade cuts the product at the first mark position. If the [OffsetFromMark] input variable is set, the blade cuts the product behind the mark position for the set value. After the cutting operation, the cam profile is calculated again to prepare the blade for the next cutting operation.

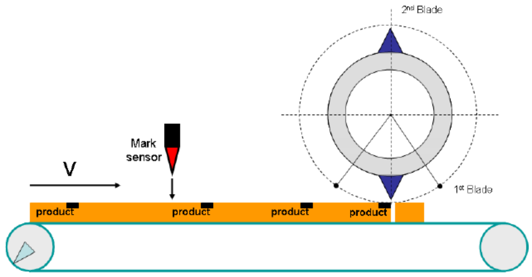


Figure 4.2.5.2.6. Detail 6 of the Mark to mark mode (source: [13]).

- After the cutting operation, the blade is synchronized with the mark position until it exits the [InSyncPhase].

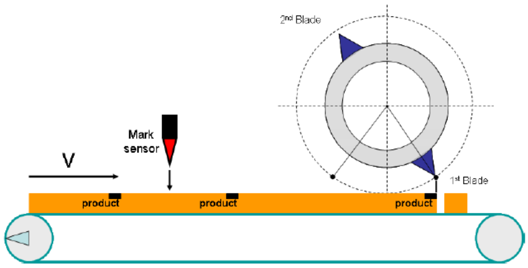


Figure 4.2.5.2.7. Detail 7 of the Mark to mark mode (source: [13]).

- The blade exits the [InSyncPhase] and is moving in the [CatchingPhase].

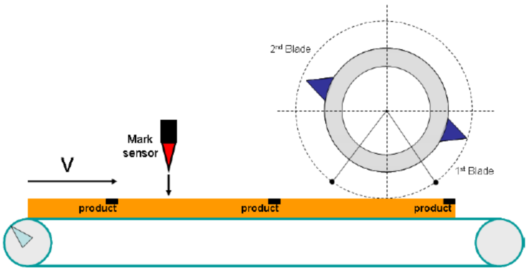


Figure 4.2.5.2.8. Detail 8 of the Mark to mark mode (source: [13]).

- The blade is synchronized with the 2^{nd} mark position.

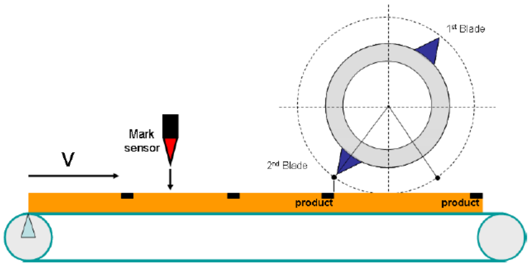


Figure 4.2.5.2.9. Detail 9 of the Mark to mark mode (source: [13]).

- The blade is in synchronization. [InSync] output changes to TRUE.

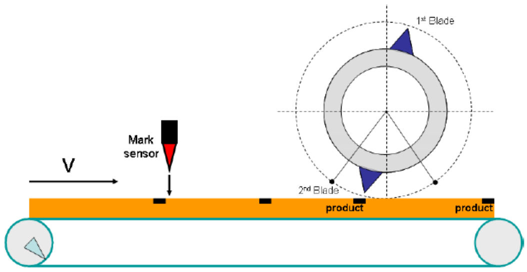


Figure 4.2.5.2.10. Detail 10 of the Mark to mark mode (source: [13]).

- The blade cuts the product. If the [OffsetFromMark] of the input variable is set, the blade cuts the product behind the mark position for the set value. After the cutting operation, a cam profile is calculated again for the 1st blade to prepare for the next cutting.

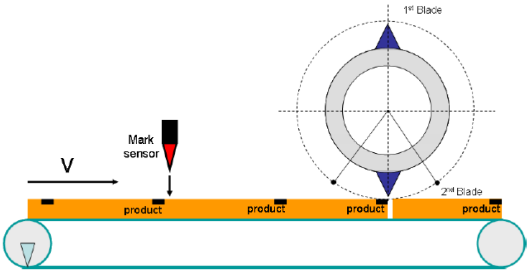


Figure 4.2.5.2.11. Detail 11 of the Mark to mark mode (source: [13]).

4.2.6. Initial conditions

These are the initial conditions than the input variables should follow to use the RK_SyncRotary Library. If these conditions are not met, the RK_SyncRotary Library will produce an error:

- The [SlaveWaitPosition] must be within the CatchingPhase (between [SlaveEndPosition] and [SlaveSyncPosition] and there must be a sufficient distance from the [SlaveEndPosition] to decelerate to a stop at a specified deceleration.
- The following condition should be met for the slave axis configuration:
    - [ModuloMinPos] < [SlaveEndPosition] < [SlaveSyncPosition] < [ModuloMaxPos]
- When using the Mode 1 (mark to mark), the relationship of the distance between the marks (cut length) and the distance between the rotary knife and mark sensor [CuttingCfg.DistanceToSensor] must be established as follows:
    - Distance between marks < [Cutting Cfg.DistanceToSensor]

4.2.7. Initial input variable values

These are the initial input variable values defined in the Sysmac Studio program and its meaning. Some of the parameters for the SlaveCnfg (slave axis configuration) and CuttingCnfg (cutting configuration) can be changed with the HMI during program execution.

- MasterCnfg (master axis configuration)

Variable	Value	Meaning
MasterConfig.CountCfg.ModuloMinPos	0	The counting position of the conveyor will start at 0 mm (home position of the servo).
MasterConfig.CountCfg.ModuloMaxPos	500	The counting position of the conveyor will finish at 500 mm.
MasterConfig.TriggerInput.Mode	_mcDrive	The trigger will be managed by the servo drive.
MasterConfig.TriggerInput.LatchID	_mcLatch1	The latch 1 is used for the servo drive.
MasterConfig.TriggerInput.InputDrive	_mcEXT	External input is used for the latch.

Table 4.2.7.1. Master axis values at the beginning of program execution.

- SlaveCnfg (slave axis configuration)

Variable	Value	Meaning
SlaveConfig.CountCfg.ModuloMinPos	0	The counting position of the rotary knife will start at 0 mm (home position of the servo).
SlaveConfig.CountCfg.ModuloMaxPos	188.4	The counting position of the rotary knife will finish at 188.4 mm. This is the perimeter of the rotary knife. So, every motor revolution the counting position will be cleared.
SlaveConfig.WaitPos	146.5	The waiting position (waiting for a CoupleOn signal) of the rotary knife is in the 146.5 mm position (280º).
SlaveConfig.SyncPos	172.7	The synchronization zone will start in the 172.7 mm position (330º).
SlaveConfig.EndPos	15.7	The synchronization zone will end in the 15.7 mm position (30º).
SlaveConfig.MaxVelocity	4000	The maximum velocity of the rotary knife is 4,000 mm/s.
SlaveConfig.Deceleration	100000	The deceleration of the rotary knife is 100,000 mm/s^2.
SlaveConfig.Acceleration	100000	The acceleration of the rotary knife is 100,000 mm/s^2.
SlaveConfig.BladeNum	1	Just one blade is used in this thesis.

SlaveConfig.ProfileType	5	5-order polynomial is used as cam profile.
SlaveConfig.VelocityToWaitPos	1800	The velocity of the rotary knife for moving to the wait position is 1,800 mm/s.
SlaveConfig.VelFactor	100	The velocity of the master axis and slave axis in the synchronization zone is the same (100%).

Table 4.2.7.2. Slave axis values at the beginning of program execution.

The perimeter of the rotary knife is 188.4 mm [SlaveConfig.CountCfg.ModuloMaxPos]. The values of the waiting position [SlaveConfig.WaitPos], and synchronization zone [SlaveConfig.SyncPos / SlaveConfig.EndPos] have been defined according to this perimeter and following the next conditions:

- SlaveSyncPos: [¾ ModuloMaxPos (141.3 mm) < SlaveSyncPos (172.7 mm) < ModuloMaxPos (188.4 mm)]
- SlaveEndPos: [ModuloMinPos (0 mm) < SlaveEndPos (15.7 mm) < ¼ ModuloMaxPos (47.1 mm)]

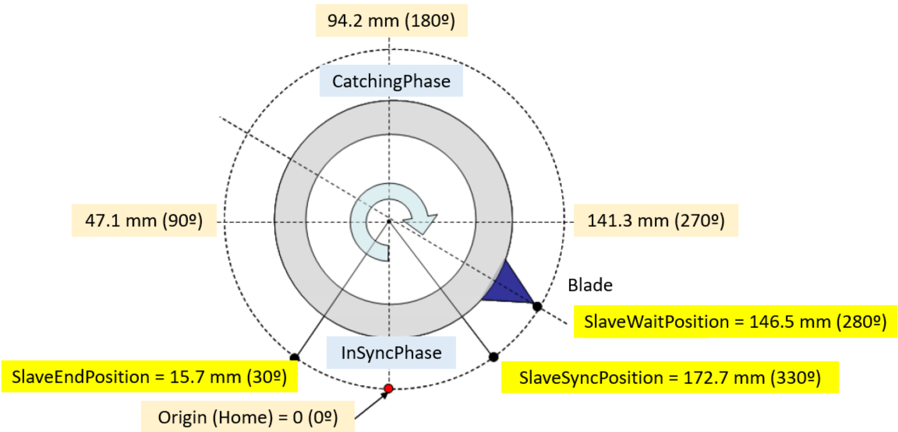


Figure 4.2.7. Slave axis values (source: own).

- CuttingCnfg (cutting configuration)

Variable	Value	Meaning
CuttingConfig.CutLength	100	The cutting length is 100 mm.
CuttingConfig.MasterSyncPos	50	In the mode 0 (continuous) the first cut is done at the 50 mm position of the conveyor.
CuttingConfig.DistanceToSensor	129	The distance between the mark sensor and the cutting position is 129 mm.
CuttingConfig.OffsetFromMark	0	No offset from the mark.

Table 4.2.7.3. Cutting configuration values at the beginning of program execution.

5. Operation mode

5.1. Running the demo

The operation mode using the thesis application through the compact demo case is described in this section. Please follow the next steps to ensure the correct machine operation with the demo case.

- Connect the demo case power cable to a 230 V plug.

Figure 5.1.1. Connecting demo case power cable to 230 V (source: own).

- Turn on the demo case.

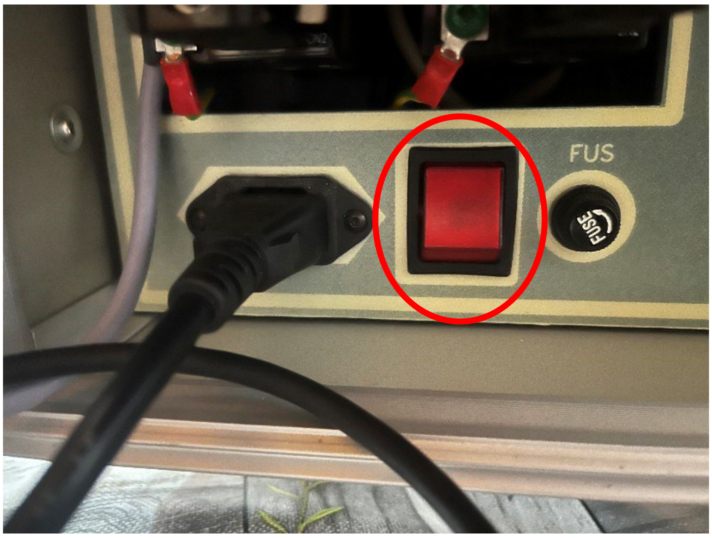


Figure 5.1.2. Turning on the demo case (source: own).

- Wait until the system is initialized. The HMI screen will show some safety errors because is necessary to reset the system before starting machine operation.

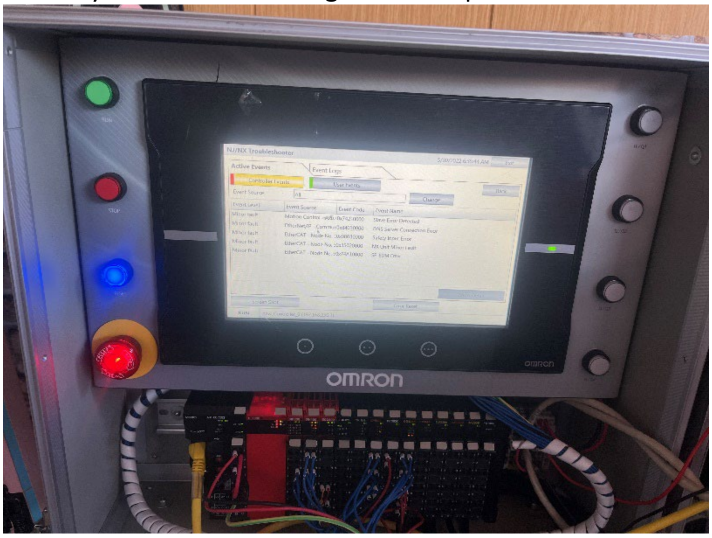


Figure 5.1.3. HMI Troubleshooter menu (source: own).

- The rotary knife servo drive is in safety mode.

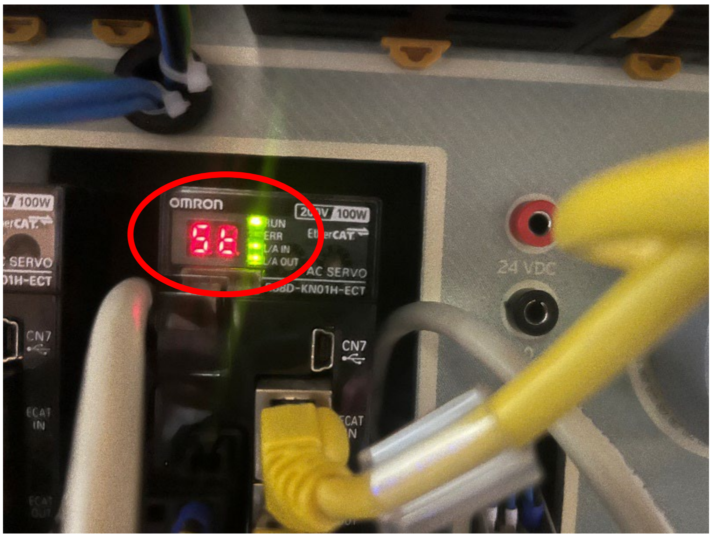


Figure 5.1.4. Rotary knife servo drive in safety mode (source: own).

- Check the E-Stop button is not pressed. If it's pressed, please release it.

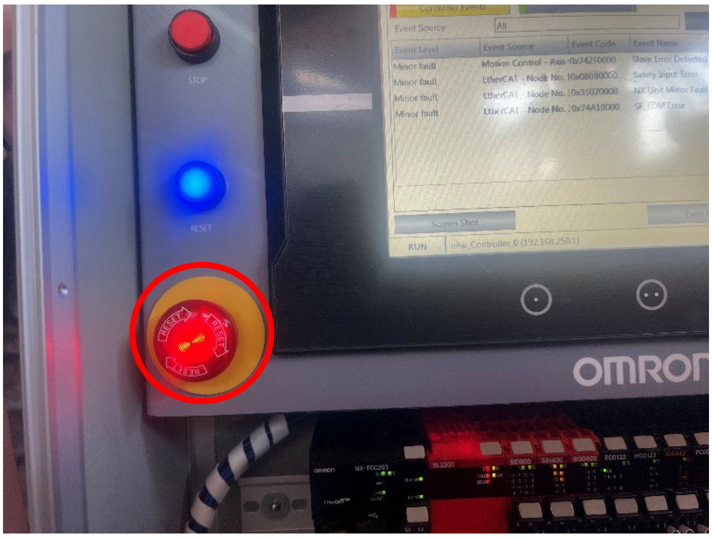


Figure 5.1.5. E-Stop button status (source: own).

- Reset the system through the Reset button close to the HMI.

Figure 5.1.6. Reset button (source: own).

- Reset the Safety input error with the ‘Error Reset’ button from the HMI.

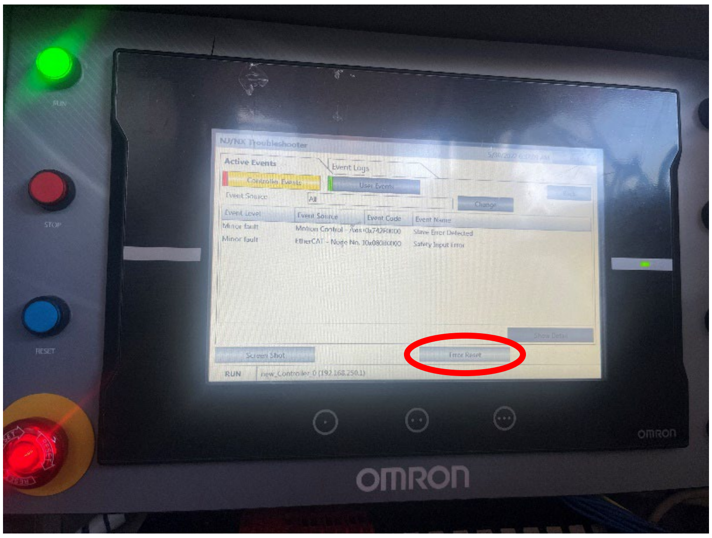


Figure 5.1.7. Error Reset button from HMI Troubleshooter menu (source: own).

- Now there is no error in the HMI troubleshooter menu. Exit from this menu with the ‘Exit’ button.

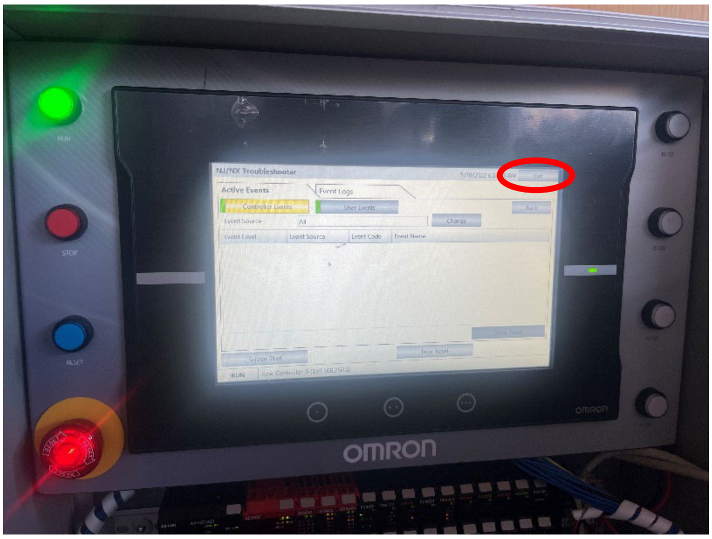


Figure 5.1.8. HMI Troubleshooter menu (source: own).

- Now the main HMI screen for controlling the machine will appear.

Figure 5.1.9. Main HMI screen (source: own).

- To see the parameters description of the system, please touch the 'Details' button from the HMI.

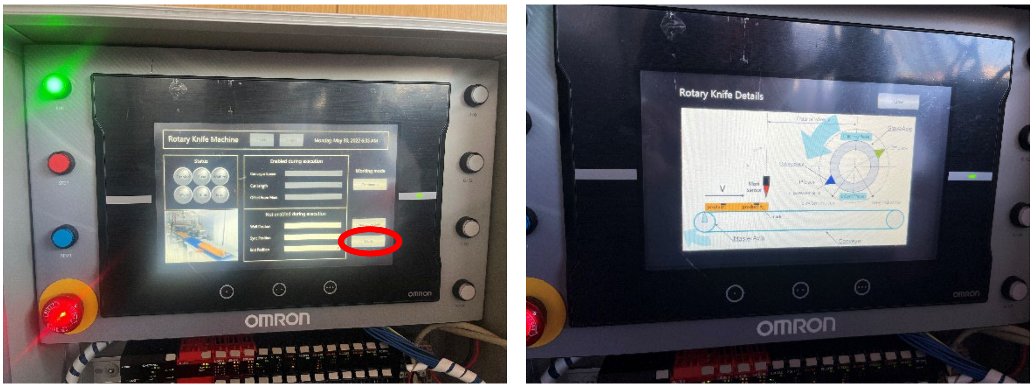


Figure 5.1.10. Access to the HMI screen with the parameter's description (source: own).

- To return to the main HMI screen, please use the 'Close' button from the HMI.

Figure 5.1.11. Returning to the main HMI screen (source: own).

- Select the working mode for the system through the HMI: Continuous or Mark to Mark mode.

Figure 5.1.12. Working mode button (source: own).

- Press the Run button close to the HMI, the 2 servo motors (master axis and slave axis) will be powered and will do homing operation. The conveyor (master axis) will start running with the predefined speed (150 mm/s).

Figure 5.1.13. Run button (source: own).

- The Enable button from the HMI will be enabled after homing operation. Touch it and the rotary knife (slave axis) will go to the waiting position [SlaveConfig.WaitPos].

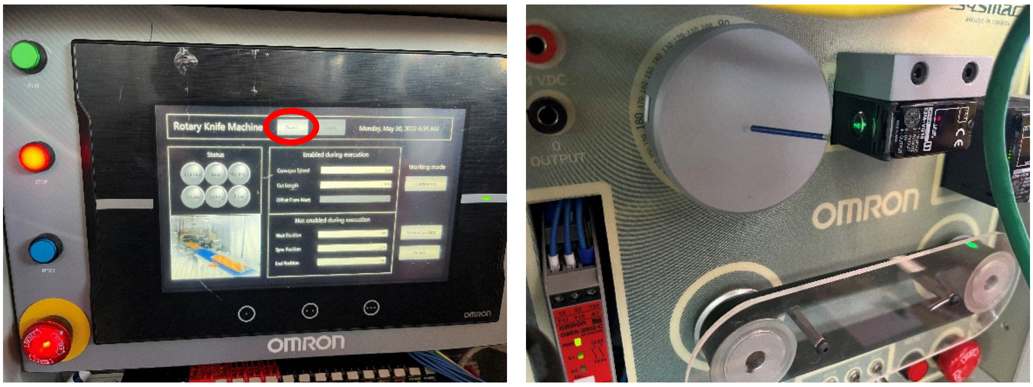


Figure 5.1.14. Enable button (source: own).

- The Couple button from the HMI will be enabled. Touch it and the and the rotary knife (slave axis) will start the synchronization with the conveyor according to the selected working mode in the HMI.

Figure 5.1.15. Couple button (source: own).

- The Status section from the HMI will show the outputs of the RK_SyncRotary FB for checking the correct library operation.

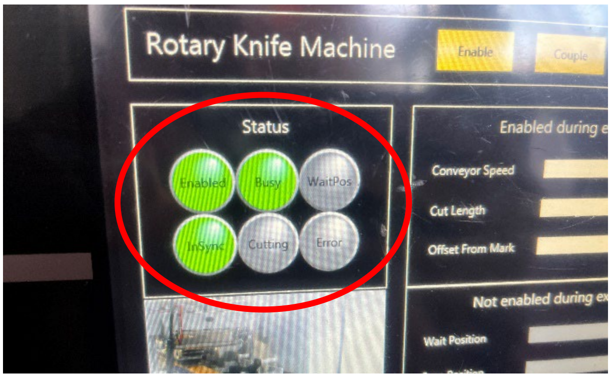


Figure 5.1.16. RK_SyncRotary FB status (source: own).

- It is not possible to change the working mode while the rotary knife library is running. For changing it, please stop the rotary knife operation using the Stop button close to the HMI and the working mode button from the HMI will be enabled.

Figure 5.1.17. Stop button (source: own).

- There are some parameters that can be changed during machine operation and other ones that are not possible (is necessary to stop the rotary knife operation for changing them).
- The value of the following parameters can be changed during rotary knife operation:
    - Conveyor Speed [from 0 to 300 mm/s]
    - Cut Length (the cut length meaning depends on the selected working mode) [from 0 to 500 mm]
    - Offset (only valid when using mark to mark working mode) [from 0 to 50 mm]

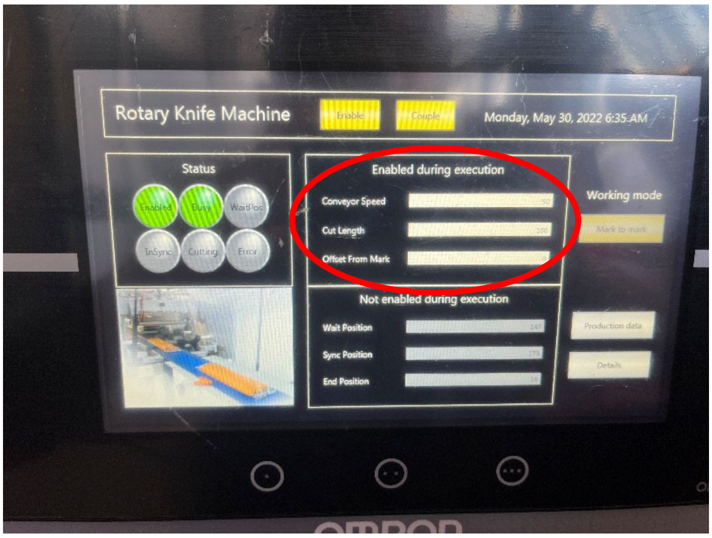


Figure 5.1.18. Parameters that can be changed during machine operation (source: own).

- The value of the following parameters cannot be changed during rotary knife operation. It is necessary to stop the rotary knife operation for changing them:
    - Wait Position [from 140 to 150 mm]
    - Sync Position [from 155 to 180 mm]
    - End Position [from 15 to 40 mm]

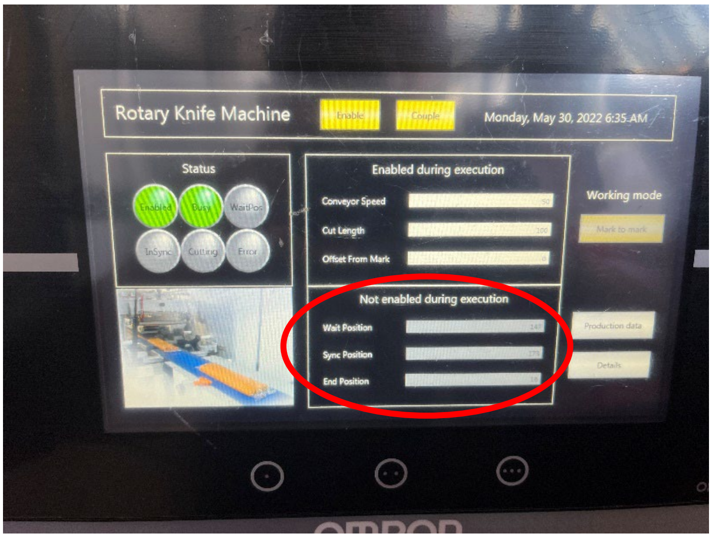


Figure 5.1.19. Parameters that cannot be changed during machine operation (source: own).

- Access to the Production data using the ‘Production data’ button from the HMI screen.

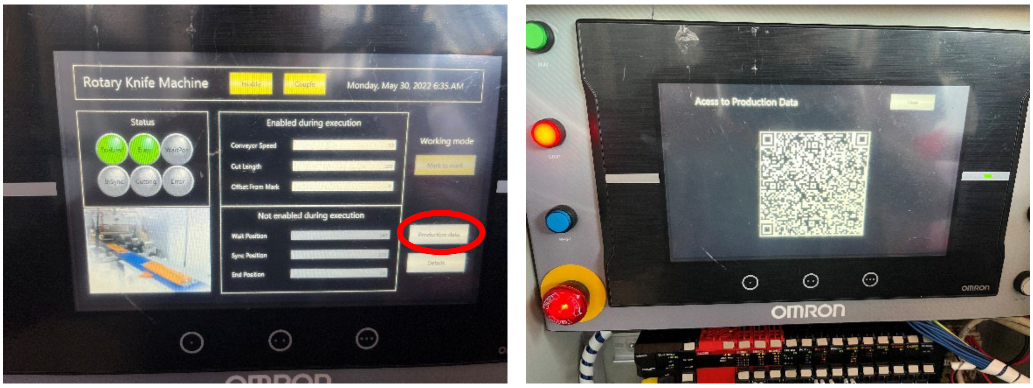


Figure 5.1.20. Access to the HMI screen with the Production data (source: own).

- To see the efficiency of the machine and the production data, please scan the QR code with a SmartPhone or a Tablet and it will redirect you to a real-time Dashboard.

Figure 5.1.21. Access to the real-time Dashboard (source: own).

- For shutting down the demo case, just stop the machine with the Stop button and turn off the demo case.

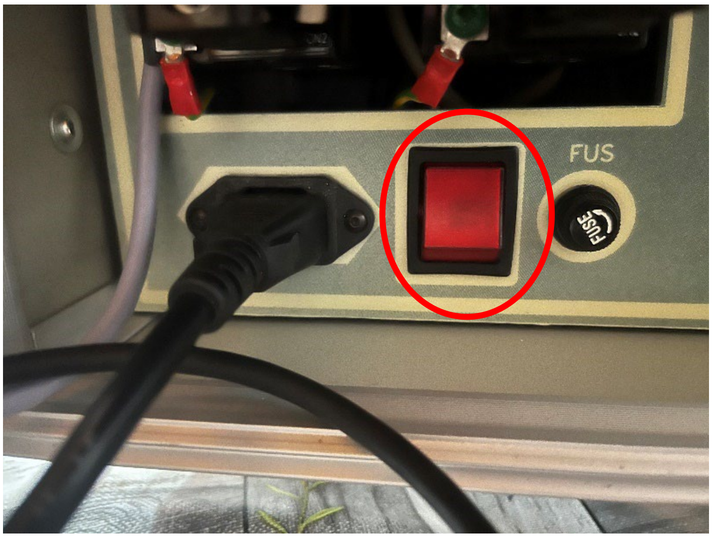


Figure 5.1.22. Shutting down the demo (source: own).

5.2. Using the E-Stop button

- For immediately stopping the machine (i.e. there is a safety risk) please push the E-Stop button.

Figure 5.2.1. E-Stop button (source: own).

- The HMI screen will show some safety errors in the troubleshooter menu. The rotary knife servo drive is in safety mode.

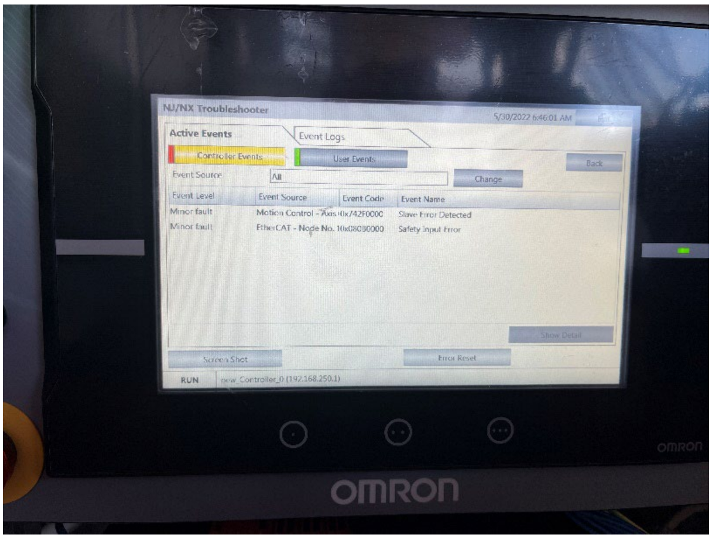


Figure 5.2.2. HMI troubleshooter menu (source: own).

- For starting again demo operation, please release the E-Stop button.

- Reset the system through the Reset button close to the HMI.

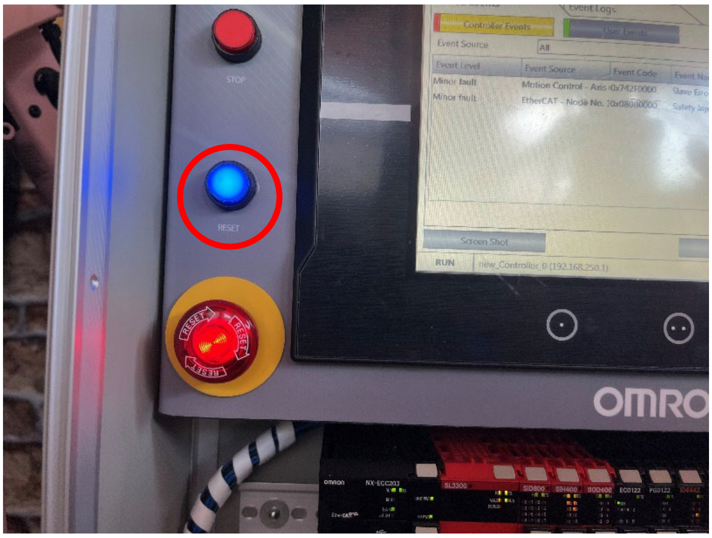


Figure 5.2.3. Reset button (source: own).

- Reset the Safety input error with the 'Error Reset' button from the HMI.

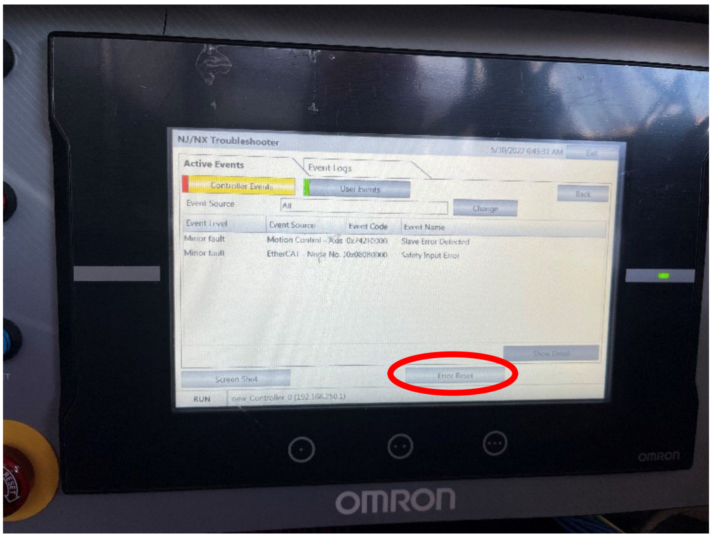


Figure 5.2.4. Error Reset button from the HMI Troubleshooter menu (source: own).

- Now there is no error in the HMI troubleshooter menu. Exit from this menu with the 'Exit' button.

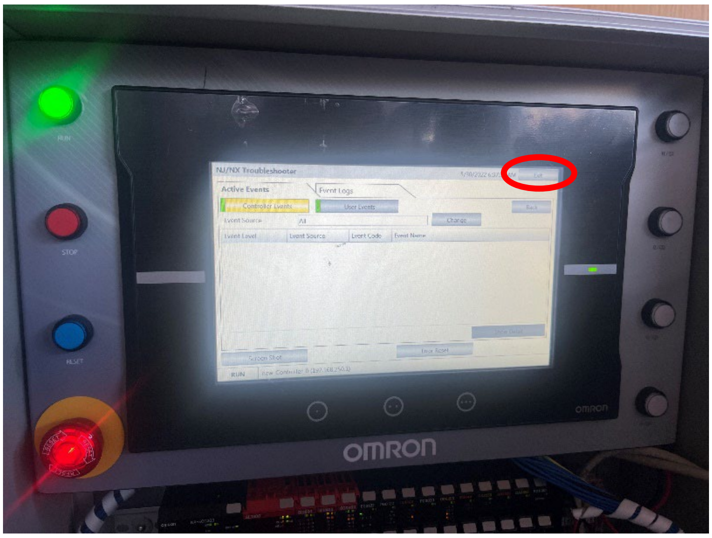


Figure 5.2.5. HMI Troubleshooter menu (source: own).

- Now is possible to start again demo operation.

Figure 5.2.6. Main HMI screen (source: own).

6. Data trace

Data trace option from Sysmac Studio has been used to check the correct demo operation for the cutting configuration modes 0 (continuous) and 1 (mark to mark) during the thesis.

6.1. Continuous mode

In this section the correct demo operation has been tested when Continuous mode is selected through the HMI. The following default parameters have been used. The meaning of each parameter is detailed in the section '4.2.7. Initial input variable values'.

- MasterConfig.CountCfg.ModuloMaxPos = 500
- SlaveConfig.CountCfg.ModuloMaxPos = 188.4
- SlaveConfig.WaitPos = 146.5
- SlaveConfig.SyncPos = 172.7
- SlaveConfig.EndPos = 15.7
- CuttingConfig.CutLength = 100
- Conveyor Speed = 150

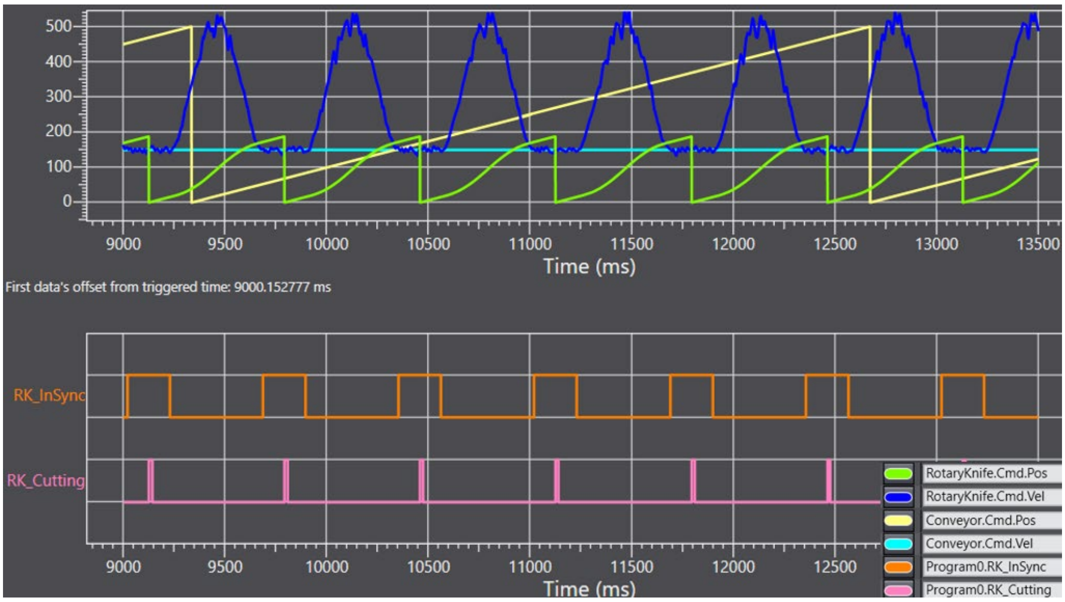


Figure 6.1.1. Data trace with default parameters in continuous mode (source: own).

From the above data trace we can see how the conveyor position (Conveyor.Cmd.Pos) is cleared every 500 mm and the rotary knife position (RotaryKnife.Cmd.Pos) is cleared every 188.4 mm (perimeter of the rotary knife). The conveyor velocity (Conveyor.Cmd.Vel) is constant at 150 mm/s and the rotary knife velocity (RotaryKnife.Cmd.Vel) changes during the execution of the RK_SyncRotary library. When the rotary knife is inside the synchronization phase (RK_InSync) the conveyor velocity and the rotary knife velocity is the same for cutting operation (RK_Cutting).

In the following data trace, the conveyor speed has been modified from 150 mm/s to 200 mm/s:

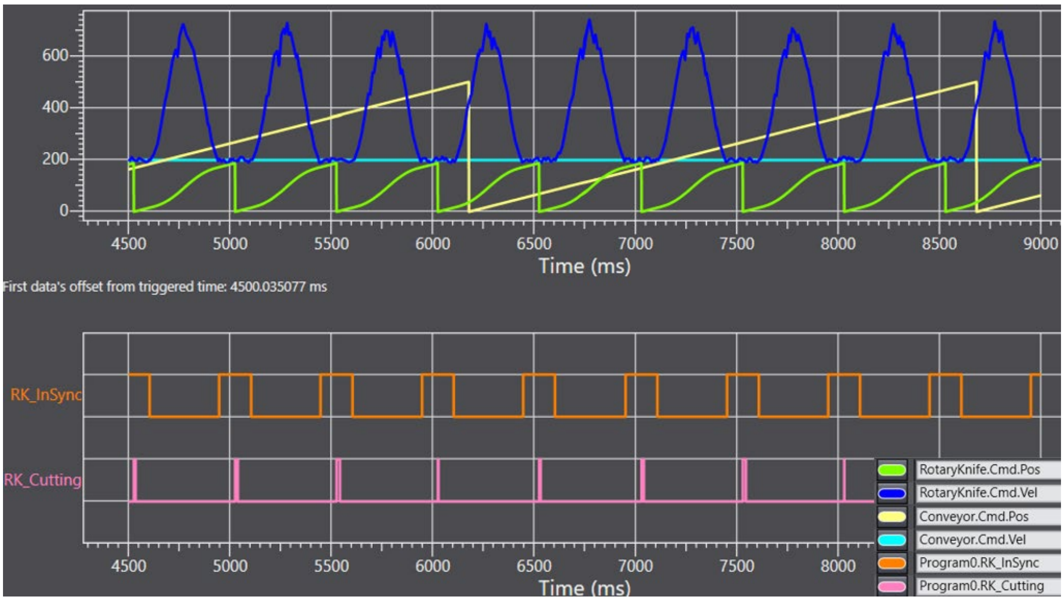


Figure 6.1.2. Data trace with conveyor speed modified to 200 mm/s (source: own).

From the above data trace we can see how the conveyor velocity (Conveyor.Cmd.Vel) is constant at 200 mm/s. For this reason, the rotary knife velocity (RotaryKnife.Cmd.Vel) is faster than in the previous case during the catching phase (non-synchronization section). The time between cutting operations (RK_Cutting) is shorter because the conveyor speed is faster than in the 1st data trace.

In the following data trace, the cut length has been modified from 100 mm to 50 mm:

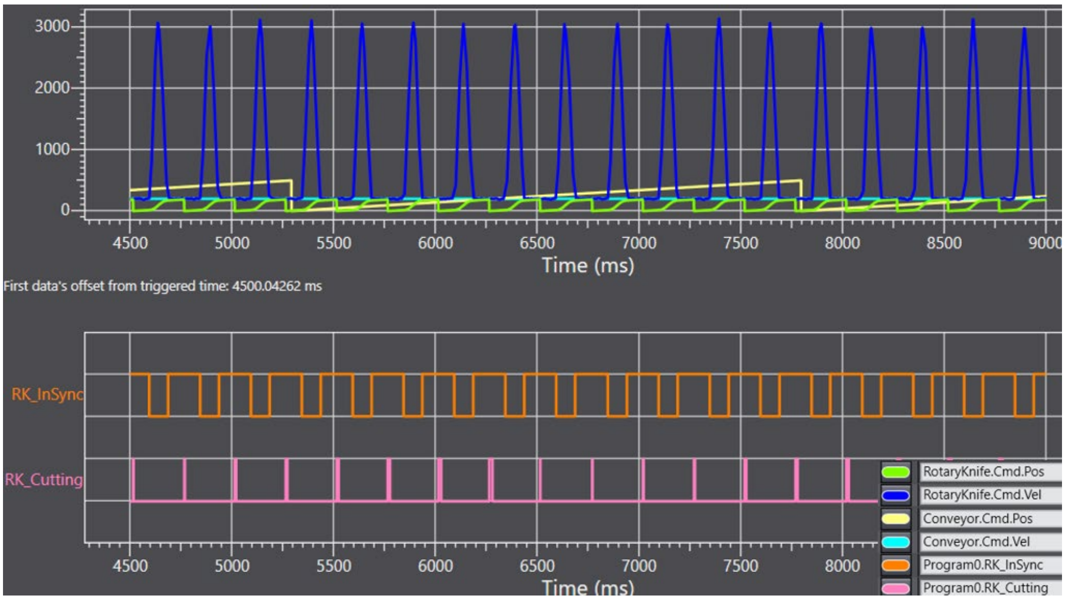


Figure 6.1.3. Data trace with cut length modified to 50 mm (source: own).

In the above data trace we can observe how the peak of the rotary knife velocity (RotaryKnife.Cmd.Vel) is very high because the conveyor speed (Conveyor.Cmd.Vel) is faster and the cut length is shorter than in the 1st data trace. The time between cutting operations (RK_Cutting) has been dramatically reduced compared to the 1st data trace. Also, the catching phase (non-synchronization section) has been shortened.

6.2. Mark to mark mode

In this section the correct demo operation has been tested when Mark to mark mode is selected through the HMI. The same default parameters than in Continuous mode (previous chapter 6.1) have been used. The meaning of each parameter is detailed in the section '4.2.7. Initial input variable values'.

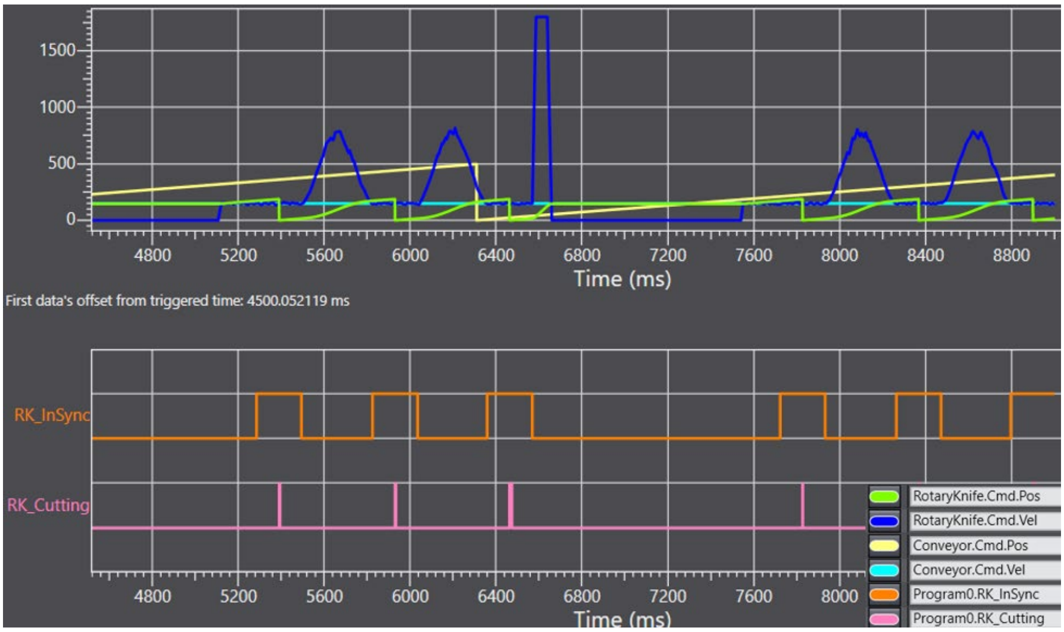


Figure 6.2.1. Data trace with default parameters in mark to mark mode (source: own).

In this mode the cutting operation is done when a mark is detected through the mark sensor. When there is no mark in the conveyor, the rotary knife (RotaryKnife.Cmd.Pos) remains in the waiting position (i.e. the velocity of the rotary knife is 0 between 6,600 ms and 7,500 ms) until a new mark is detected.

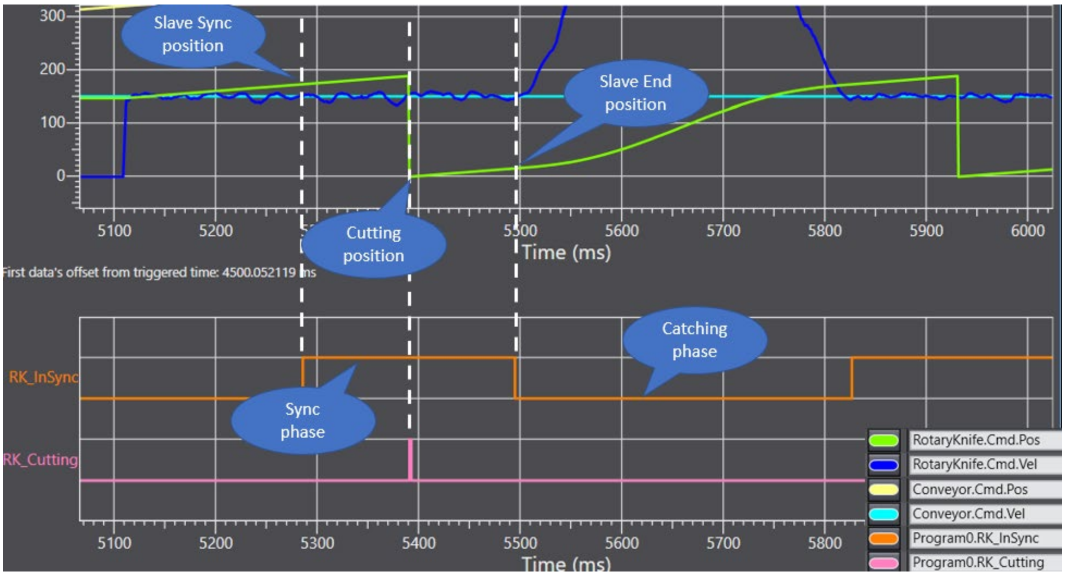


Figure 6.2.2. Details of the data trace in mark to mark mode (source: own).

The above data trace shows the details of the synchronization between rotary knife and conveyor. During the synchronization phase the rotary knife and conveyor are at the same speed, during the catching phase both have different speeds. The cutting position is in the homing position (0 mm) of the rotary knife. The slave sync position (172.7) and end position (15.7) are the ones defined previously.

In the following data trace, the conveyor speed has been modified from 150 mm/s to 200 mm/s:

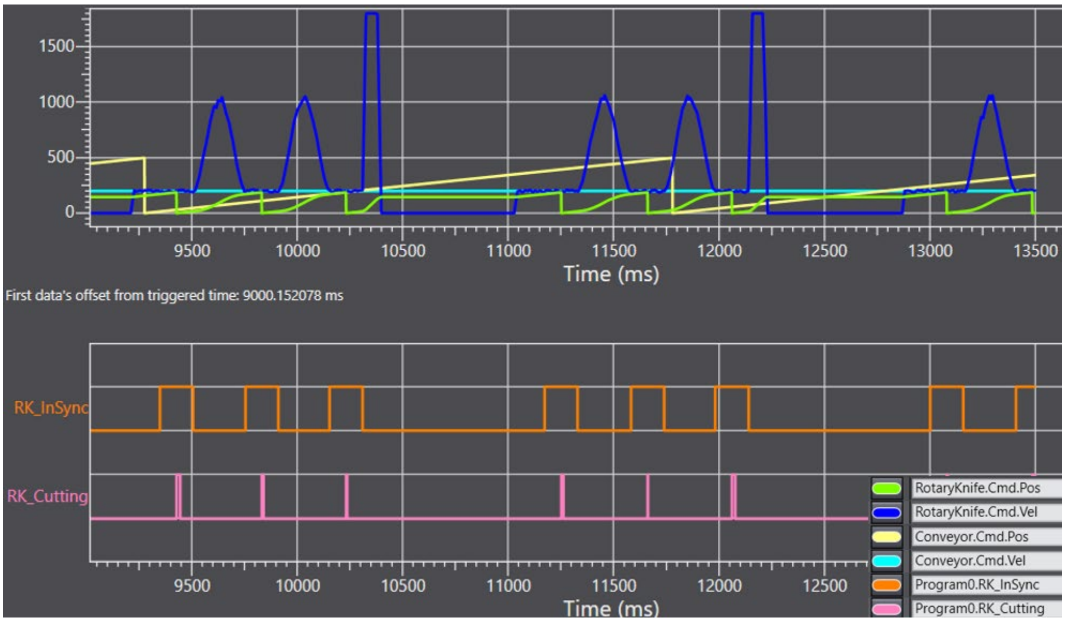


Figure 6.2.3. Data trace with conveyor speed modified to 200 mm/s (source: own).

The rotary knife velocity (RotaryKnife.Cmd.Vel) is faster than in the 1st data trace during the catching phase (non-synchronization section). The time between cutting operations (RK_Cutting) is shorter when there are marks in the conveyor.

When an offset is applied (with the ‘Offset From Mark’ option from the HMI) the system adds an offset to the position where the mark is detected for cutting operation.

7. Data monitoring

The process of production data collection and sharing this data to a web application is described in this section.

7.1. MQTT protocol

The MQTT (Message Queuing Telemetry Transport) protocol has been used in this thesis. MQTT is a very popular open and standard communication protocol for IoT devices to exchange data to Cloud services. MQTT works using a MQTT server that collects the published messages from the MQTT clients under a 'Topic'. The MQTT client can also be subscribed on different topics from the MQTT server. Leading Cloud companies such as AWS, MSAzure, IBM and others includes a MQTT server to get data from MQTT clients.

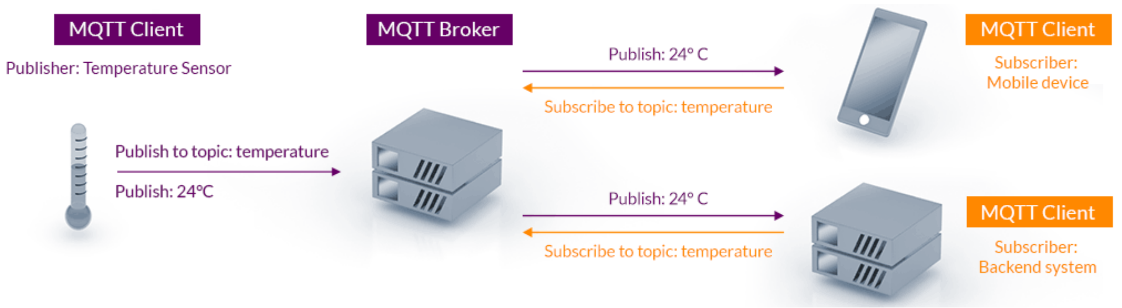


Figure 7.1.1. MQTT Publish/Subscribe architecture (source: [5]).

The MQTT library version 0.0.46 from Omron has been used in this thesis to send the production data from NJ-series machine controller to the web application using the MQTT protocol. The FBs used in this thesis for it are the following ones:

- **MQTT Client:** FB to connect the MQTT client to the MQTT server.
- **MQTT Ping:** FB that sends periodically (every 30 seconds) a heart bit command to notify the MQTT server than the connection is alive.
- **MQTT Publish:** FB to publish data from the MQTT client to the MQTT server. The data are published every second.

The NJ-series machine controller from the compact demo case is used as MQTT client. The MQTT server in this case is the web application (Dashboard).

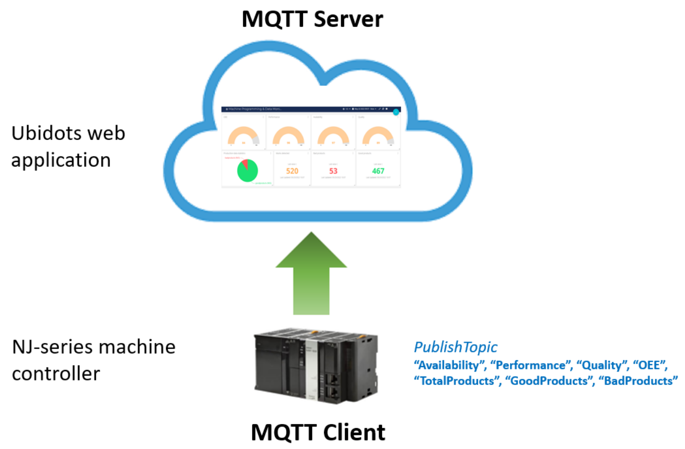


Figure 7.1.2. MQTT Server and Client from this thesis (source: own).

7.2. JSON data format

JSON (JavaScript Object Notation) is one of the most popular data formats for IT and for IoT devices. It's easy for humans to read and write. JSON can be used to easily exchange data to web applications and Cloud services.

A JSON data structure consists of one or more pairs of names and values separated by comma (,) and delimited by keys {..}.

```
{
  "TimeStamp":"2017-11-08T15:37:58.926Z",
  "Stage":"On Preparation",
  "Temperature": 98.7,
  "Pressure": 1568,
  "PH": 7,
  "Pump": true,
  "Heater": false
}
```

Figure 7.2.1. Example of JSON Data format (source: own).

The JSON data format is used to send data to the server. The JSON Encoding library version 0.0.57 from Omron has been used in this thesis to convert the NJ-series variables to JSON string to be shared with the MQTT server (Dashboard).

Figure 7.2.2. Data conversion to JSON format with the JSON Encoding Library (source: own).

The production data variables converted to JSON format in this thesis are the following ones:

- **Availability:** Machine Availability
- **Performance:** Machine Performance
- **Quality:** Production Quality
- **OEE:** Overall Equipment Efficiency
- **TotalProducts:** Total number of products (products detected by the mark sensor + bad products simulated by the user)
- **GoodProducts:** Number of cut products by the rotary knife
- **BadProducts:** Number of products not cut by the rotary knife

7.3. OEE

OEE (Overall Equipment Efficiency) is the standard for measuring manufacturing productivity. An OEE score of 100% means the machine is manufacturing only good parts, as fast as possible, with no Stop time.

By measuring OEE and the underlying losses, it is possible to gain important insights on how to improve the manufacturing process.

OEE parameter is the result of the following operation:

- Availability x Performance x Quality

Figure 7.3.1. OEE operation (source: [6]).

The description of each parameter is shown in the following picture:

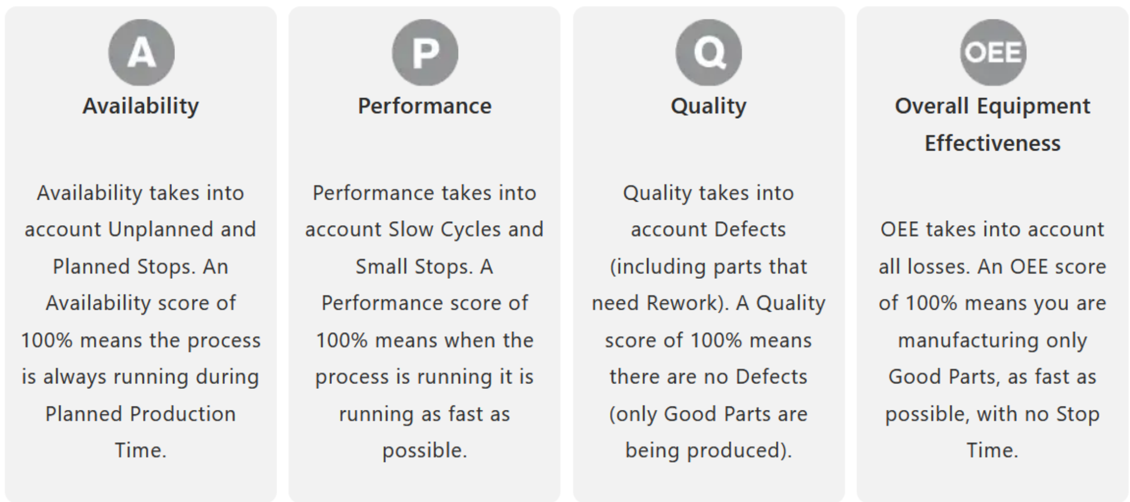


Figure 7.3.2. Description of each OEE parameter (source: [6]).

7.4. Dashboard

The web application (Dashboard) used in this thesis is from Ubidots. It is a free software version for students. This free software version is limited to:

- **Use:** Limited to non-commercial use only
- **Devices:** Connection of up to 3 devices free
- **Variables:** Up to 10 variables per device
- **Data ingestion:** 4,000 dots per day
- **Data extraction:** 500,000 dots per day
- **Data rate:** 1 request per second
- **Data retention:** 1 month
- **Dashboards:** Up to 3 dashboards

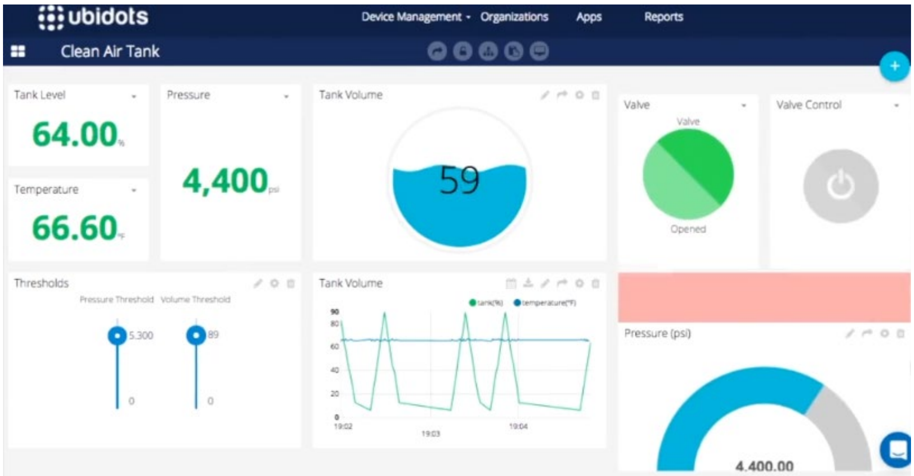


Figure 7.4.1. Example of an Ubidots Dashboard (source: [4]).

This web application is used as a MQTT server to collect the production data information from the NJ-series machine controller.

The OEE (Overall Efficiency Equipment), Performance, Availability and Quality of the machine is shown in the Dashboard. In addition, it also shows the production data (total number of products, good products and bad products). The data published by the MQTT client is refreshed every second in the Dashboard.

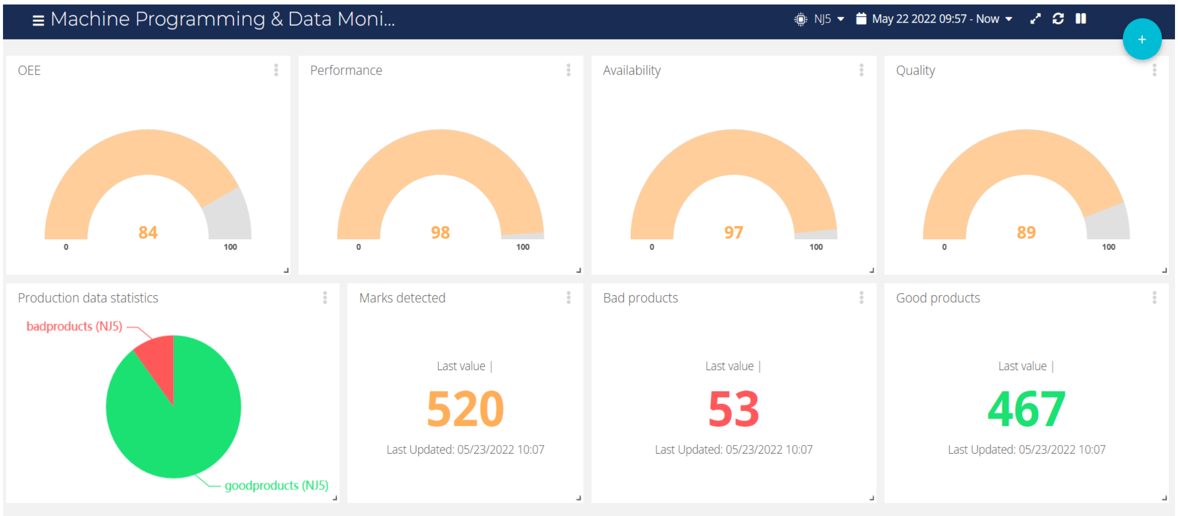


Figure 7.4.2. Dashboard from this thesis (source: own).

It is also possible to access to the Dashboard with a Smartphone or a Tablet scanning the QR code available on the HMI screen.

Figure 7.4.3. Access to the Dashboard with the QR code (source: own).

Environmental impact analysis

The product developed in this thesis would not directly affect to the environment because it is simulated with a compact demo case.

But when this project is used in a real rotary knife machine will require electrical power and this would affect to the environment depending on the technology used by the company providing the service.

Conclusions

The thesis is based on a real machine simulation. It covers different automation disciplines like Motion, Safety, HMI and Data monitoring.

The first step of the thesis was to understand how the different products were connected and wired in the compact demo case to correctly configure them in the Sysmac Studio software tool. After that, was necessary to understand how the different libraries created by Omron works (Rotary Knife, MQTT, JSON Encoding) to program the thesis application. Finally, when the machine was ready to work, it was necessary to acquire an industrial router for sharing production data information with a MQTT server (Ubidots Dashboard).

The main benefits provided by the program created in this thesis are the following ones:

- The rotary knife delivers high-precision product cutting at high-working speeds.
- Some options available in the HMI program, such as ‘Mark to mark’ working mode or the ‘Offset from mark’ option allow flexible production to the user.
- The real-time OEE (Overall Equipment Effectiveness) and Production Data visualization allows the user to see production line bottlenecks to improve the manufacturing process.

It has not been possible to include all the interesting machine information for the user in the real-time Dashboard due to the limitations of the Ubidots free-license for students. It would have been interesting to include the following data in the Dashboard:

- Rotary knife and Conveyor speed
- Maintenance data:
  - Motors temperature
  - Motors time in operation
- Alarms and errors history
- MQTT connection status

The thesis application could be easily reused in real machines just adapting some parameters such as the perimeter of the rotary knife or the distance between the mark sensor and the rotary knife with the real machine data.

Budget

There are two types of expenses in this thesis: Hardware and Engineering.

- Hardware: Considers all the required devices for developing and running this thesis.
- Engineering: Considers the necessary time for developing the thesis and create the related documentation.

- Hardware

No	Supplier	Reference	Description	Price	Qty	Total price
1	Omron	NJ501-1500	NJ5 Machine Controller, 20 MB memory, built-in EtherCAT (64 servo axes) and EtherNet/IP	7,601.58 €	1	7,601.58 €
2	Omron	NA5-9W001B-V1	Touch screen HMI, 9-inch-wide screen, TFT LCD, 24bit color, 800x480 resolution, frame color: Black	2,431.95 €	1	2,431.95 €
3	Omron	R88D-KN01H-ECT	G5 servo drive EtherCAT type, 100 W, 230 V	867.40 €	2	1,734.80 €
4	Omron	R88M-K10030H-S	G5 servo motor, 100 W, incremental encoder	475.92 €	2	951.84 €
5	Omron	R88A-CRKA001-5CR-E	Encoder cable for G5, 1.5 m	105.39 €	2	210.78 €
6	Omron	R88A-CAKA001-5SR-E	Power cable without brake for G5, 1.5 m	150.57 €	2	301.14 €
7	Omron	R88A-CSK003S-E	Safety cable for G5, 3 m	66.25 €	2	132.50 €
8	Omron	NX-ECC203	NX I/O, EtherCAT Coupler, 2 ports, 125 µs cycle time, 63 I/O units, max I/O current 10 A, screwless push-in connector, delivered with end cover	418.79 €	1	418.79 €
9	Omron	NX-SL3300	NX I/O, Safety controller, 32 safety master connections, up to 256 safety I/O	576.20 €	1	576.20 €
10	Omron	NX-SID800	NX I/O, 8 Digital Safety Input, PNP 24 VDC, screwless push-in connector, 12 mm wide	347.11 €	1	347.11 €
11	Omron	NX-SIH400	NX I/O, 4 Digital Safety Input, PNP 24 VDC, screwless push-in connector, 12 mm wide	249.91 €	1	249.91 €

12	Omron	NX-SOD400	NX I/O, 4 Digital Safety Output, PNP 24 VDC, 0.5 A/point, 2.0 A/NX Unit, screwless push-in connector, 12 mm wide	201.86 €	1	201.86 €
13	Omron	NX-ID4442	NX I/O, 8 Digital Input, Standard speed, PNP 24 VDC, screwless push-in connector, 12 mm wide	74.21 €	1	74.21 €
14	Omron	NX-OD4256	NX I/O, 8 Digital Output, Standard speed, PNP 24 VDC, 0.5 A/point, 4 A/NX Unit, screwless push-in connector, 12 mm wide	96.49 €	1	96.49 €
15	Omron	NX-PC0030	NX I/O, Power connection unit, IOV+IOG, 5-24 V DC input, 8 + 8 terminals, screwless push-in connector, 12mm wide	61.17 €	1	61.17 €
16	Omron	E3M-VG16	Mark sensor, 10+3 mm setting distance, 1 x 4mm spot diameter, PNP output	53.54 €	2	107.08 €
17	Omron	G9SB-2002-C	Safety relay, 2 safety contacts, inverse input type, 24 VAC/VDC	201.86 €	1	201.86 €
18	Omron	A22L-TG	Pushbutton lighted, projection type, green color	1.83 €	1	1.83 €
19	Omron	A22-24AG	LED lamp, green color, 24 V	28.67 €	1	28.67 €
20	Omron	A22L-TR	Pushbutton lighted, projection type, red color	1.83 €	1	1.83 €
21	Omron	A22-24AR	LED lamp, red color, 24 V	28.67 €	1	28.67 €
22	Omron	A22L-TA	Pushbutton lighted, projection type, blue color	1.83 €	1	1.83 €
23	Omron	A22-24AA	LED lamp, blue color, 24 V	28.67 €	1	28.67 €
24	Omron	A22-10M	Pushbutton switch, momentary switch operation	16.20 €	3	48.60 €
25	Omron	A22E-MP-01	E-Stop pushbutton, 40-dia. Head, Medium Pull-reset, 1 NC	48.80 €	1	48.80 €
26	Omron	W4S1-05B	Ethernet hub, 5 ports	312.70 €	1	312.70 €
27	Omron	XS6W-5PUR8SS100CM-G	Ethernet cable, 1 m	16.86 €	2	33.72 €
28	Omron	XS6W-5PUR8SS50CM-	Ethernet cable, 0.5 m	14.72 €	1	14.72 €

		G				
29	Omron	XS6W-6LSZH8SS100CM-Y	EtherCAT cable, 1 m	17.79 €	1	17.79 €
30	Omron	XS6W-6LSZH8SS50CM-Y	EtherCAT cable, 0.5 m	12.87 €	1	12.87 €
31	Omron	XS6W-6LSZH8SS20CM-Y	EtherCAT cable, 0.2 m	11.72 €	1	11.72 €
32	Westermo	MRD-305-DIN	Industrial M2M/3G Gateway/Router	535.78 €	1	535.78 €
TOTAL WITHOUT IVA						**16,827.47 €**
IVA (21%)						**3,533.77 €**
TOTAL HARDWARE						**20,361.24 €**

Table Budget 1. Hardware.

- Engineering

Type	Price per hour	Qty	Total price
Programming and development	25 €	150	3,750 €
Documentation	15 €	50	750 €
TOTAL WITHOUT IVA			**4,500 €**
IVA (21%)			**945 €**
TOTAL ENGINEERING			**5,445 €**

Table Budget 2. Engineering.

- Total cost

Type	Total price
Hardware	20,361.24 €
Engineering	5.445 €
TOTAL PROJECT	**25,806.24 €**

Budget 3. Total cost of the thesis.

Bibliography

[1] Omron Europe website. <https://industrial.omron.eu/en/home>

[2] Mouser Electronics website. <https://www.mouser.es>

[3] Westermo website. <https://www.westermo.com>

[4] Ubidots website. <https://ubidots.com/stem/>

[5] MQTT website. <https://mqtt.org/>

[6] OEE website. <https://www.oee.com/>

[7] Omron, NJ-series CPU Unit Hardware User's Manual (W500-E1-29)

[8] Omron, G5-series with Built-in EtherCAT Communications User's Manual (I576-E1-05)

[9] Omron, NA-series Hardware User's Manual (V125-E1-02)

[10] Omron, NX-series EtherCAT Coupler Unit User's Manual (W519-E1-15)

[11] Omron, NX-series Safety Control Unit User's Manual (Z930-E1-20)

[12] Omron, Sysmac Studio V1 Operation Manual (W504-E1-39)

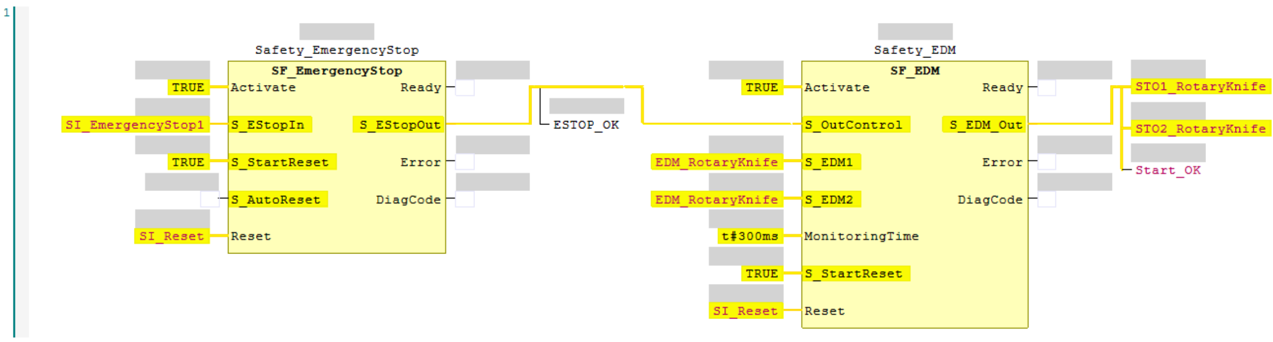
[13] Omron, Rotary Knife Function Block User's Manual (W531-E1-03)

[14] Omron, MQTT Library Function Block User's Manual

[15] Omron, JSON Encoding Function Block User's Manual

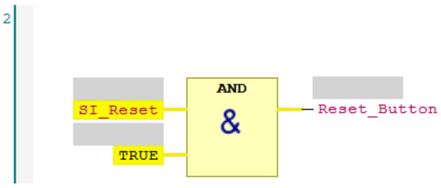
Annex A. Program

A.1. Safety



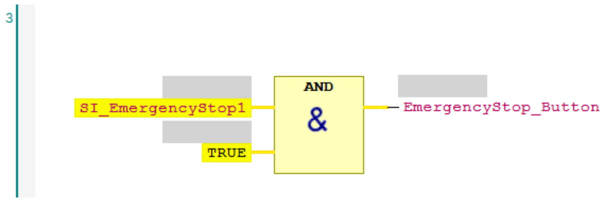
Line 1

The SF_EmergencyStop FB confirms the E-Stop button is not pressed and the system has been reset. The SF_EDM FB checks if the rotary knife is not in safety mode. If the previous conditions are meted, the machine can start operation through the output variable ‘Start_OK’. This variable is used to validate the system can start machine operation (main program).



Line 2

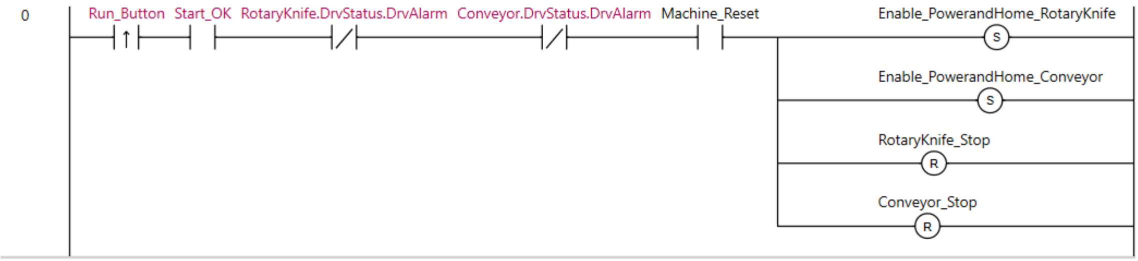
As the Reset button is connected to the Safety inputs (managed through the Safety CPU), with this condition the Reset button can be used in the main program from the machine controller. The ‘Reset_Button’ is an output variable from the Safety CPU.



Line 3

As the E-Stop button is connected to the Safety inputs (managed through the Safety CPU), with this condition the E-Stop button can be used in the main program from the machine controller. The 'EmergencyStop_Button' is an output variable from the Safety CPU.

A.2. Power and Home



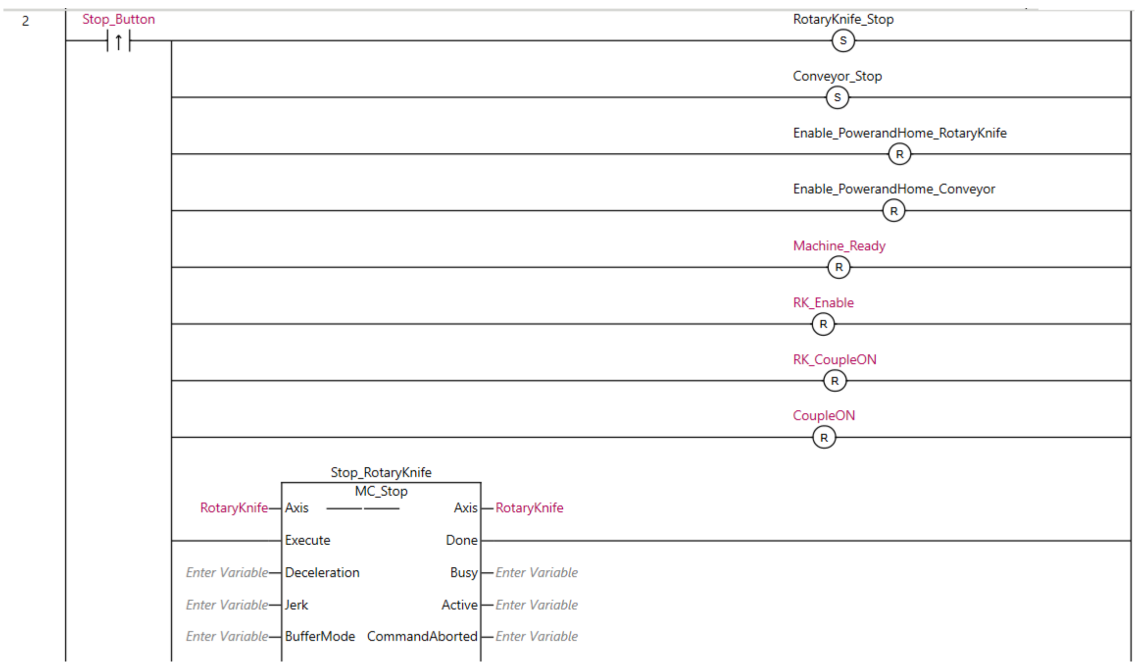
Line 0

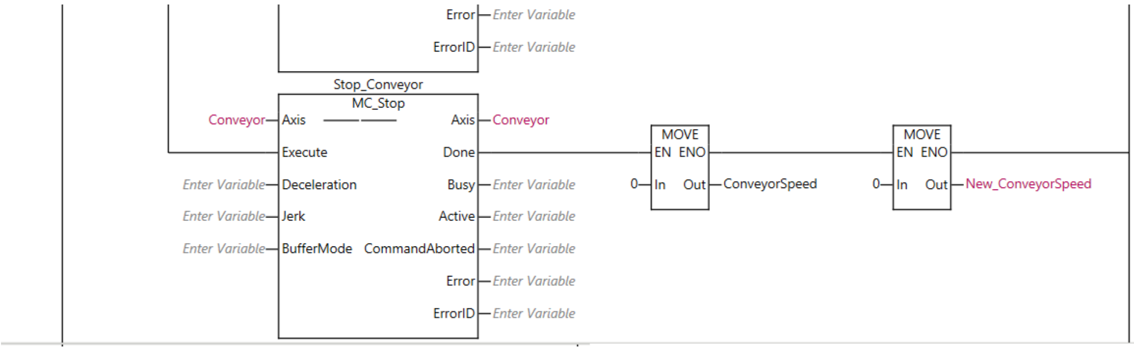
If the Run button is pressed, the validation from the Safety CPU is done and the servo drives are not in alarm mode, the machine can enable the power of both servo systems (rotary knife and conveyor).

```
IF(EmergencyStop_Button=TRUE)AND(Start_OK=TRUE)AND
(Enable_PowerandHome_RotaryKnife=FALSE)AND(Enable_PowerandHome_Conveyor=FALSE)THEN
    LED_Run:=TRUE;
ELSE;
    LED_Run:=FALSE;
END_IF;
```

Line 1

Conditions to manage the status of the Run button lamp.





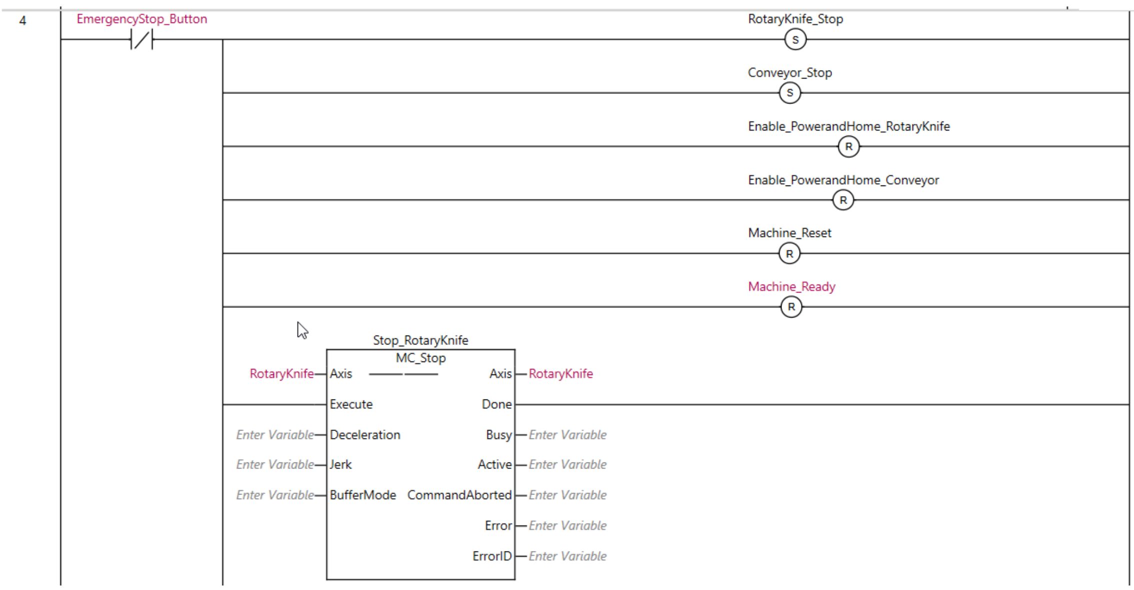
Line 2

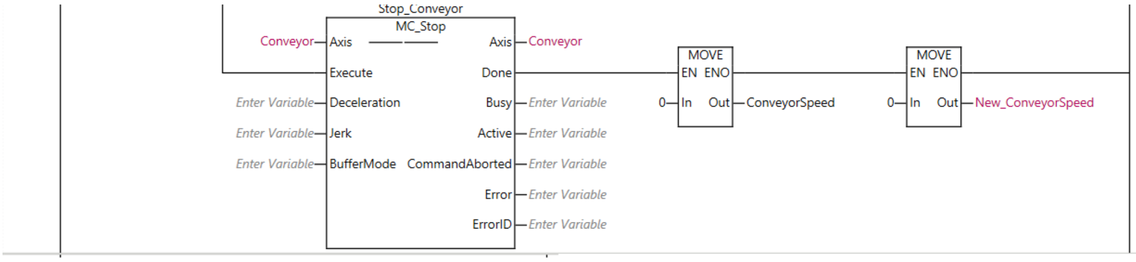
When the Stop button is pressed, the rotary knife and conveyor axes are stopped and the variables for managing the synchronization between rotary knife and conveyor are reset. The variables for managing the speed of the conveyor are set to '0'.

```
IF(EmergencyStop_Button=TRUE)AND(Machine_Ready=TRUE)THEN
    LED_Stop:=TRUE;
ELSE;
    LED_Stop:=FALSE;
END_IF;
```

Line 3

Conditions to manage the status of the Stop button lamp.





Line 4

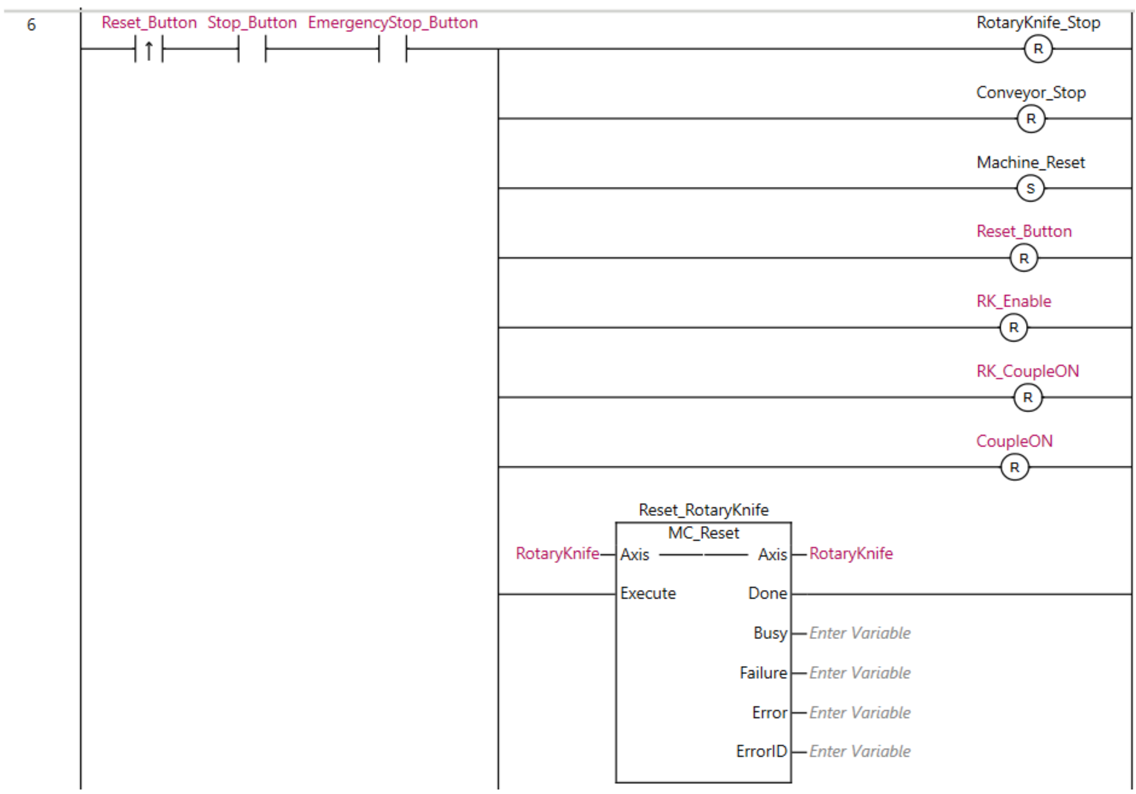
When the E-Stop button is pressed, both servo systems are stopped (rotary knife and conveyor), the machine is not ready for operation and the machine needs to be restarted through the Reset button. The variables for managing the speed of the conveyor are set to ‘0’.

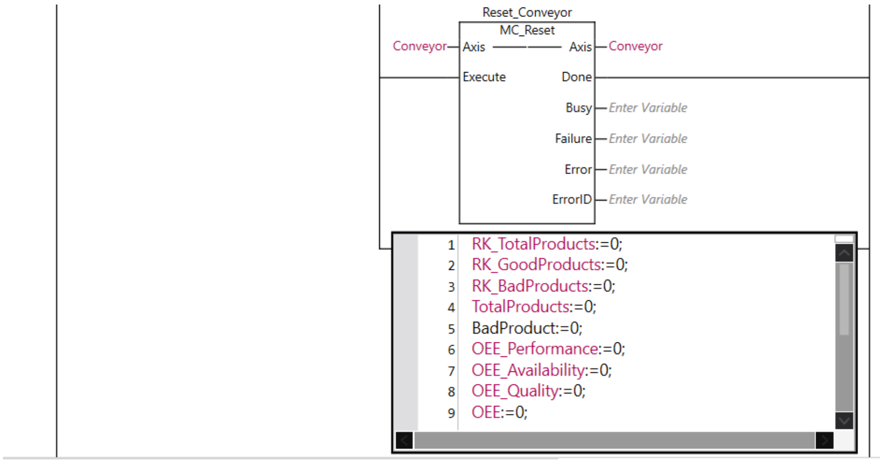
5

```
IF(EmergencyStop_Button=TRUE)THEN
    LED_EmergencyStop:=TRUE;
ELSE;
    LED_EmergencyStop:=FALSE;
END_IF;
```

Line 5

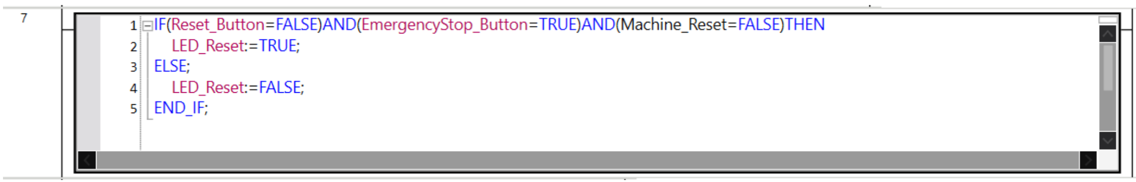
Conditions to manage the status of the E-Stop button lamp.





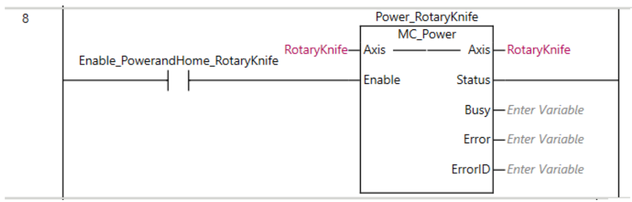
Line 6

When the Reset button is pressed, both servo systems are reset (rotary knife and conveyor) and the variables for managing the synchronization between rotary knife and conveyor are reset. The production data variables are cleared.



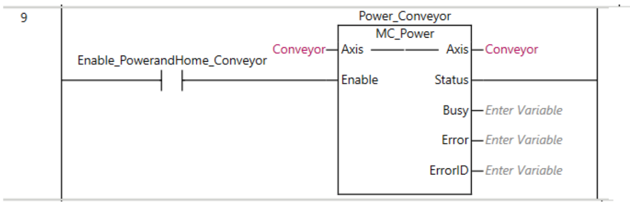
Line 7

Conditions to manage the status of the Reset button lamp.



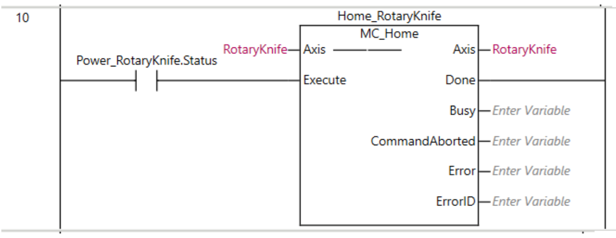
Line 8

The rotary knife motor is powered when is possible to start machine operation.



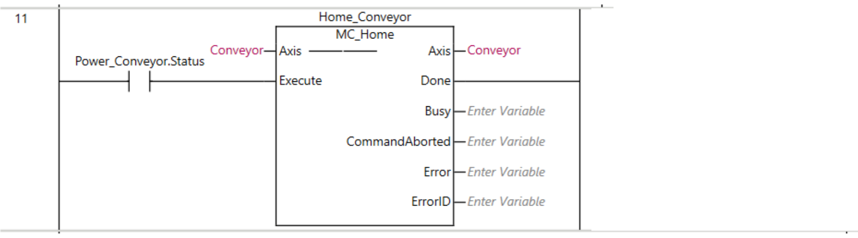
Line 9

The conveyor motor is powered when is possible to start machine operation.



Line 10

The homing operation of the rotary knife motor is done when the motor is powered.



Line 11

The homing operation of the conveyor motor is done when the motor is powered.

Line 12

If both servo systems (rotary knife and conveyor) are homed, the machine is ready to operate. The ‘Machine_Ready’ variable is used to enable the execution of the ‘Rotary Knife Program’.

A.3. Rotary Knife Program

```
0
IF(ModeSelection=FALSE) THEN
    CuttingConfig.Mode:=0; // Continuous mode
ELSE;
    CuttingConfig.Mode:=1; // Mark to mark mode
END_IF;
```

Line 0

The ‘ModeSelection’ variable is used to select the cutting mode (continuous or mark to mark mode) through the HMI.

```
1
Home_Conveyor.Done
New_ConveyorSpeed:=150;
```

Line 1

When the conveyor is homed, the initial speed is 150 mm/s.

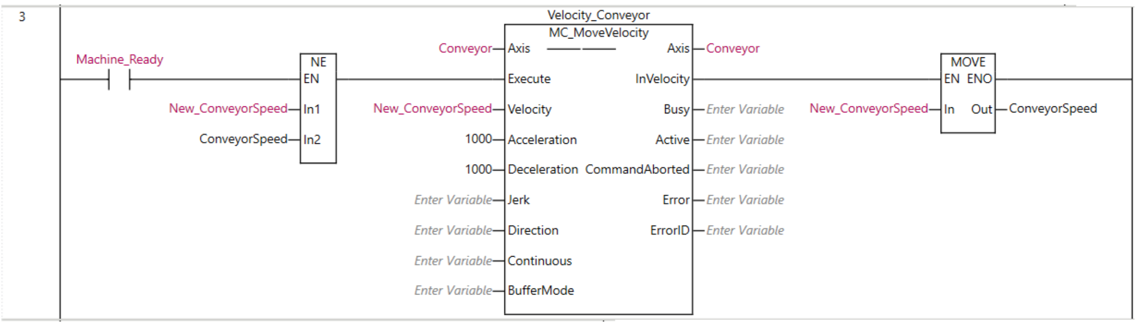
```
2
Machine_Ready
MasterConfig.CountCfg.ModuloMinPos:=0;
MasterConfig.CountCfg.ModuloMaxPos:=500;
MasterConfig.TriggerInput.Mode:= _mcDrive; //Drive mode
MasterConfig.TriggerInput.LatchID:= _mcLatch1; //Latch 1
MasterConfig.TriggerInput.InputDrive:= _mcEXT; //External input

SlaveConfig.CountCfg.ModuloMinPos:=0; //Home position of the rotary knife
SlaveConfig.CountCfg.ModuloMaxPos:=188.4; //Perimeter of the rotary knife
SlaveConfig.WaitPos:=146.5; //Wait position (146.5 mm = 280º)
SlaveConfig.SyncPos:=172.7; //Synchronization start position (172.7 mm = 330º)
SlaveConfig.EndPos:=15.7; //Synchronization end position (15.7 mm = 30º)
SlaveConfig.MaxVelocity:=4000; //Maximum velocity
SlaveConfig.Deceleration:=100000;
SlaveConfig.Acceleration:=100000;
SlaveConfig.BladeNum:=1; //One blade
SlaveConfig.ProfileType:=5; //5-order polynomial
SlaveConfig.VelocityToWaitPos:=1800; //Arpproaching velocity to Wait position
SlaveConfig.VelFactor:=100;

CuttingConfig.CutLength:=100; //Cut length (mm)
CuttingConfig.MasterSyncPos:=50; //Synchronous start position of master axis
CuttingConfig.DistanceToSensor:=129; //Distance between mark sensor and cutting position
CuttingConfig.OffsetFromMark:=0;
```

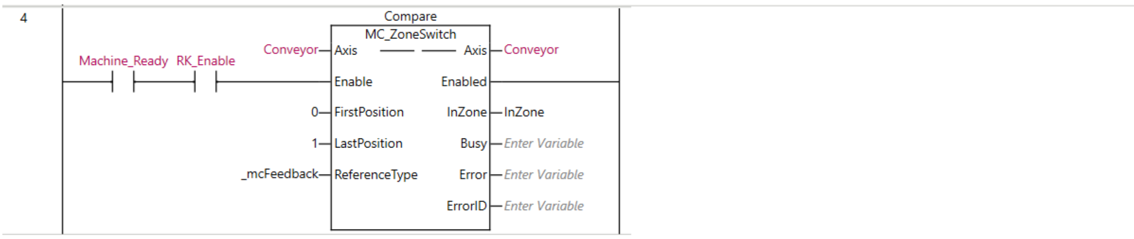
Line 2

Initial parameters for the master axis (conveyor), slave axis (rotary knife) and cutting configuration when the machine is ready to operate. The details of each value are described in the section ‘4.2.7. Initial input variable values’.



Line 3

The variable 'New_ConveyorSpeed' allows to change the speed of the conveyor through the HMI. Every time the current conveyor speed is not equal to the one set in the HMI, the MC_MoveVelocity FB is executed.



Line 4

After enabling the rotary knife operation (the rotary knife goes to the wait position) through the HMI, the MC_ZoneSwitch FB checks if the conveyor position is between the specified range (between 0 and 1 mm).

Line 5

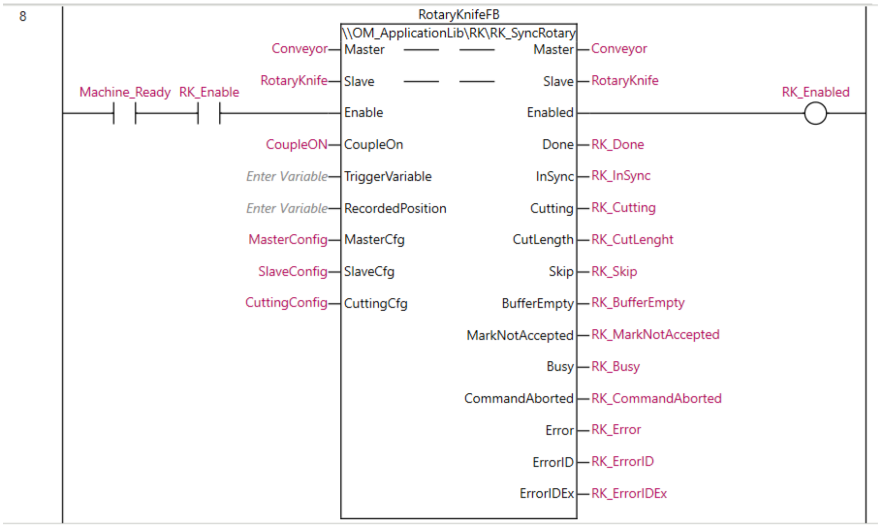
If the machine is ready for operation, the 'Couple_ON' button from the HMI is pressed and the conveyor position is between the specified range (between 0 and 1 mm), then is possible to start synchronization between the master axis (conveyor) and slave axis (rotary knife).

Line 6

If the machine is ready for operation, but the 'RK_Enable' button from the HMI is disabled, the 'RK_CoupleON' button from the HMI is also disabled.

Line 7

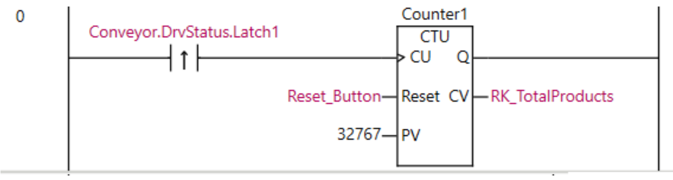
If the machine is ready for operation, but the 'RK_CoupleON' button from the HMI is disabled, the variable 'CoupleON' responsible to manage the synchronization between the master axis (conveyor) and slave axis (rotary knife) is reset.



Line 8

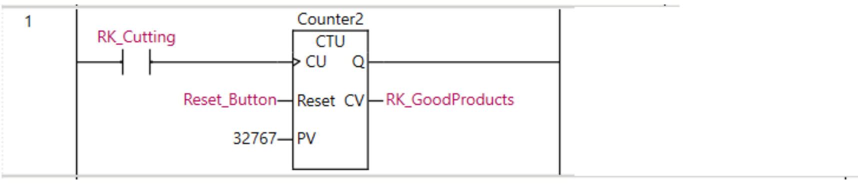
Input and output variables to manage the correct performance of the RK_SyncRotary library. The 'RK_Enabled' output is ON when the RK_SyncRotary library is working. The details of the input and output variables of the RK_SyncRotary library are described in the section '4.2. Variables'.

A.4. Data Monitoring



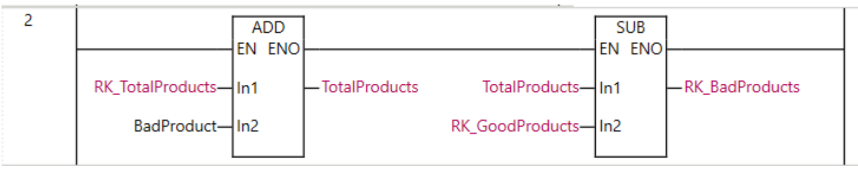
Line 0

FB to count the number of marks detected by the mark sensor in the conveyor.



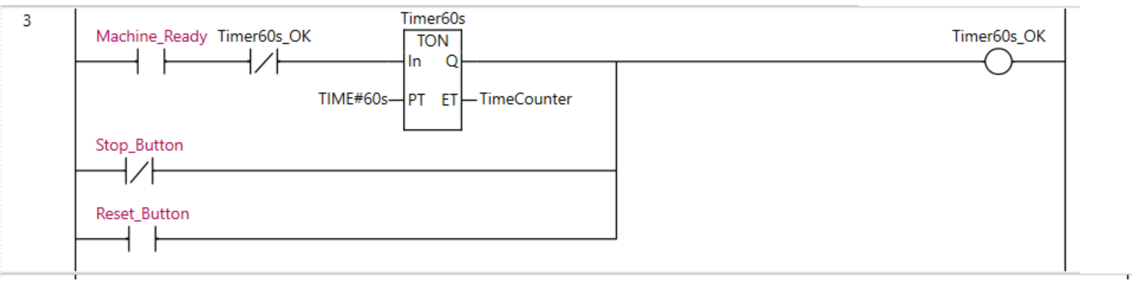
Line 1

FB to count the number of cut pieces during the operation of the RK_SyncRotary FB.



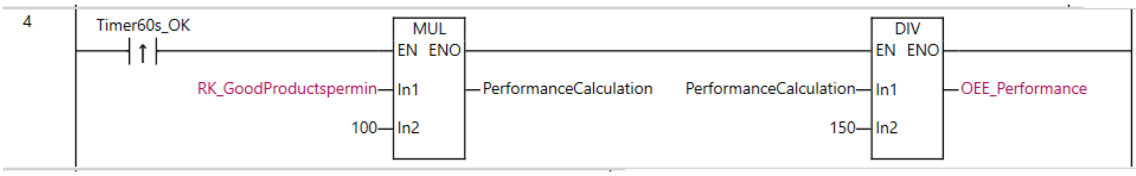
Line 2

The total number of products is the ones detected by the mark sensor plus the bad products simulated by the user. The number of bad products is the total number of products less the good products.



Line 3

Timer of 60s that starts when the machine is ready. The timer is restarted every 60s or every time the Stop or Reset button is pressed.

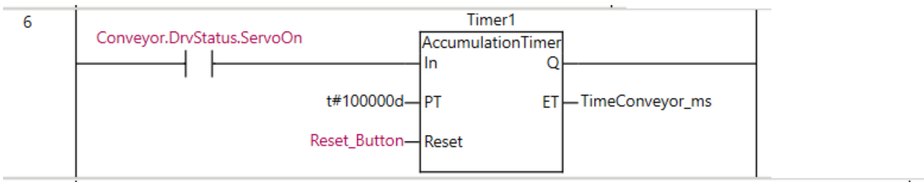


Line 4

Every 60s the calculation of the Machine Performance is done. The good products per minute counter is compared to the maximum production rate (150 pieces/min).

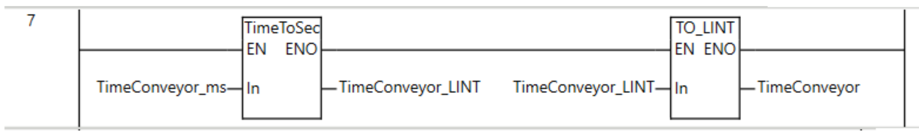
Line 5

FB to count the number of cut pieces (good products) per minute.



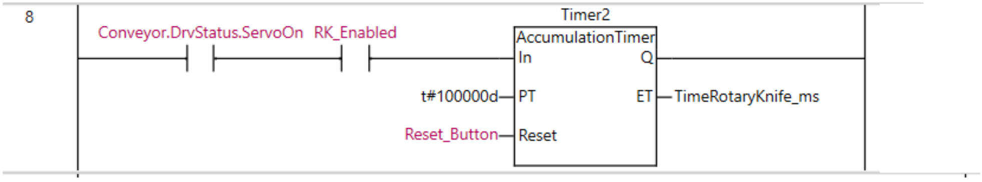
Line 6

FB to display the time than the conveyor motor is running.



Line 7

Conversion of the conveyor motor running time to an integer number.

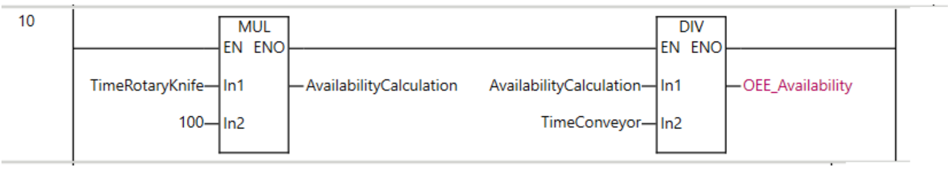


Line 8

FB to display the time than the rotary knife motor is running.

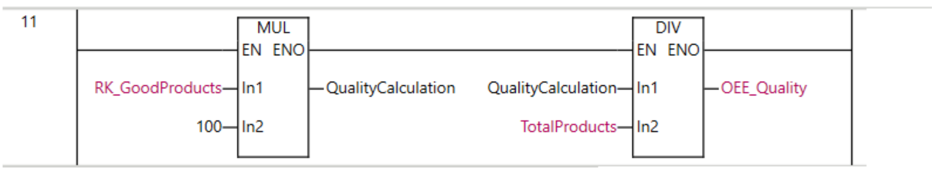
Line 9

Conversion of the rotary knife motor running time to an integer number.



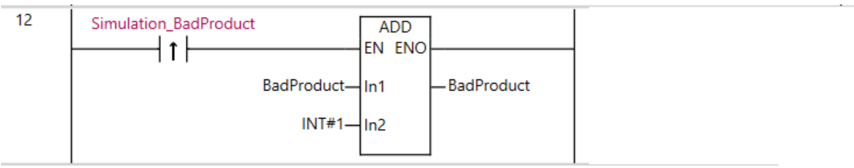
Line 10

Comparison between the time than the rotary knife is running and the time than the conveyor is running to calculate the Machine Availability.



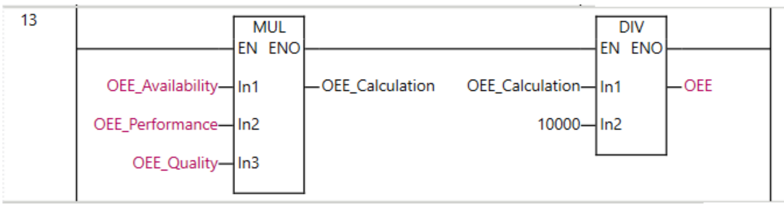
Line 11

Comparison between the total number of products (products detected by the mark sensor plus bad products simulated by the user) and the good products to calculate the Production Quality.



Line 12

Pushbutton that allows the user to simulate bad products.



Line 13

OEE (Overall Equipment Efficiency) calculation as a result of the following operation:

- Availability x Performance x Quality

14

```
// Conversion of the necessary data for the dashboard to JSON format
Clear(JSON_Buffer);
JSON_LINT('Availability', OEE_Availability, JSON_Buffer);
JSON_LINT('Performance', OEE_Performance, JSON_Buffer);
JSON_LINT('Quality', OEE_Quality, JSON_Buffer);
JSON_LINT('OEE', OEE, JSON_Buffer);
JSON_LINT('TotalProducts', TotalProducts, JSON_Buffer);
JSON_LINT('GoodProducts', RK_GoodProducts, JSON_Buffer);
JSON_LINT('BadProducts', RK_BadProducts, JSON_Buffer);
JSON_Message:=JSONBuild(JSON_Buffer);
```

Line 14

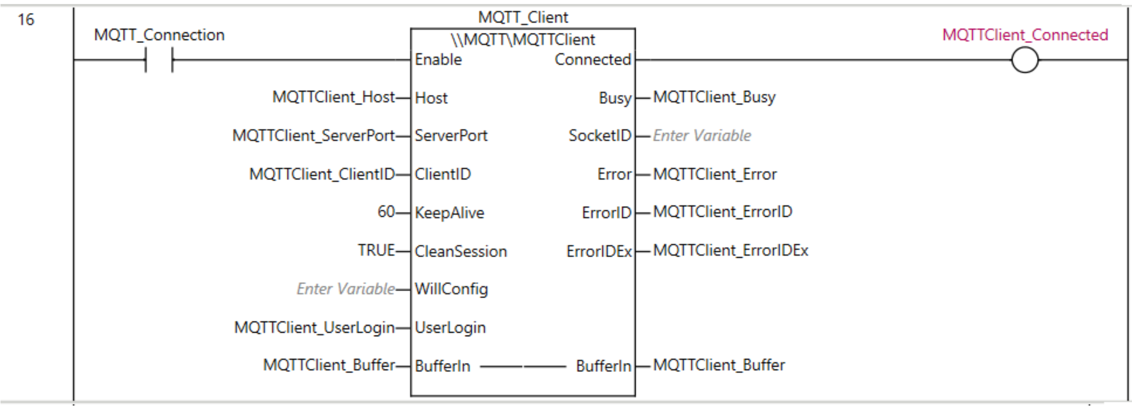
Conversion of the necessary production data to JSON format to be published in the MQTT server.

```
// MQTT server connection details
MQTTClient_Host:='things.ubidots.com';
MQTTClient_ServerPort:=1883;
MQTTClient_ClientID:='NJ5';
MQTTClient_UserLogin.User:='BBFF-zzF6LjdtsLfTCOyUADvZSE6OP81sOL';

PublishTopic:=CONCAT('/v1.6/devices/','NJ5');
```

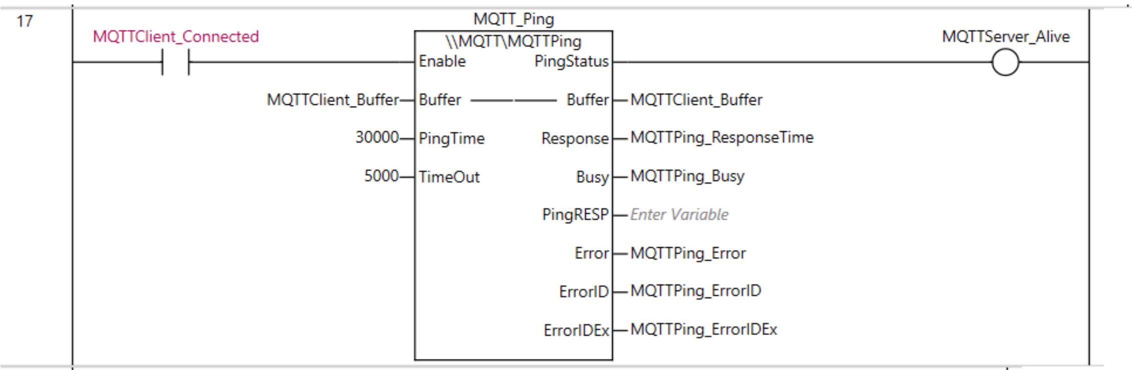
Line 15

Details of the MQTT client (NJ5 machine controller) connection to the MQTT server (Dashboard).



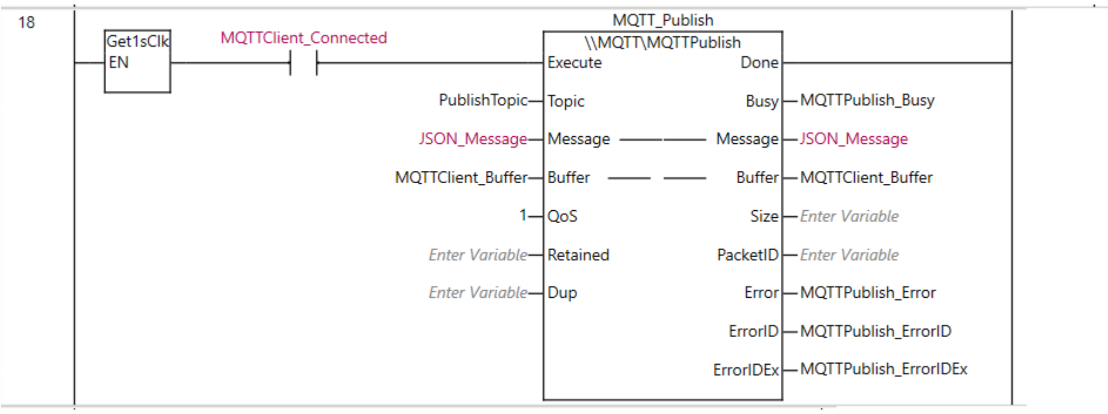
Line 16

FB to establish the connection between the MQTT client and the MQTT server.



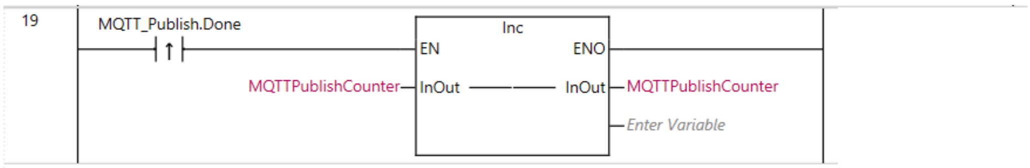
Line 17

FB that sends periodically (every 30s) a heart bit command to notify the server than the connection is alive.



Line 18

FB to publish the production data to the MQTT server. The MQTT client is publishing the updated data every second.



Line 19

Counter of production data publications to the MQTT server.

Annex B. Variables

B.1. Global variables (Controller)

These variables can be read and written not only inside the Controller program, but also in the Safety CPU and HMI programs.

Name	Data type	Description
Conveyor	_SAXIS_REF	Master axis (Conveyor)
CoupleON	BOOL	Execution flag to start synchronization between master axis and slave axis
CuttingConfig	OM_ApplicationLib\RK\sCUTTING_CFG	Cutting configuration
EmergencyStop_Button	BOOL	E-Stop button status
JSON_Buffer	JSON\JSON Buffer	Production data buffer
JSON_Message	STRING[1956]	Message in JSON format to be shared with the MQTT server
LED_EmergencyStop	BOOL	Lamp of E-Stop button
LED_Reset	BOOL	Lamp of Reset button
LED_Run	BOOL	Lamp of Run button
LED_Stop	BOOL	Lamp of Stop button
Machine_Ready	BOOL	Condition to start the execution of the Rotary Knife program (both motors are ready: powered and homed)
MasterConfig	OM_ApplicationLib\RK\sMASTER_CFG	Configuration of the master axis (conveyor)
ModeSelection	BOOL	Cutting mode selection through the HMI: Continuous mode or Mark to mark mode
MQTTClient_Connected	BOOL	Status of the MQTT client connection to the MQTT server
MQTTPublishCounter	LINT	Counter of publications to the MQTT server
New_ConveyorSpeed	REAL	Set the new conveyor speed
OEE	LINT	OEE (Overall Equipment Efficiency) calculation
OEE_Availability	LINT	Machine Availability calculation
OEE_Performance	LINT	Machine Performance calculation

OEE_Quality	LINT	Production Quality calculation
Reset_Button	BOOL	Reset button status
RK_BadProducts	BOOL	Number of bad products in the production line (total products – good products)
RK_BufferEmpty	BOOL	Next cut length is unknown because the buffer of the cut length is empty
RK_Busy	BOOL	Cutting execution
RK_CommandAborted	BOOL	Execution of an instruction is aborted
RK_CoupleON	BOOL	Check if it's possible to start the synchronization between master axis and slave axis
RK_CutLength	LREAL	Contains the defined cut length
RK_Cutting	BOOL	True when the rotary knife is cutting a product
RK_Done	BOOL	Rotary knife is waiting at the slave wait position
RK_Enable	BOOL	Enable RK_SyncRotary library
RK_Enabled	BOOL	Status of the Rotary knife library (working or not working)
RK_Error	BOOL	An error occurs in the Rotary knife library
RK_ErrorID	WORD	Contains the error code when an error occurs in the Rotary knife library
RK_ErrorIDEx	DWORD	Contains the error code when an error occurs in the Rotary knife library
RK_GoodProducts	LINT	Number of cut products by the rotary knife
RK_GoodProductsperm in	LINT	Number of cut products per minute by the rotary knife
RK_Insync	BOOL	Master axis (conveyor) and slave axis (rotary knife) are being synchronized
RK_MarkNotAccepted	BOOL	The mark sensor detects a mark during Buffer Empty process
RK_Skip	BOOL	Next cutting operation is skipped
RK_TotalProducts	LINT	Products detected by the mark sensor
RotaryKnife	_SAXIS_REF	Master axis (Rotary Knife)
Run_Button	BOOL	Run button status
Simulation_BadProduct	BOOL	Button that allows the user to simulate bad

		products
SlaveConfig	OM_ApplicationLib\RK\sSLAVE_CFG	Configuration of the slave axis (rotary knife)
Start_OK	BOOL	Permission from the Safety CPU program to start the main program (Controller)
Stop_Button	BOOL	Stop button status
TotalProducts	LINT	Total sum of products (products detected by the mark sensor + bad products simulated by the user)

Table Annex B.1. Global variables (Controller).

B.2. Local variables (Controller)

These variables can be read and written only in the Controller program.

Name	Data type	Description
AvailabilityCalculation	LINT	Intermediate variable in the Machine Availability calculation
BadProduct	LINT	Counter of bad products simulated by the user
Compare	MC_ZoneSwitch	FB for checking if the current conveyor position is within a specified zone
Conveyor_Stop	BOOL	Conveyor stop status
ConveyorSpeed	REAL	Current conveyor speed
Counter1	CTU	FB to count the number of pieces detected by the mark sensor
Counter2	CTU	FB to count the number of cut pieces
Counter3	CTU	FB to count the number of cut pieces per minute
Enable_PowerandHome_Conveyor	BOOL	Enable the execution of the MC_Power and MC_Home FBs for the master axis (conveyor)
Enable_PowerandHome_RotaryKnife	BOOL	Enable the execution of the MC_Power and MC_Home FBs for the slave axis (rotary knife)

Home_Conveyor	MC_Home	FB for homing conveyor axis
Home_RotaryKnife	MC_Home	FB for homing rotary knife axis
InZone	BOOL	Check if the current conveyor position is within a specified zone
Machine_Reset	BOOL	Reset status
MQTT_Client	MQTT\MQTTClient	FB to connect the MQTT client to the MQTT server
MQTT_Connection	BOOL	Execution flag to start the connection between MQTT client and MQTT server
MQTT_Ping	MQTT\MQTTPing	FB that sends periodically a heart bit command to notify the server than the connection is alive
MQTT_Publish	MQTT\MQTTPublish	FB to publish messages to the MQTT server
MQTTClient_Buffer	MQTT\ClientBuffer	MQTT client data buffer
MQTTClient_Busy	BOOL	True when the MQTT Client FB is executed
MQTTClient_ClientID	STRING[256]	MQTT client ID
MQTTClient_Error	BOOL	An error occurs in the MQTT Client FB
MQTTClient_ErrorID	WORD	Contains the error code when an error occurs in the MQTT Client FB
MQTTClient_ErrorIDEx	DWORD	Contains the error code when an error occurs in the MQTT Client FB
MQTTClient_Host	STRING[256]	MQTT server host name
MQTTClient_ServerPort	UINT	MQTT server inbound port
MQTTClient_UserLogin	MQTT\Login	User login to the MQTT server
MQTTPing_Busy	BOOL	True when the MQTT Ping FB is executed
MQTTPing_Error	BOOL	An error occurs in the MQTT Ping FB
MQTTPing_ErrorID	WORD	Contains the error code when an error occurs in the MQTT Ping FB
MQTTPing_ErrorIDEx	DWORD	Contains the error code when an error occurs in the MQTT Ping FB
MQTTPublish_Busy	BOOL	True when the MQTT Publish FB is executed
MQTTPublish_Error	BOOL	An error occurs in the MQTT Publish FB
MQTTPublish_ErrorID	WORD	Contains the error code when an error occurs in the MQTT Publish FB
MQTTPublish_ErrorIDEx	DWORD	Contains the error code when an error

		occurs in the MQTT Publish FB
MQTTServer_Alive	BOOL	Status of the MQTT Ping action
OEE_Calculation	LINT	Intermediate variable for the OEE calculation
PerformanceCalculation	LINT	Intermediate variable in the Machine Performance calculation
Power_Conveyor	MC_Power	FB to power on master axis (conveyor)
Power_RotaryKnife	MC_Power	FB to power on slave axis (rotary knife)
PublishTopic	STRING[128]	Topic to be published
QualityCalculation	LINT	Intermediate variable in the Production Quality calculation
Reset_Conveyor	MC_Reset	FB to reset the master axis (conveyor)
Reset_RotaryKnife	MC_Reset	FB to reset the slave axis (rotary knife)
RotaryKnife_Stop	BOOL	Rotary knife stop status
RotaryKnifeFB	OM_ApplicationLib\RK\RK_SyncRotary	RK_SyncRotary library
Stop_Conveyor	MC_Stop	FB to stop the master axis (conveyor)
Stop_RotaryKnife	MC_Stop	FB to stop the slave axis (rotary knife)
TimeConveyor	LINT	Time than the conveyor is running in integer
TimeConveyor_LINT	LINT	Time than the conveyor is running in seconds
TimeConveyor_ms	TIME	Time than the conveyor is running in ms
TimeCounter	TIME	Elapsed time since the timer of 60 seconds started
Timer1	AccumulationTimer	Timer to show how long the conveyor is running
Timer2	AccumulationTimer	Timer to show how long the rotary knife is running
Timer60s	TON	TON FB of 60 seconds
Timer60s_OK	BOOL	Output of the TON FB that is true every 60 seconds
TimeRotaryKnife	LINT	Time than the rotary knife is running in integer
TimeRotaryKnife_LINT	LINT	Time than the rotary knife is running in seconds

TimeRotaryKnife_ms	TIME	Time than the rotary knife is running in ms
Velocity_Conveyor	MC_MoveVelocity	Velocity control over the conveyor motor

Table Annex B.2. Local variables (Controller).

B.3. Global variables (Safety CPU)

These variables can be read and written not only inside the Safety CPU program, but also in the Controller and HMI programs.

Name	Data type	Description
EDM_RotaryKnife	SAFEBOOL	Detects a safety function failure in the rotary knife servo drive
EmergencyStop_Button	BOOL	E-Stop button status (output to the controller program)
Reset_Button	BOOL	Reset button status (output to the controller program)
SI_EmergencyStop1	SAFEBOOL	E-Stop button status CH1
SI_EmergencyStop2	SAFEBOOL	E-Stop button status CH2
SI_Reset	SAFEBOOL	Reset button status
Start_OK	BOOL	Permission to start the Controller program (output to the controller program)
STO1_RotaryKnife	SAFEBOOL	Safety input 1 status of the rotary knife servo drive
STO2_RotaryKnife	SAFEBOOL	Safety input 2 status of the rotary knife servo drive

Table Annex B.3. Global variables (Safety CPU).

B.4. Local variables (Safety CPU)

These variables can be read and written only in the Safety CPU program.

Name	Data type	Description
ESTOP_OK	BOOL	E-Stop button is not pressed
Safety_EDM	SF_EDM	FB to detect if there is a safety failure in the rotary knife servo drive
Safety_EmergencyStop	SF_EmergencyStop	FB to check the status of the E-Stop button

Table Annex B.4. Local variables (Safety CPU).

B.5. Exposed variables (Safety CPU)

These are the exposed Safety CPU variables to the Controller program. The 3 variables are Safety CPU outputs to the Controller.

Name	Data type	Description
Start_OK	BOOL	Condition to start the main program (Controller)
Reset_Button	BOOL	Reset button status
EmergencyStop_Button	BOOL	E-Stop button status

Table Annex B.5. Exposed variables (Safety CPU).

B.6. Variable mapping (HMI)

Variable mapping refers to assigning global variables in the controller to global variables in the HMI. This mapping variable is required to link input value from the user in the HMI with the input parameters in the FBs from the Controller program.

HMI variable	Data type	Controller variable
CuttingConfig	OM_ApplicationLib\RK\sCUTTING_CFG	new_Controller_0.CuttingConfig
DateTime	Date	DateTime
Machine_Ready	BOOL	new_Controller_0.Machine_Ready
MasterConfig	OM_ApplicationLib\RK\sMASTER_CFG	new_Controller_0.MasterConfig
ModeSelection	BOOL	new_Controller_0.ModeSelection
New_Conveyor Speed	REAL	new_Controller_0.New_ConveyorSpeed

RK_Busy	BOOL	new_Controller_0.RK_Busy
RK_CoupleON	BOOL	new_Controller_0.RK_CoupleON
RK_Cutting	BOOL	new_Controller_0.RK_Cutting
RK_Done	BOOL	new_Controller_0.RK_Done
RK_Enable	BOOL	new_Controller_0.RK_Enable
RK_Enabled	BOOL	new_Controller_0.RK_Enabled
RK_Error	BOOL	new_Controller_0.RK_Error
RK_InSync	BOOL	new_Controller_0.RK_InSync
RK_Skip	BOOL	new_Controller_0.RK_Skip
SlaveConfig	OM_ApplicationLib\RK\sSLAVE_CFG	new_Controller_0.SlaveConfig

Table Annex B.6. Variable mapping (HMI).

Annex C. Wiring diagrams

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Customer	OMRON EUROPE
Project description	SYSMAC DEMO CASE V3
Customer project	14043
FIR project	14043 UE

Customer	
Place of installation	
Product	
Power supply	230V AC F+N
Power supply of control	24V DC
Manufacturing date	2014
Responsible for project	
Version software	2.4.4

Date of creation	10/02/2014	Review:	2
Date of modification	18/02/2016	Number of pages:	27

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Date	10/02/2014
Made by	Miquel
Reviewed	20/03/2014
Approved	

OMRON EUROPE
NJ DEMO (UE)

Index of pages

Diagram: 14043 UE | Review: 2
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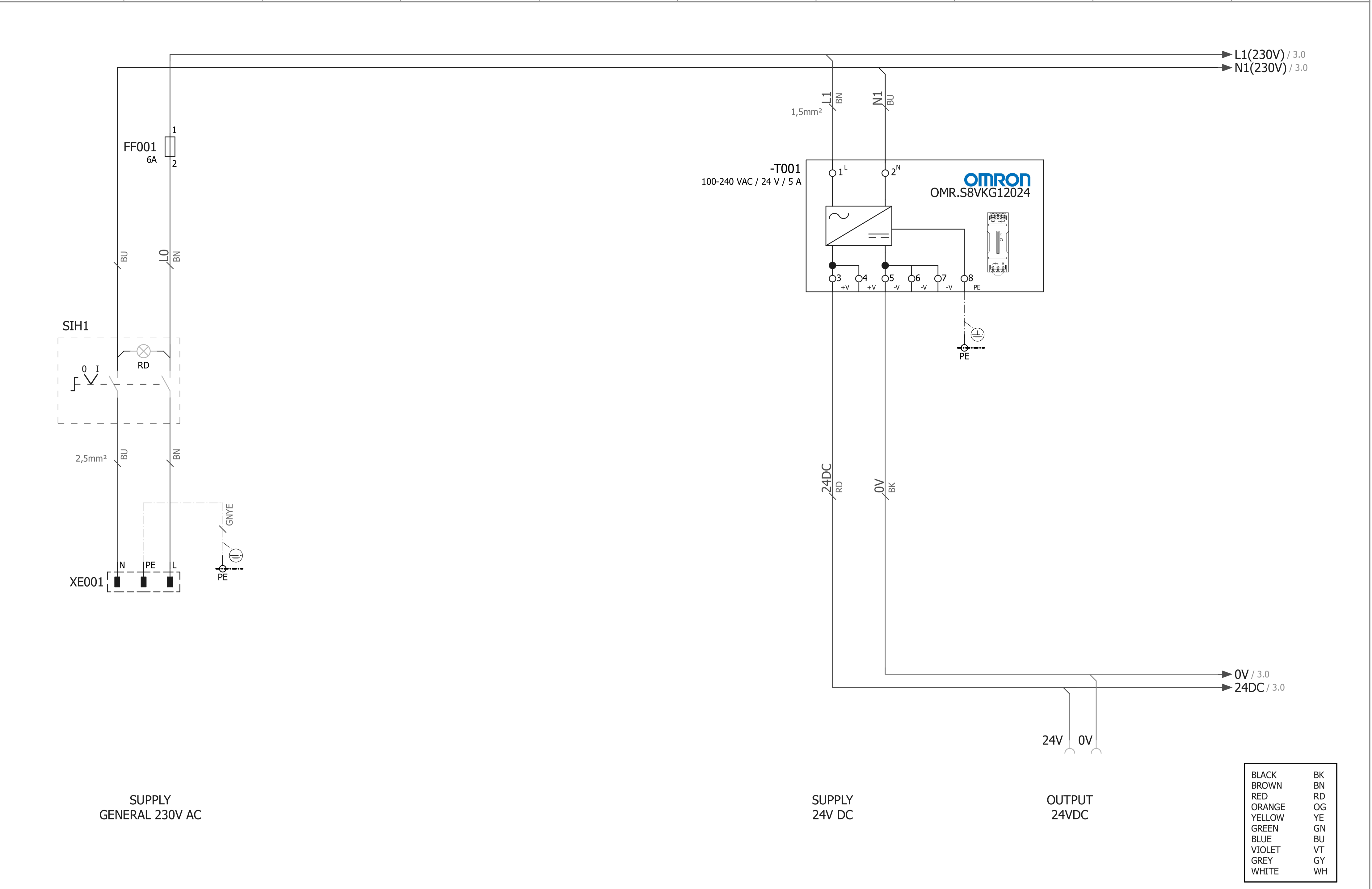

BLACK	BK
BROWN	BN
RED	RD
ORANGE	OG
YELLOW	YE
GREEN	GN
BLUE	BU
VIOLET	VT
GREY	GY
WHITE	WH

1a

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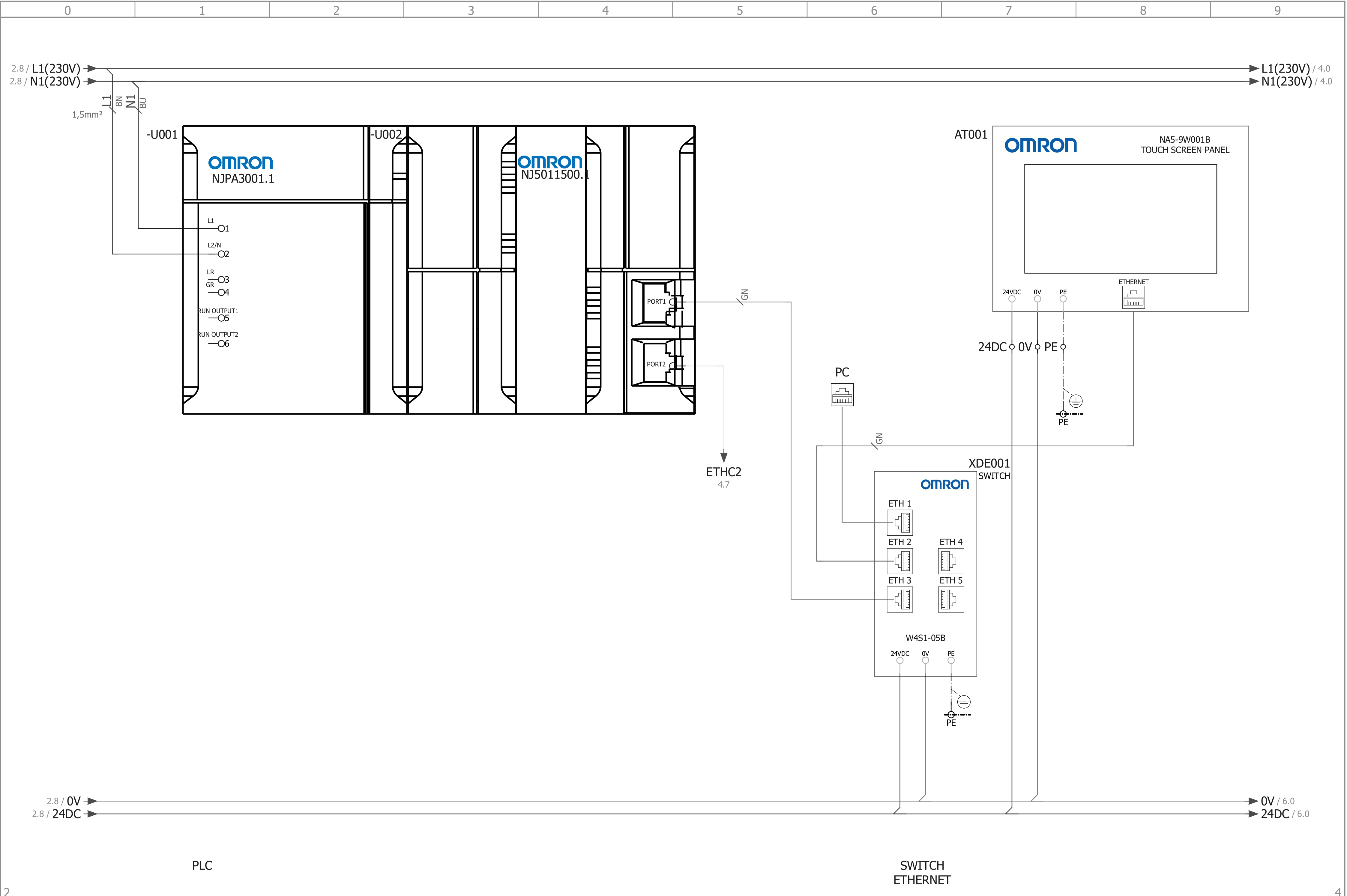

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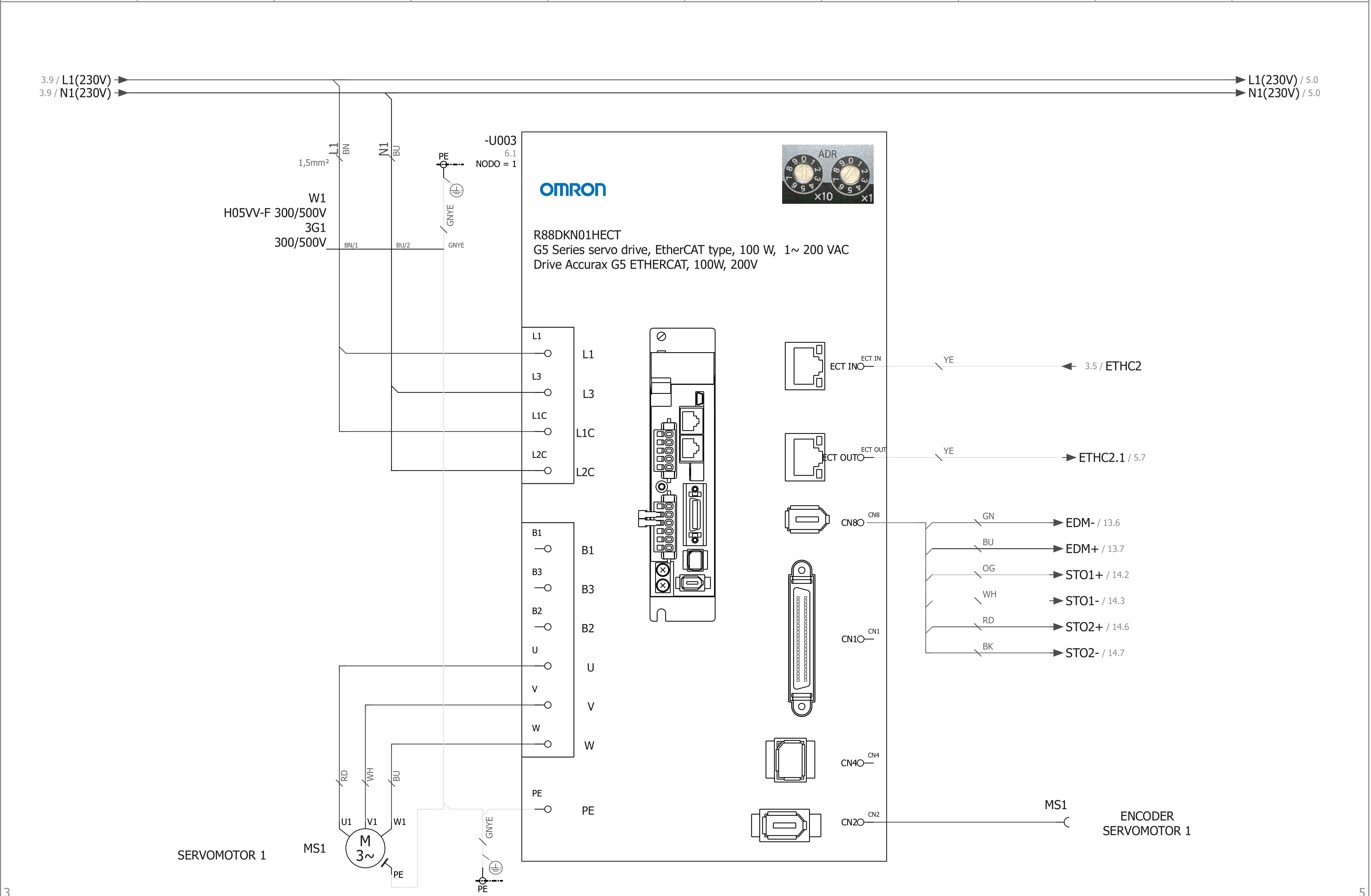

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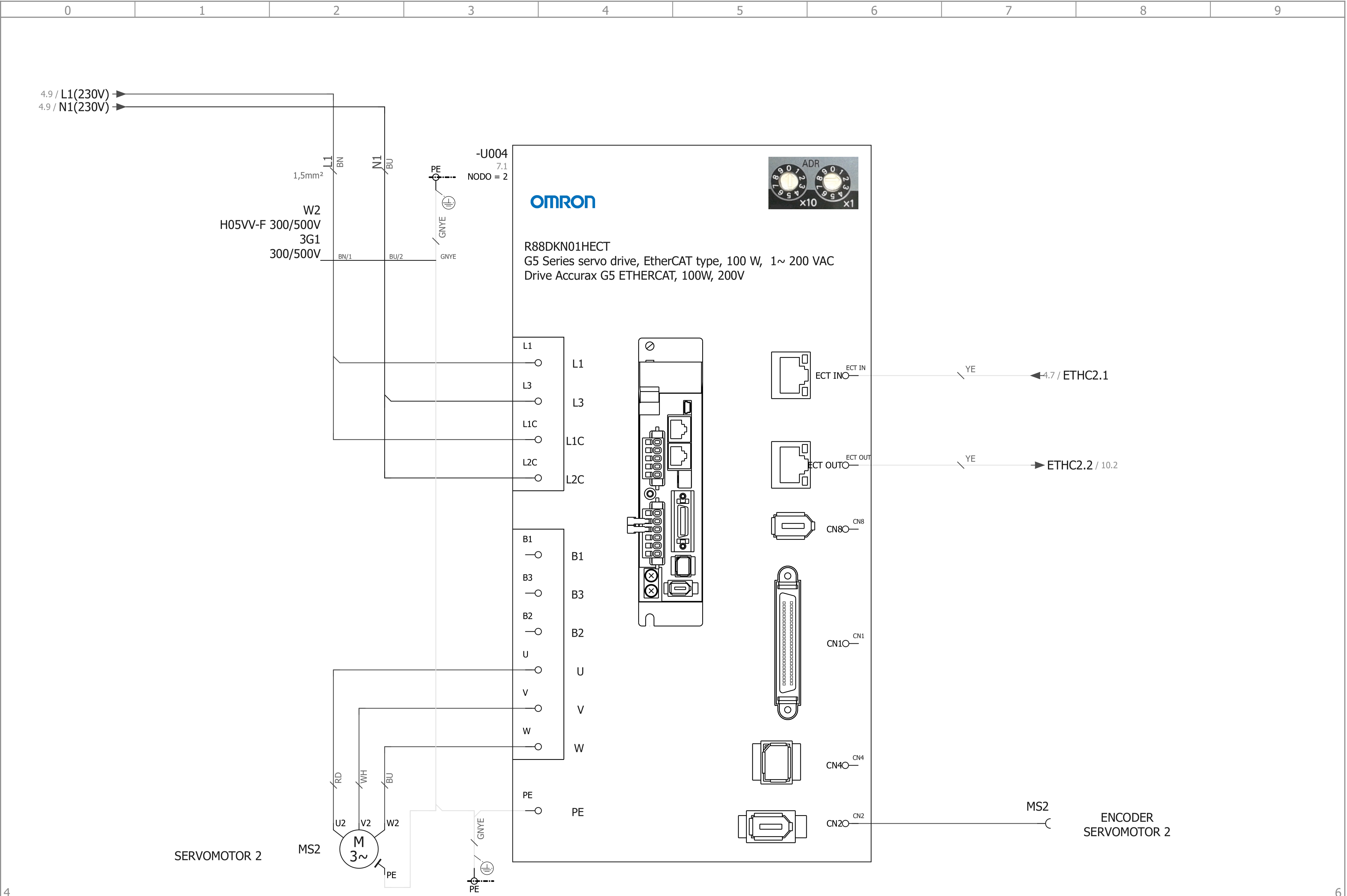

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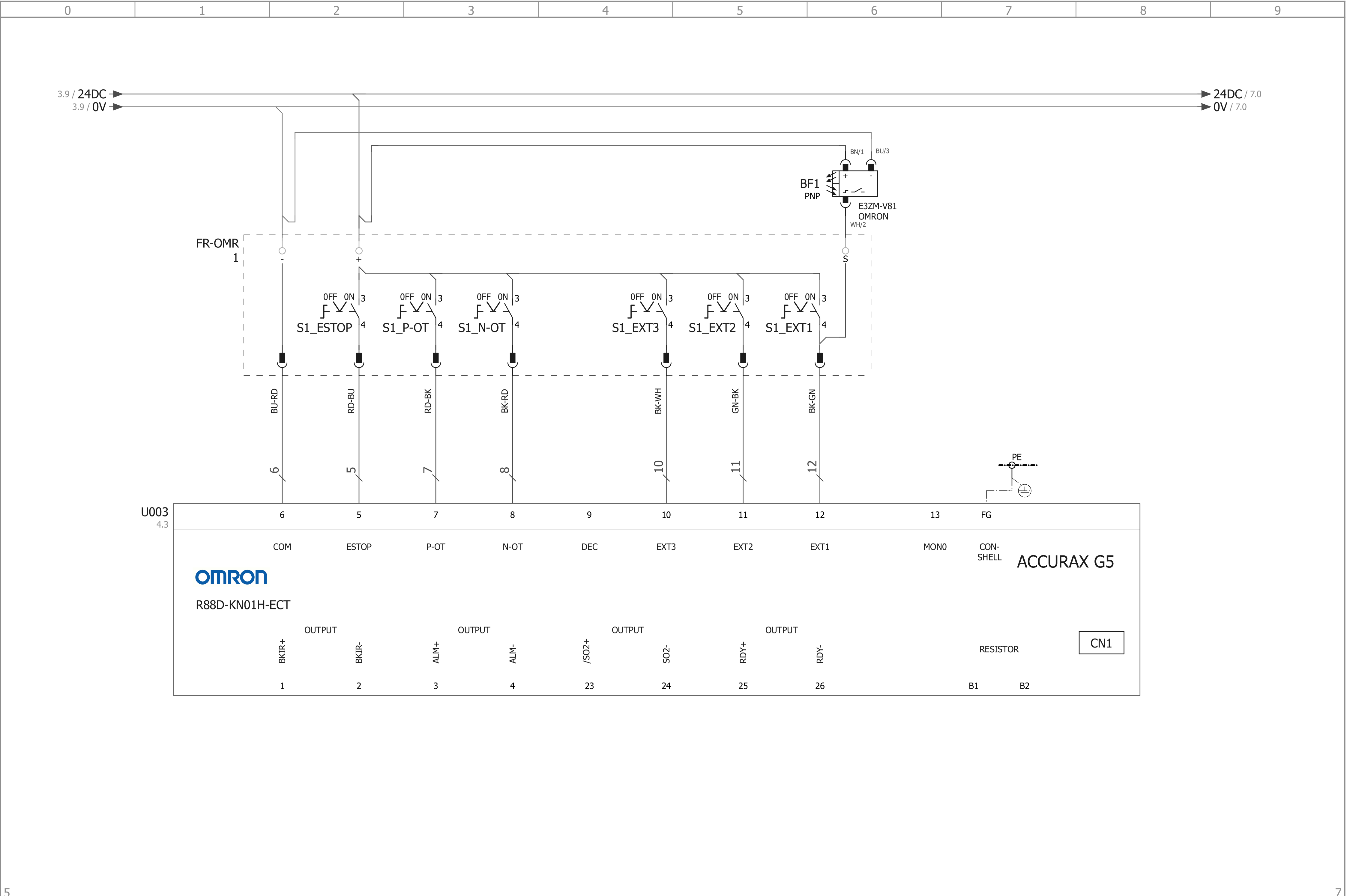
		Approved					



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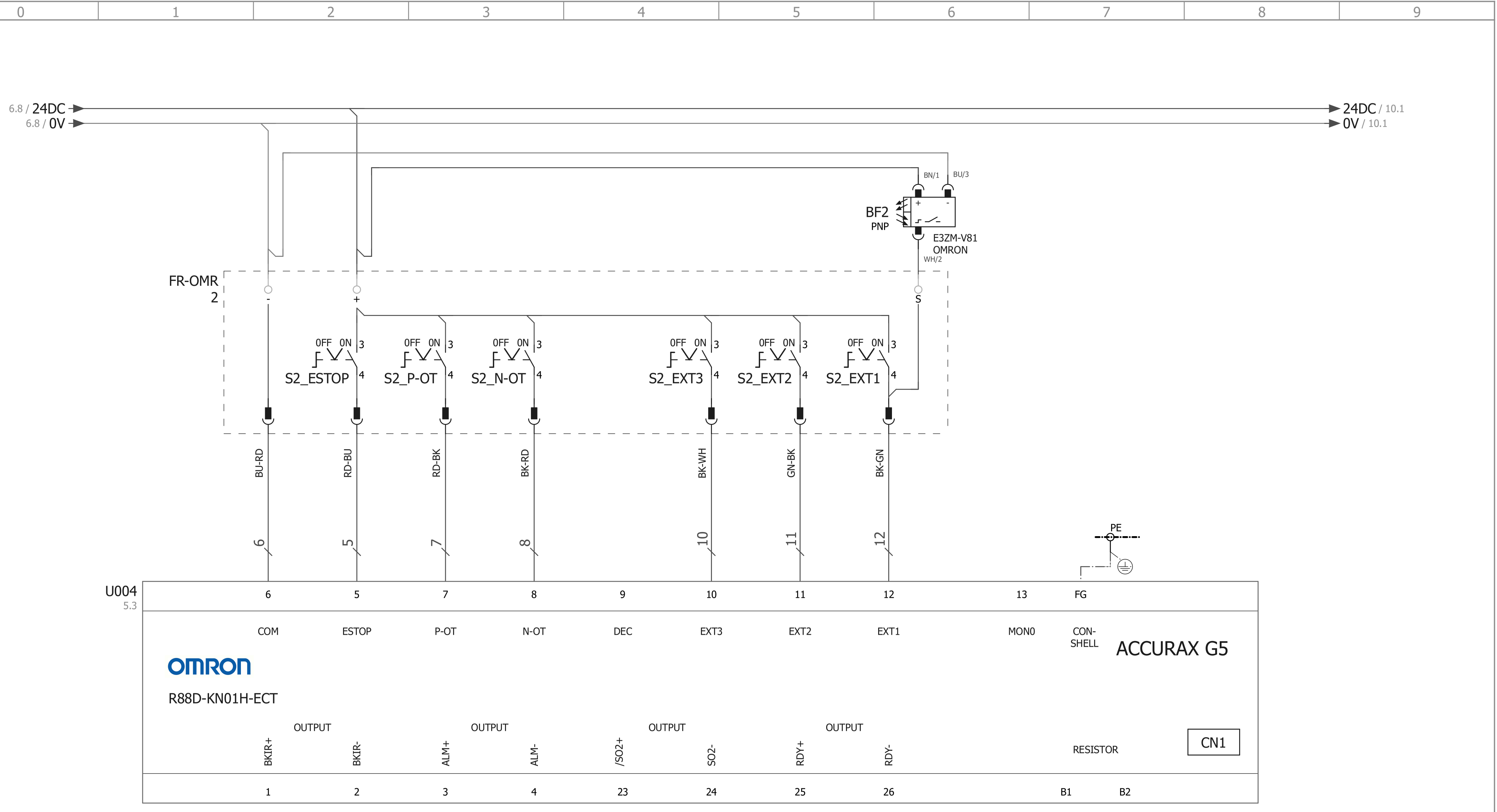
					Review: 2 14043 Sheet: 6



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CN1

PIN	COLOUR
1(BKIR+)	WHITE-RED
2(BKIR-)	RED-WHITE
3(ALM+)	RED-GREEN
4(ALM-)	GREEN-RED
5(ESTOP)	RED-BLUE
6(24VIN)	BLUE-RED
7(P-OT)	RED-BLACK
8(N-OT)	BLACK-RED
9(DEC)	WHITE-BLACK
10(EXT3)	BLACK-WHITE
11(EXT2)	GREEN-BLACK
12(EXT1)	BLACK-GREEN
13(MON0)	BLUE-BLACK
14	YELLOW-BLACK
15	BLACK-YELLOW
16	BLACK-BLUE
17	
18	
19	
20	
21	
22	
23	
24	
25(RDY)	BROWN-BLACK
26(RDYCOM)	BLACK-BROWN

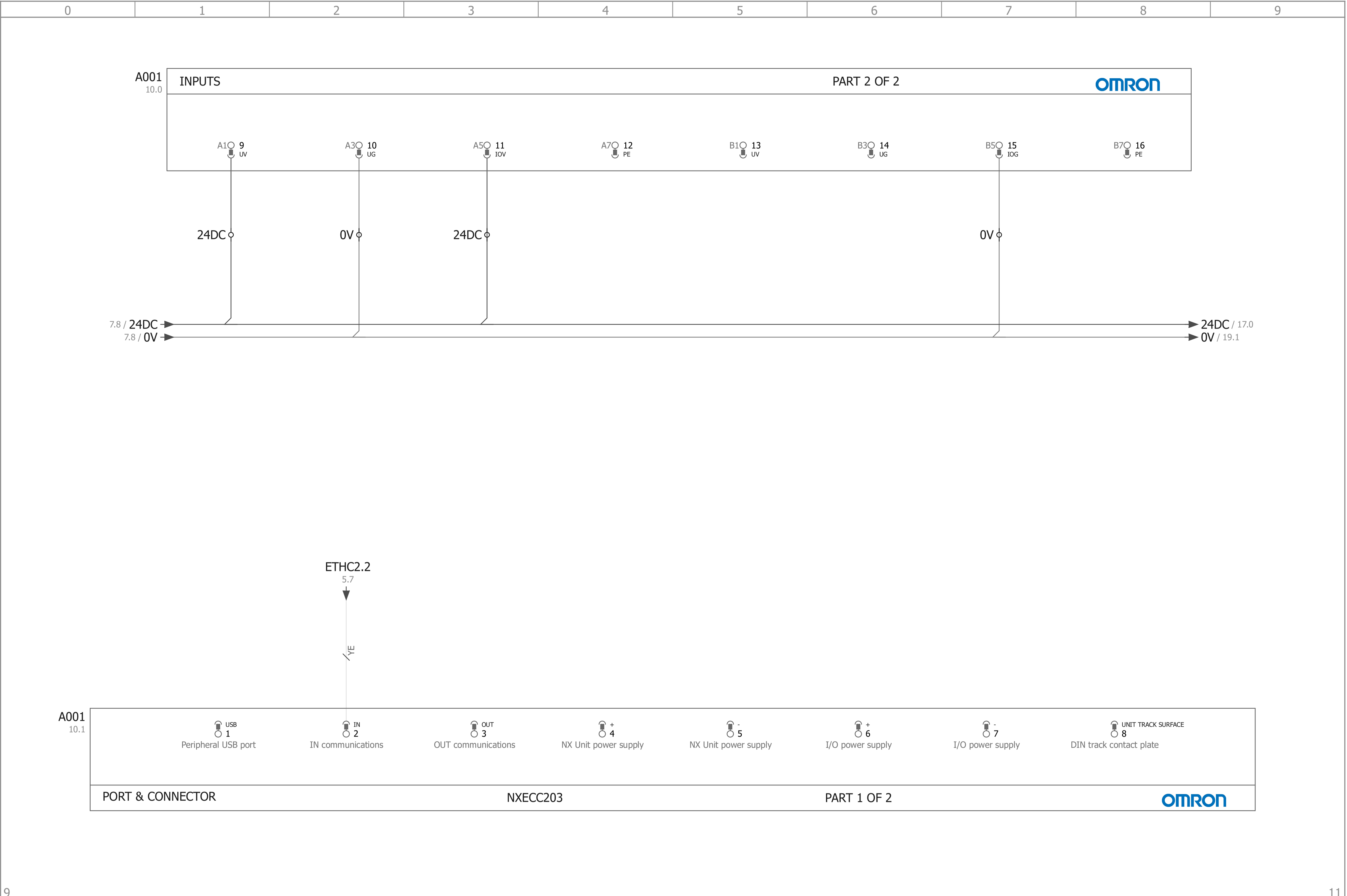
CN8

PIN	CABLE COLOUR
1	
2	
3(HWBB1-)	WHITE
4(HWBB1+)	ORANGE
5(HWBB2-)	RED
6(HWBB2+)	BLACK
7(EDM-)	GREEN
8(EDM+)	BLUE

0	1	2	3	4	5	6	7	8	9

A001	A002	A003	A004	A005	A006	A007	A008	A009	A010	A011	A012	A013	A014	A015
NX-ECC203	NX-SL330	NX-SID800	NX-SIH400	NX-SOD400	NX-EC0122	NX-PG0122	NX-ID4442	NX-PC0030	NX-OD4256	NX-ID3444	NX-OD2258	NX-AD2608	NX-DA2605	NX-PD1000
3 X1 0 X10	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14

8 10



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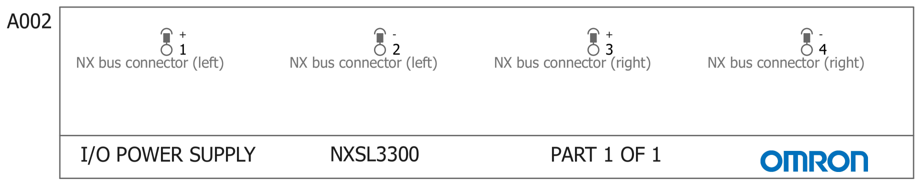
0 1 2 3 4 5 6 7 8 9



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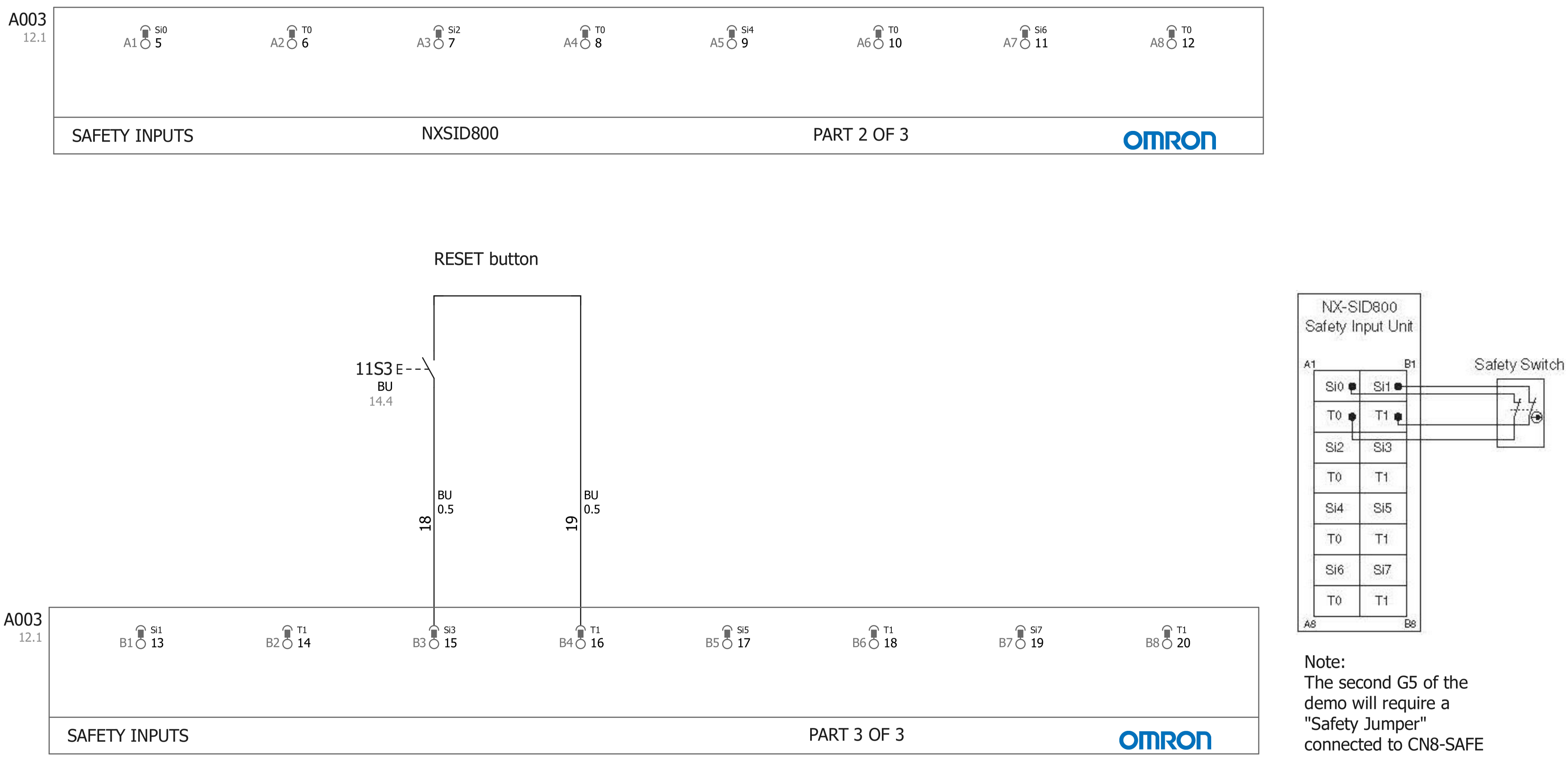

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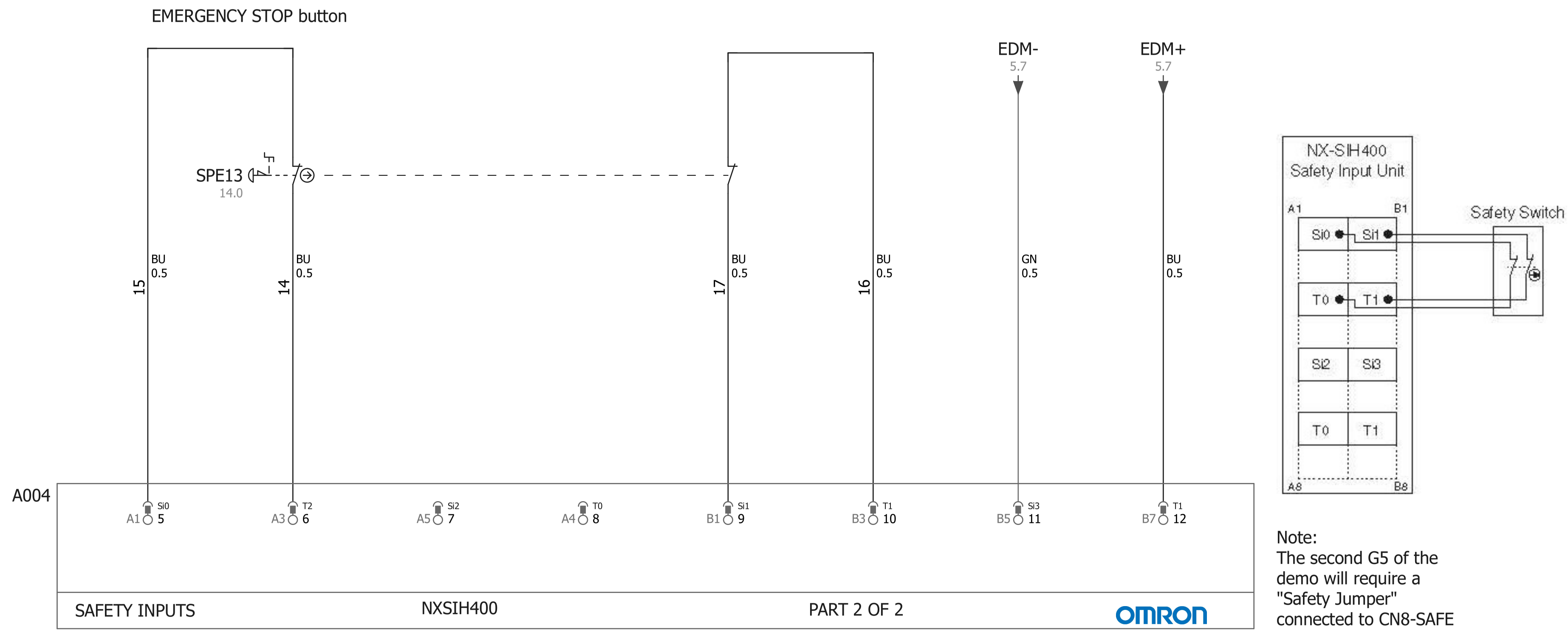
NJ DEMO (UE)

NX-SID800



Note:
The second G5 of the demo will require a "Safety Jumper" connected to CN8-SAFE

12 14

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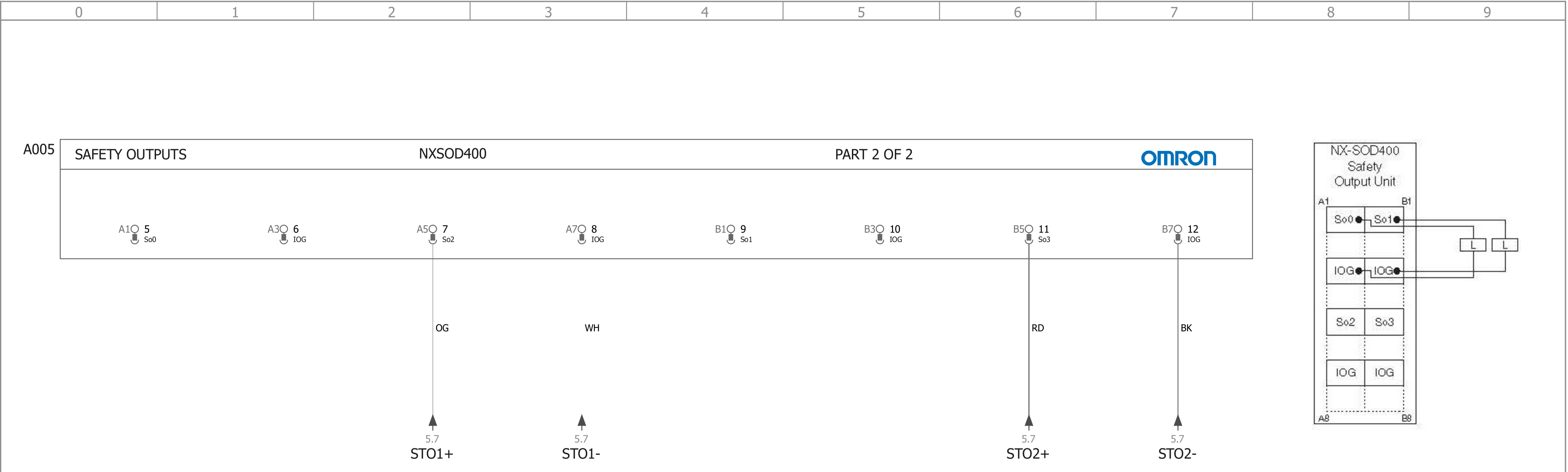

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NJ DEMO (UE)

NX-SOD400

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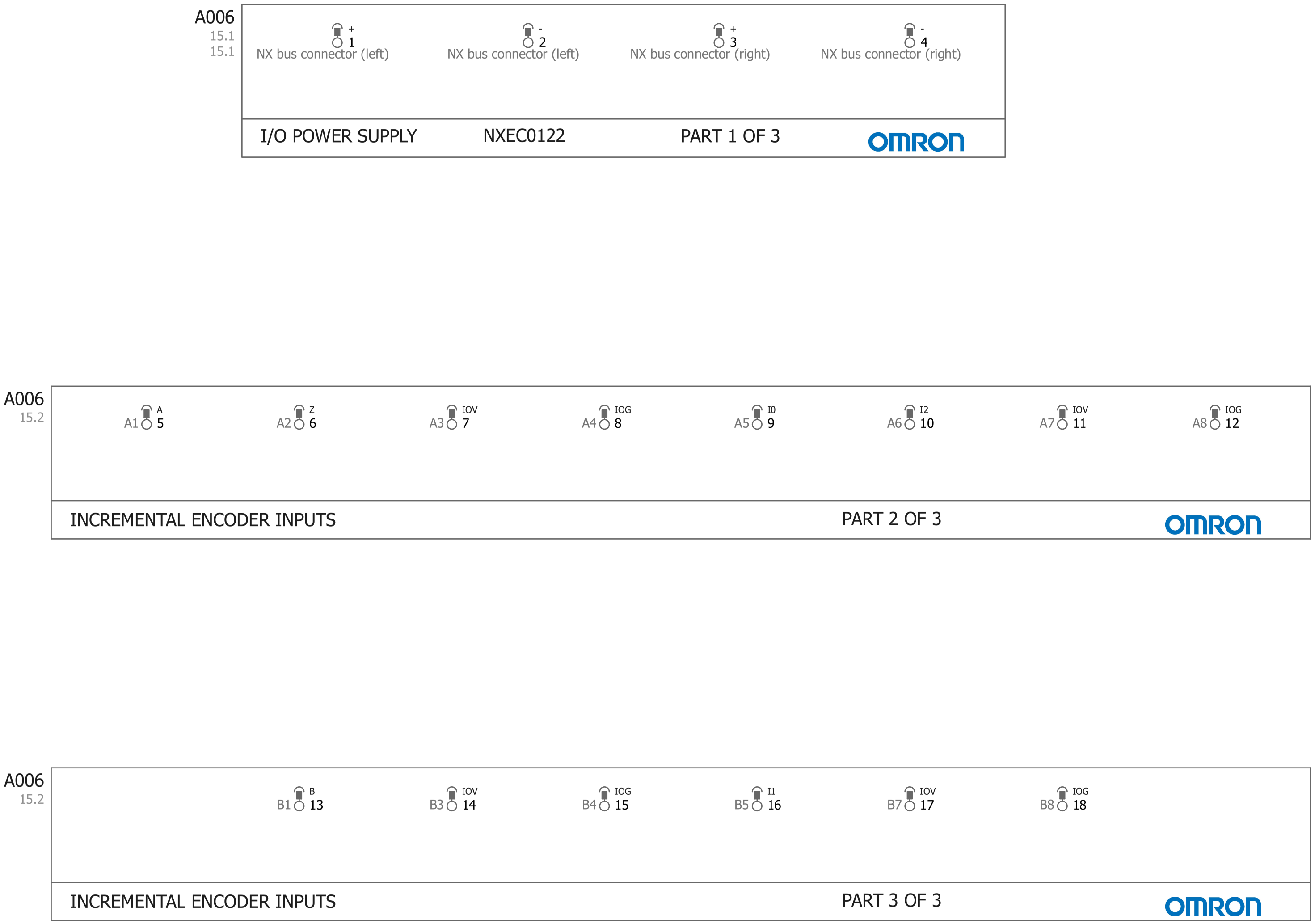

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NJ DEMO (UE)

NX-EC0122

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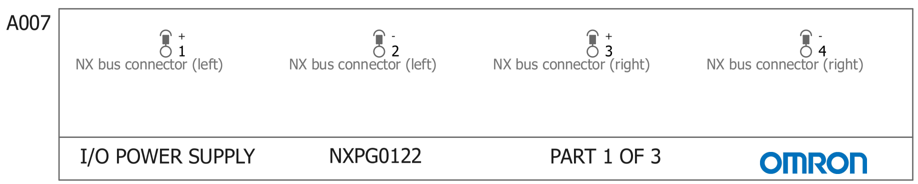

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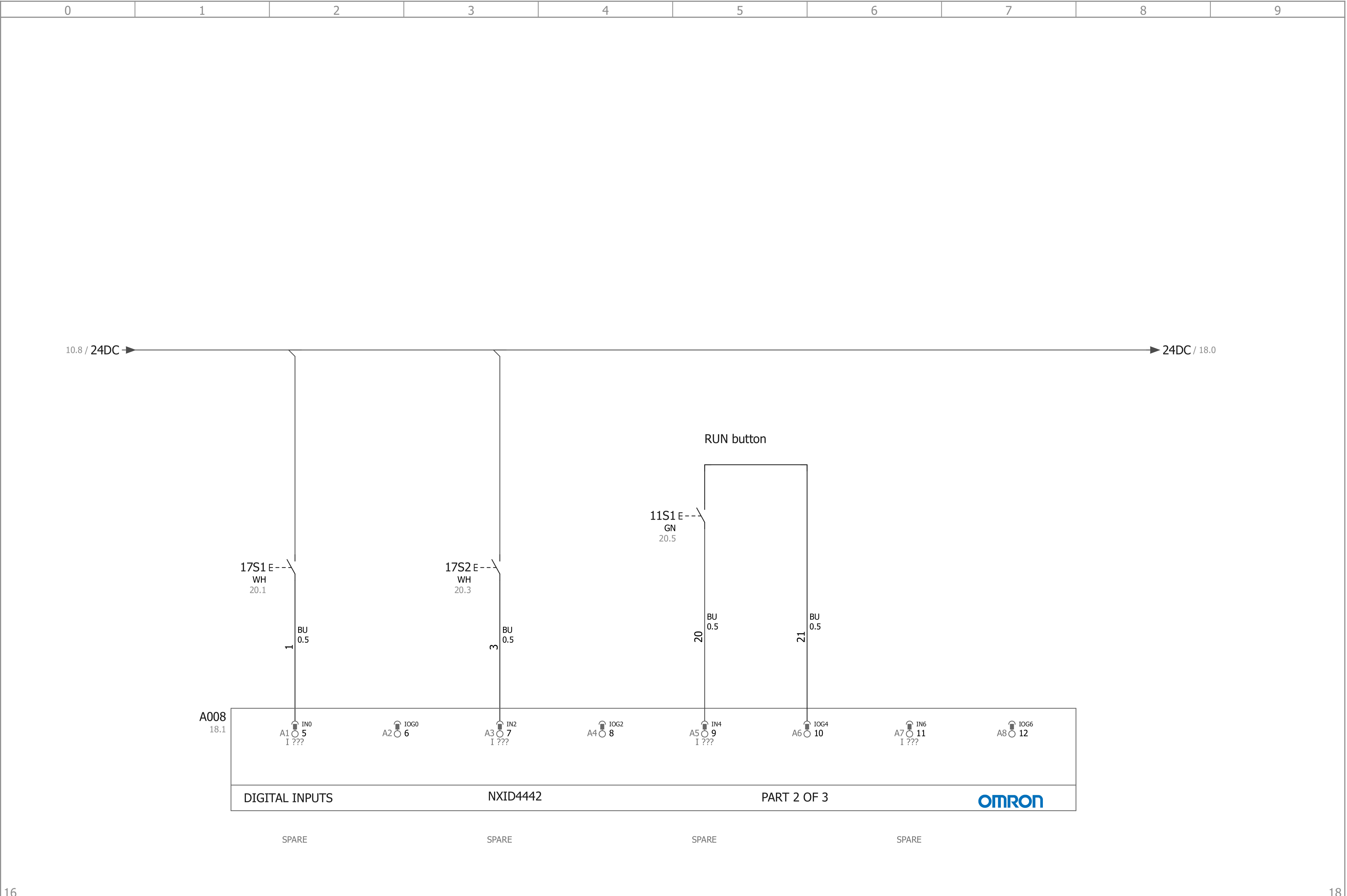

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NJ DEMO (UE)

NX-ID4442

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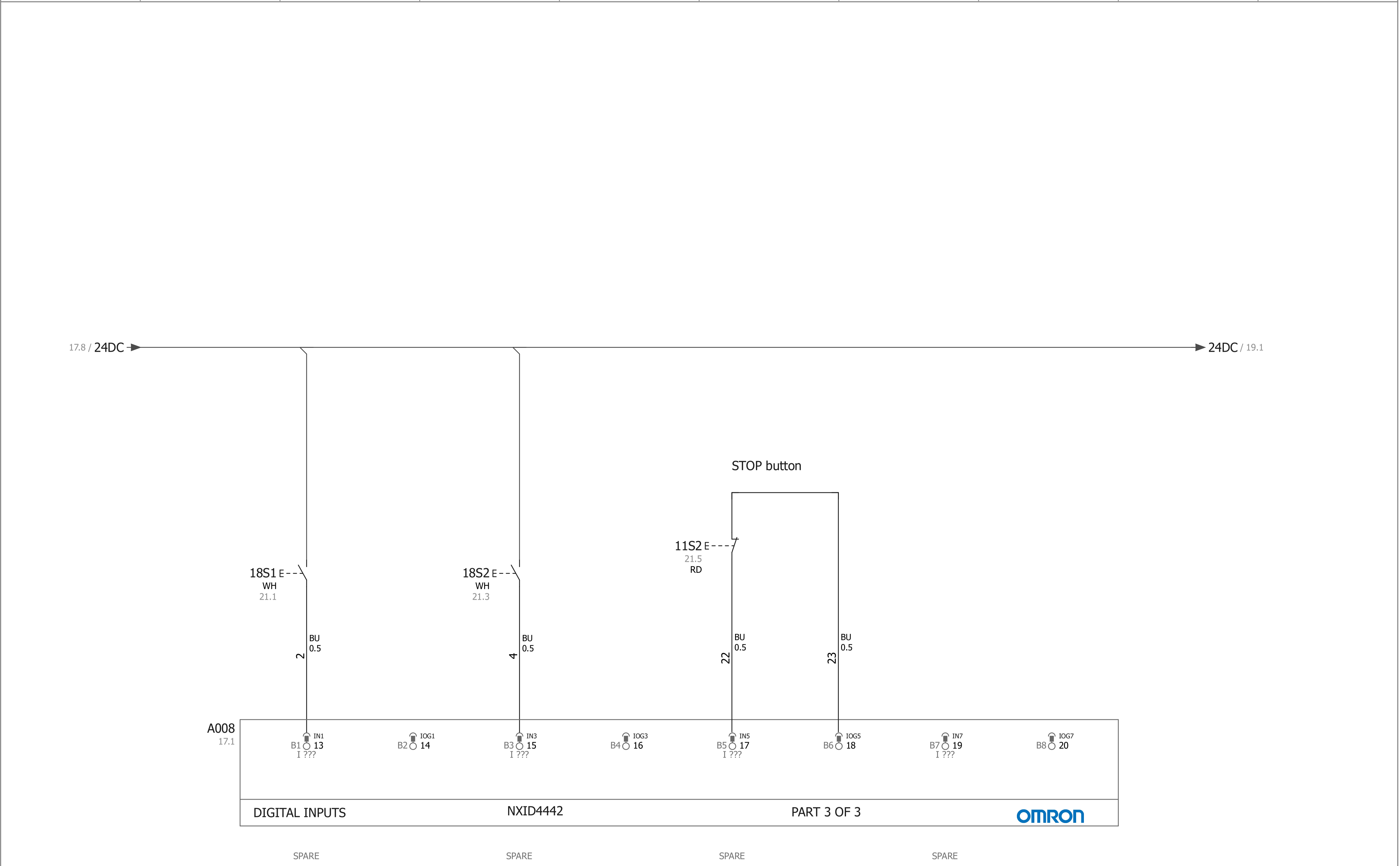

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Approved	

OMRON EUROPE

NJ DEMO (UE)

NX-ID4442

Diagram: 14043 UE

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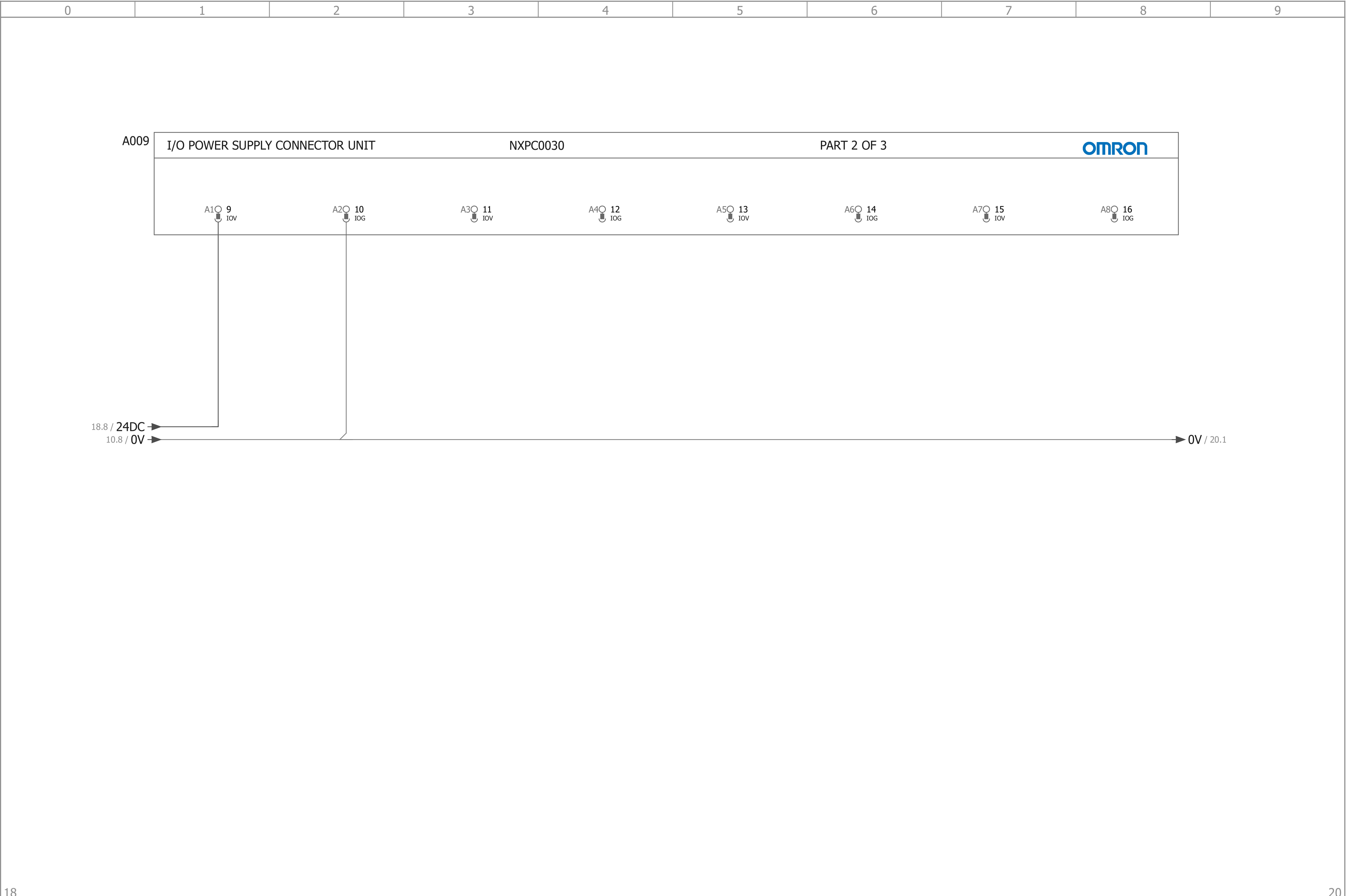
Review: 2

14043



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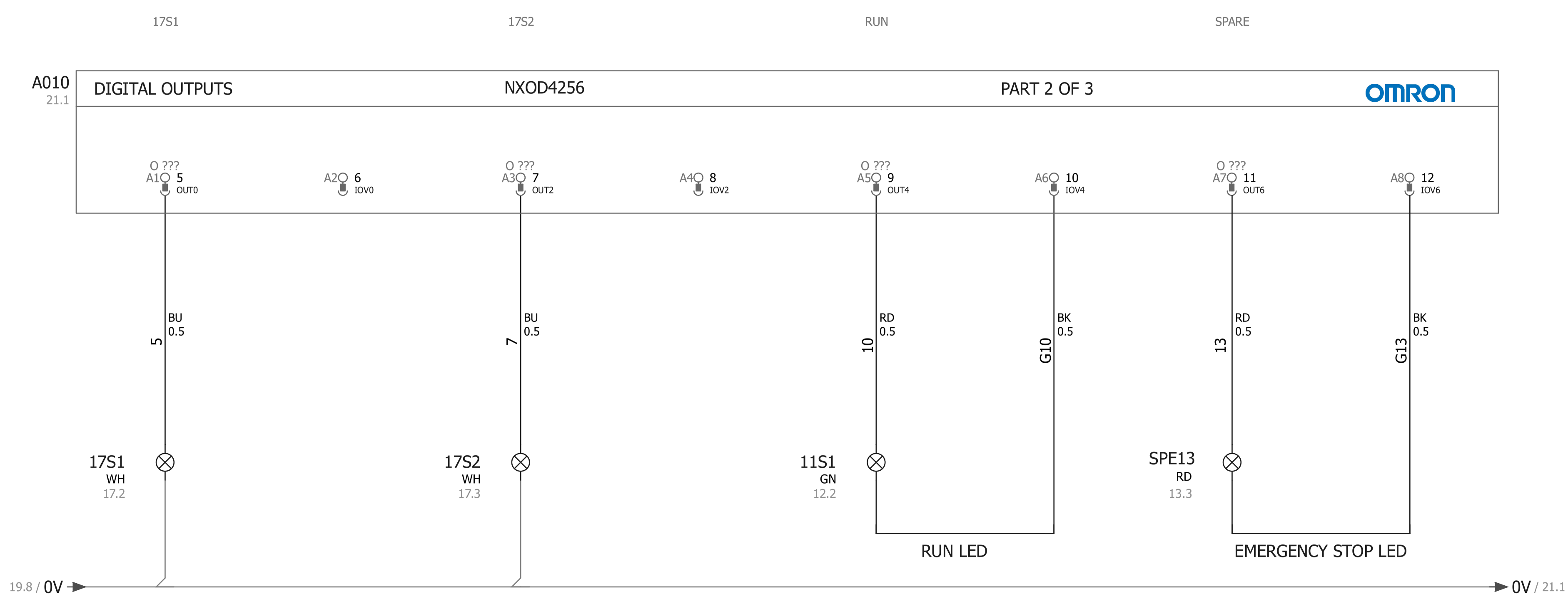
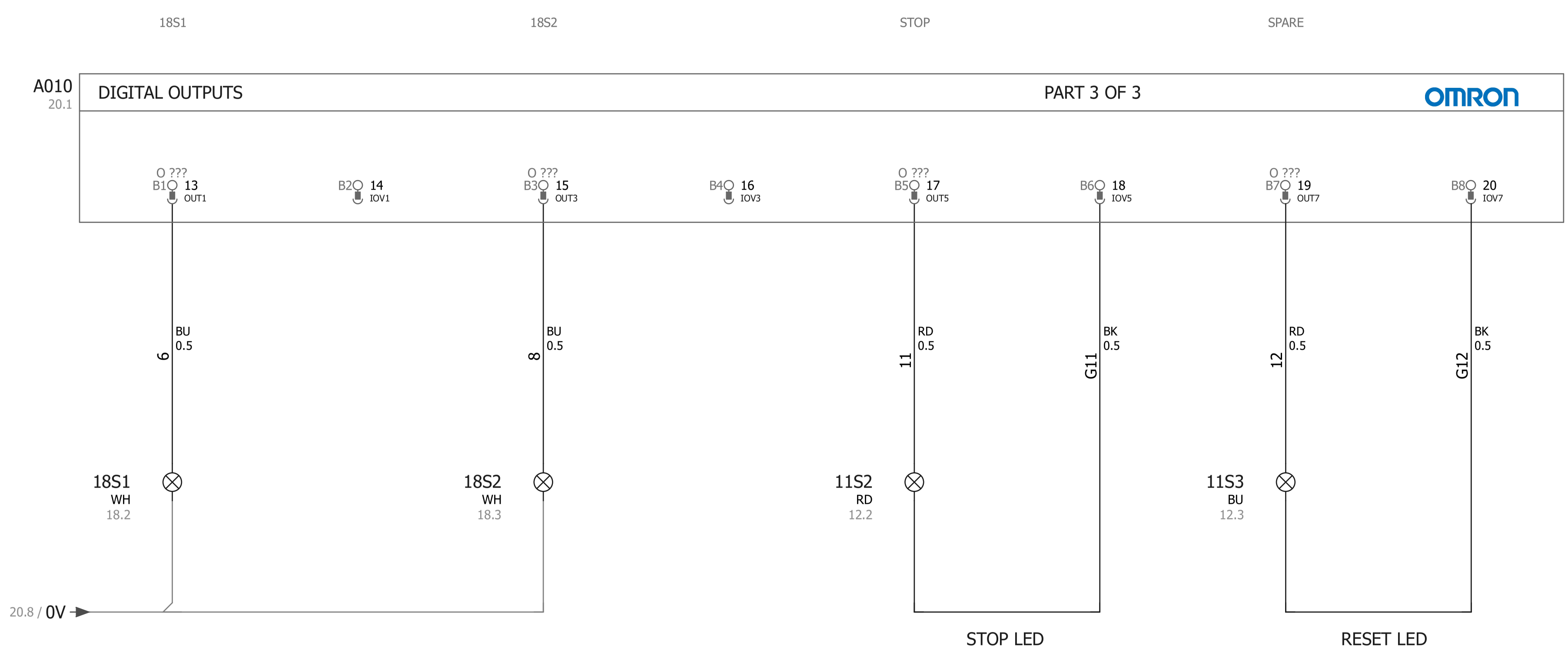
		Reviewed	08/02/2016			== = 14043
		Approved				++ + Sheet: 19



19 | 21

FREIXAS I ROS S.L. FiR Automàtica + Comunicacions	c/ L' Agricultura, 128 08223 Terrassa (Spain) Tel. 93.736.27.00 Fax. 93.783.27.05 www.all-done.com	Date: 10/02/2014 Made by: Miquel Reviewed: 08/02/2016 Approved:	OMRON EUROPE NJ DEMO (UE)	NX-OD4256	Diagram: 14043 UE == = ++ + Review: 2 14043 Sheet: 20



20

22

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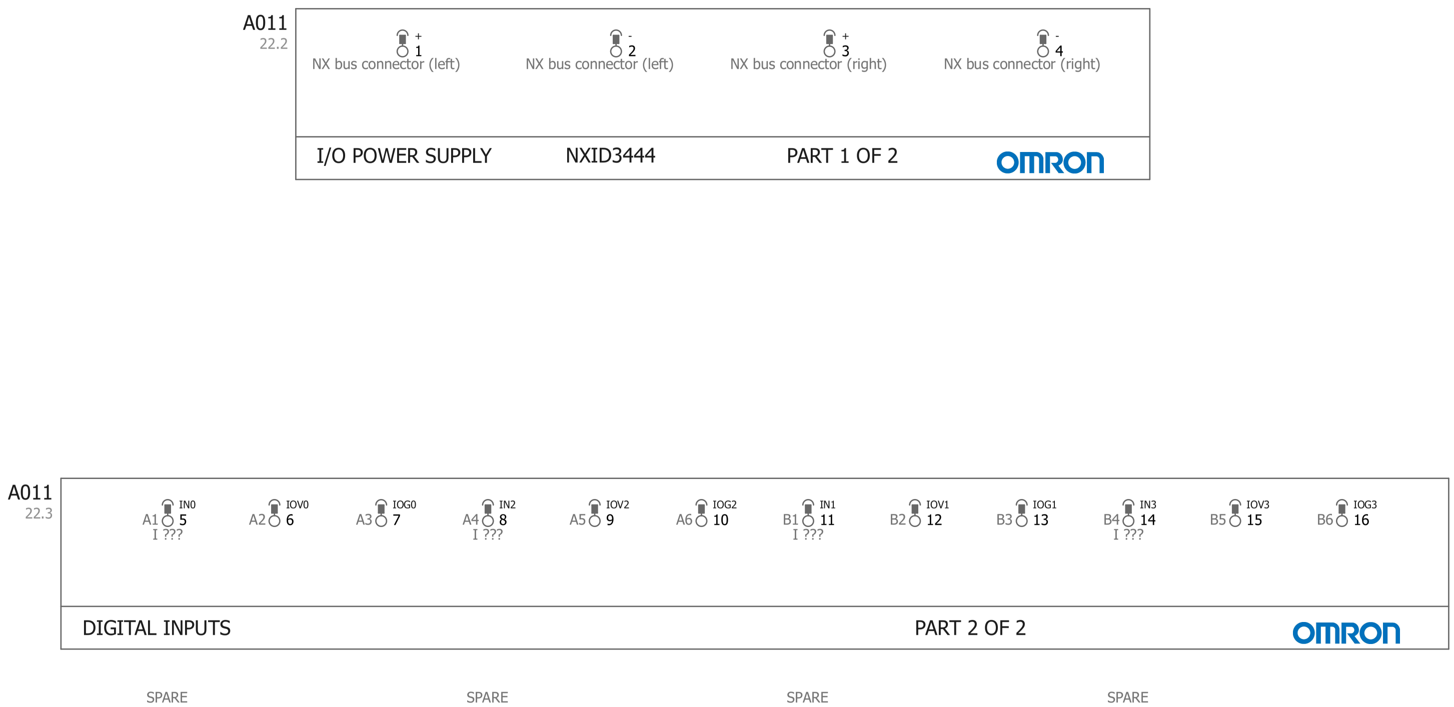
		Made by	Miquel	NJ DEMO (UE)		== =	14043
		Reviewed	08/02/2016				
		Approved				++ +	Sheet: 21



21 | 23

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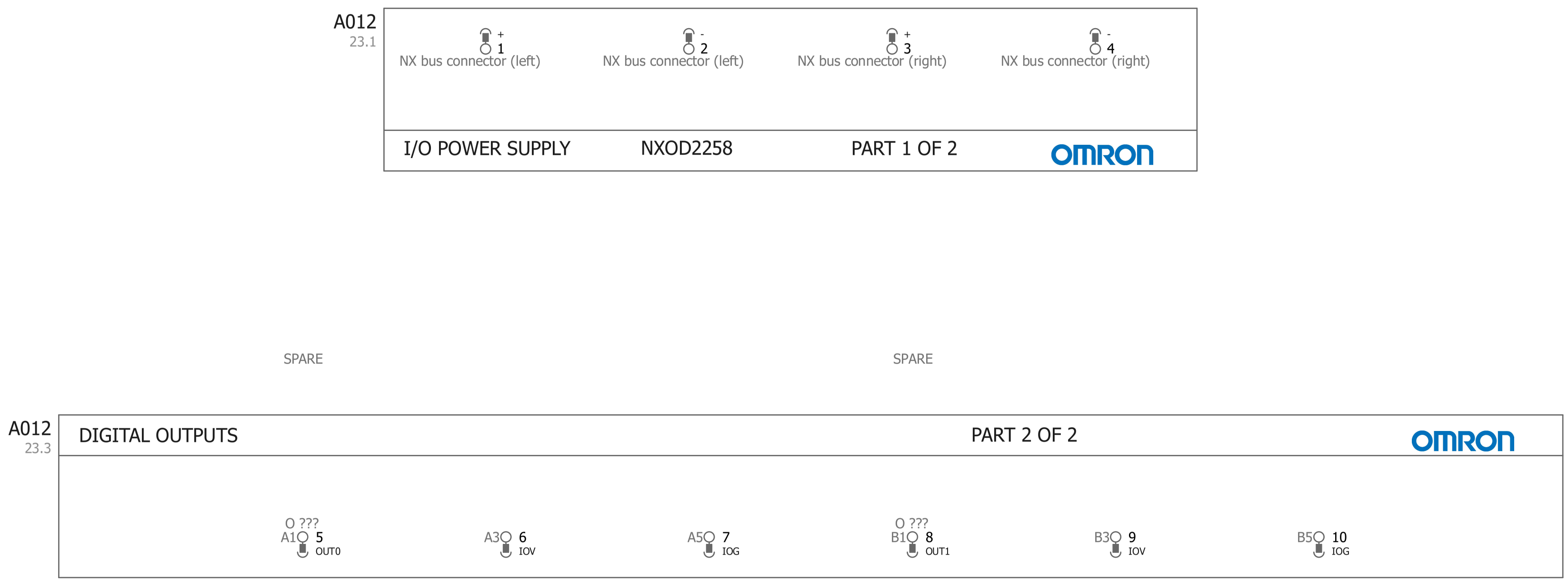
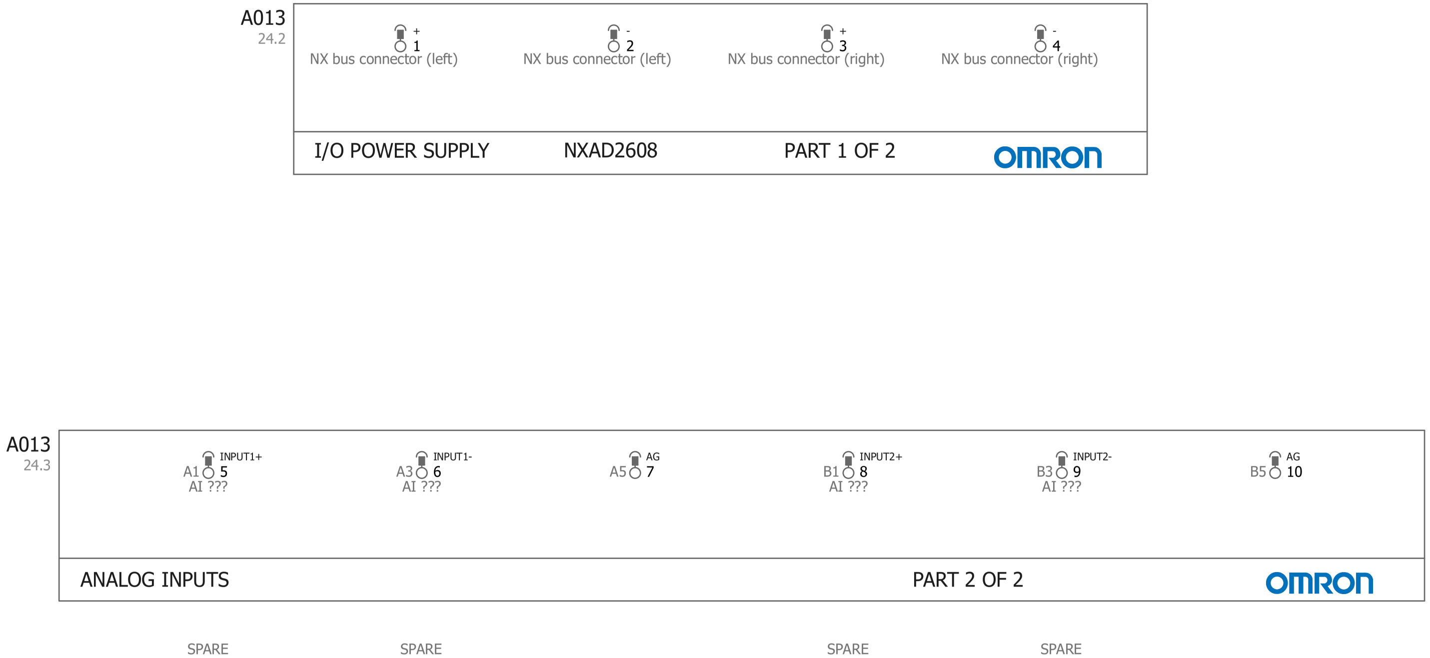

A012
23.1
+ 1
NX bus connector (left)
- 2
NX bus connector (left)
+ 3
NX bus connector (right)
- 4
NX bus connector (right)
I/O POWER SUPPLY
NXOD2258
PART 1 OF 2
SPARE
SPARE
A012
23.3
DIGITAL OUTPUTS
PART 2 OF 2
O ???
A1 5 OUT0
A3 6 IOV
A5 7 IOG
O ???
B1 8 OUT1
B3 9 IOV
B5 10 IOG

0 1 2 3 4 5 6 7 8 9



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Date	10/02/2014
Made by	Miquel
Reviewed	02/02/2016
Approved	

OMRON EUROPE

NJ DEMO (UE)

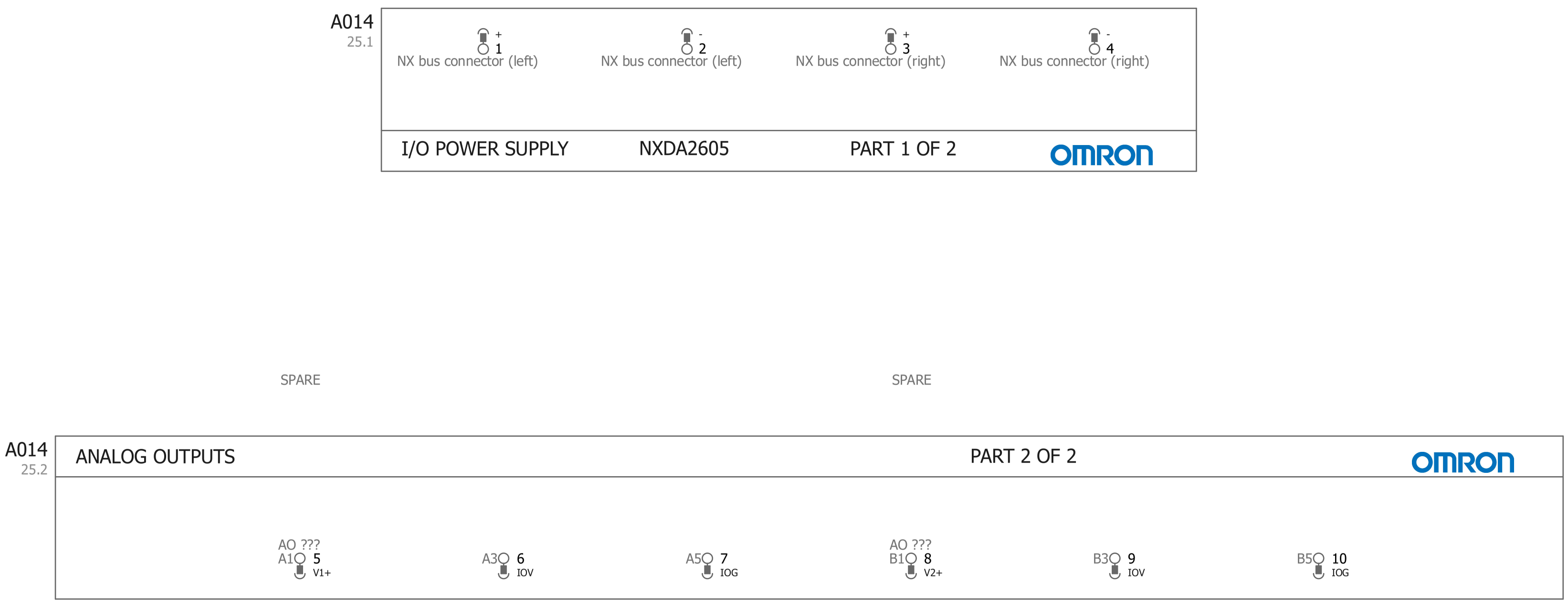
NX-AD2608

Diagram: 14043 UE

Review: 2

== = 14043

++ +



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Reviewed	02/02/2016
Approved	

OMRON EUROPE

NJ DEMO (UE)

NX-DA2605

Diagram: 14043 UE | Review: 2
== = | 14043
++ + | Sheet: 25

0	1	2	3	4	5	6	7	8	9

A015
26.1

1	+	NX Unit power supply
2	-	NX Unit power supply
3	+	I/O power supply
4	-	I/O power supply
5	+	NX Unit power supply
6	-	NX Unit power supply
7	+	I/O power supply
8	-	I/O power supply
9	UNIT TRACK SURFACE	DIN track contact plate

NX UNIT & I/O POWER SUPPLY — NXPD1000 — PART 1 OF 2 — OMRON

A015
26.0

ADDITIONAL NX UNIT POWER SUPPLY UNIT — PART 2 OF 2 — OMRON

A1	10	UV
A3	11	UG
A5	12	NC*2
A7	13	PE
B1	14	UV
B3	15	UG
B5	16	NC*2
B7	17	PE

25