

Festo Storage Station 8049013

Commissioning, configuration, and diagnostics

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Danila Goncharenko

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Abstract <p>The main objective of the planned work is to examine and correct the error that occurred with the Festo Storage Station 8049013, as well as to create documentation for the device.</p> <p>The station will be used as part of an assembly line realized at the automation laboratory of the LAB University of Applied Sciences. The device's main purpose is to give students an opportunity to commission and program the station.</p> <p>The station components, network settings, software features, and manual operation of the device are discussed in detail. The potential uses of the station are explored, and improvements are made to the layout.</p>		
Keywords Festo electronic devices, automation, CoDeSys, documentation		

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Appendix 1. Overview of the Storage Station program

LIST OF SYMBOLS AND ABBREVIATIONS

LED – Light-emitting diode

PC – Personal computer

PLC – Programmable Logic Controller

SPS (EduTrainer Universal) – SpeicherProgrammierbare Steuerung (eng: PLC)

MPS – Modular Production System

I/O – Inputs / Outputs

CPU – Central Processing Unit

CoDeSys – Controller Development System

TIA Portal – Totally Integrated Automation Portal

RSLogicx500 – Rockwell Software Logicx500

SP – Soft PLC

SFC – Sequential Function Charts

FBD – Function Block Diagram

ST – Structured Text

LD – Ladder Logic

FCT – Festo Configuration Tool

FFT – Festo Field Device Tool

1 Introduction

1.1 Origins

LAB University of Applied Sciences has a long business partnership history with the industrial control and automation company Festo SE & Co. KG. This company specializes in pneumatic and electrical automation technology.

Automation engineering is a very relevant industry in modern society. Automation allows companies to reduce the load on the workers. Decreasing the demand for people could help people to consistently manufacture good quality products. This is especially beneficial for Finland, where the natural resources and energy are not lacking, but the human resources are rather deficient.

Although with the development of automation, companies can hire fewer workers for low-quality work, the need for highly skilled workers is rising. Therefore, it is important to create enough educational material for people to be able to operate automated machines.

For these reasons, LAB University has been purchasing educational stations and other equipment from Festo SE & Co. KG for many years. Among the purchased products there was a Festo Storage Station 8049013. After a series of events, all the documentation for the station was lost. Moreover, it was impossible to initiate the work sequence of the storage station.

The tasks of creating documentation for the Festo Storage Station 8049013, as well as finding and analyzing the problem with starting the station were offered to the student as the thesis topic.

1.2 Main problem description

The station was supplied with electricity and compressed air, but the start sequence could not be initialized. The control console in the station did not respond to any commands from the user, even though the LEDs on the console were working.

It is possible to operate the station manually without a control panel by connecting the 3 station control units to a PC with specific network settings via ethernet. By entering a pre-defined web address into the browser search bar, the “webvisu” control interface is found.

It can be used for position teaching, opening, and closing the gripper, switching the station between manual and automatic mode, moving the planar surface gantry, arranging the racks by color, and issuing the workpieces from the racks.

One of the positions was set to the wrong coordinates, which led to the continuously appearing error at the same stage of the station's work cycle. The "Pos. Workpiece" is the position by reference to which the code calculates the next position the gripper should move to.

Since these calculations are based on this position's coordinates, returning to the initial coordinates should solve the problem, but they were missing from the Storage Station 8049013 manual. Another thing missing from the manual was the descriptions for the positions.

The indicator light on the PLC device was yellow, which meant that it contained some program, but waited for some additional action. One may assume that the action it waited for is the start sequence executed from the control console, but it was later revealed that the control console was powered by the program in the PLC device, thus it was not the case.

Manually connecting and monitoring the program flow was also a challenge. The direct ethernet connection between the PC and PLC device did not allow monitoring of the program flow.

2 Components

The main components of the Storage Station are the carrier with motor controller board, the profile plate and the control console, the planar surface gantry with spindle axis, the high-bay racking system, the SPS EduTrainer Universal, and the feed unit assembly with the detection module.

2.1 Carrier

The station is built around a metal trolley. This is a standard element of Festo MPS stations used in a carrier because it makes transporting the device easier. The space inside the trolley is filled by the control units listed below:

- CECC – open-loop controller
- CMMO – motor controller
- EXCM – drive package comprising a controller

The profile plate that holds the other components of the station was fixed to the trolley with nuts. The control console that receives commands from the user and sends them to the control units was fastened to the trolley with screws (Figure 1).

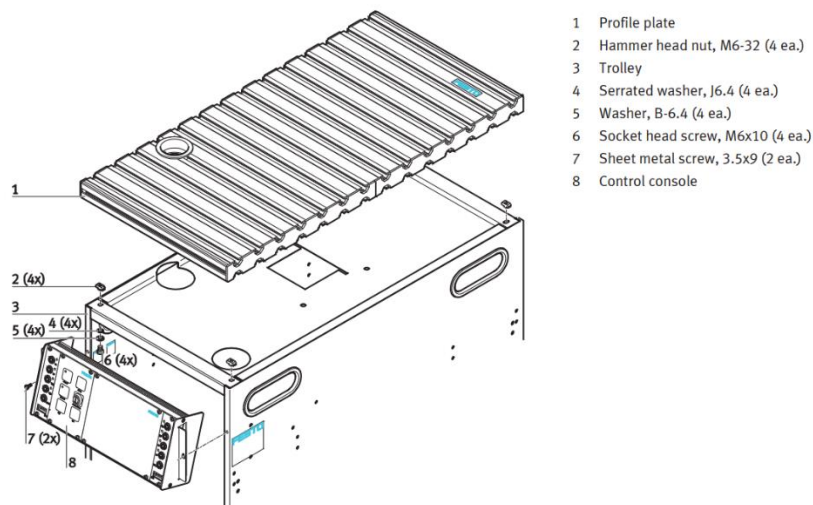


Figure 1. Mounting the profile plate and the control console (Festo Didactic SE)

MPS Metal trolley

MPS trolley is a square cuboid-shaped metal frame with 4 wheels. Its dimensions of it are 350 x 700 x 740 mm (dimensions are given in weight x length x height format). This kind of trolley is also used in other educational Festo stations, meaning that the station can have several applications. For example, it could be implemented in an automated assembly line situated in the LAB University laboratory, as its elements also use the same type of trolley.

The trolley has several storage compartments: one large shelf under the control console where all controllers are stored, and two smaller shelves where the ethernet switch and cables are kept. The compartments are separated from each other by two metal plates.

The first metal plate, in the middle of the trolley, divides the trolley into two large storage compartments. The second, in the middle of the resulting compartment, divides the large compartment into two smaller ones.

Profile plate and control console

The anodized aluminum profile plate holds the racking system and the feed unit assembly. It is also a standard Festo element, frequently used in other MPS stations. The plate was designed so that Festo components could fit between the grooves that are compatible with the item profile system (item Industrietechnik GmbH). Plate dimension are 350 mm x 750 mm x 30 mm. The grid is 50 mm in width. (Festo SE 2022.)

The control console is a board through which the user can control the station. It has 3 buttons: start, reset, and stop, as well as a key switch for shifting between automatic and manual modes. There are 8 indicator lights and cable sockets on the console: 4 for inputs I4 – I8 and another 4 for outputs Q4 - Q8. (Frank Ebel, Claus Knoblich 2003.)

The pin assignment data in the manual says that the I4 input has no destination, although this is not entirely true. It will be actively used during the operation of the device, as the workpiece issuing has been implemented with the BitCode incremented to the input. (Christian & Remo 2018, 46.)

The console also has 2 lights marked Q1 and Q2. Q1 light is activated when issuing is requested, but no workpieces meet the request. Q4 blinks when the station is in automatic mode. Q5 light is on when the station is ready to store or issue.

CECC, CMMO, EXCM

The CECC-D controls pneumatic and electric drives, interrogates electric sensor signals, and exchanges signals with other devices via ethernet. It can be found in FCT by its part number 574415. It is unlikely that if the assignment of the storing station changes, the device will need to be reconfigured, but the CECC manual contains all the necessary instructions. (Controller CECC 2014.)

CECC-D is the most basic version of the CECC controller, which features are CANopen interface and 14 inputs/8 outputs. There are two other CECC variants: CECC-LK, which is also used in a storage station as a PLC controller, and CECC-S.

It must be noted that Festo Storing Station 8049013 manual contains an error stating that CECC-LK is used inside the trolley, which was proven to be wrong. (Christian & Remo 2018, 60.)

This device variant may not be used at all in the station if another type of CPU is selected for storing the program. The additional features of CECC-LK are:

- 4 IO-Link master interfaces
- 1 IO-Link device interface.

The CECC-S is the most advanced variant, with its memory capacity significantly higher than that of the others. The additional (to CECC-D) features of the device are (Controllers CECC 2021, 2.):

- 2 RS232 interfaces,
- 1 multiple communication interface,
- Either encoder, RS485 or RS422,
- 1 IO-Link master interface
- 1 IO-Link device interface.

Such features are not necessary for this application: CECC-D serves as a signals transition point, so there is no need for IO-Link interfaces. CECC-LK can be replaced by its -S variant if the need for its features arises. Instructions on how to install the program on the device using a USB stick will be given in the following chapters.

The CMMO-ST is a controller responsible for the stepper motor in the spindle axis. The device can be found in FCT by its identity code of CMMO-ST-C5-1-DIOP. When a PLC device issues a command to change the state of a stepper motor, the CMMO receives the signal sent from the digital I/O terminal via IO-link. The CMMO then sends this signal directly to the stepper motor EMMS-ST. (Stepper motors EMMS-S 2022.)

The closed-loop servo controller is equipped with low heat development for the motor. It includes safe positions that are monitored and a smooth-running motor. There are up to 64 position sets in the position set table of the device to ensure flexibility in positioning. The device has many functions, and these, according to the Festo manual, are (Motor controller CMMO-ST 2019, 4.):

- Acceleration with jerk limitation
- Monitoring of arbitrarily set positions and torque ranges
- Parameters such as position, speed, acceleration, and braking rate can be flexibly set for each application

- Position drive and power mode with optional torque limiter
- Speed mode with stroke and force limitation

The functions described can be used with the FCT software. This will enable students to configure the controller and make changes to the gantry movement. The webvisu visual interface allows setting up some positions, but a connection to the CMMO must be ensured for full access to the positions and coordinates references.

The EXCM consist of two elements: the planar surface gantry and the controller for it. The identity code of the controller is EXCM-2ST-C3-1. The gantry will be discussed in the following chapter. The controller is responsible for the movement of the gantry in the horizontal and vertical directions.

An ethernet connection between CECC and CMMO is required for the station to operate. The controllers and I/O terminal are mounted with H-rail mounting to the motor controller board, which is riveted to the large metal plate inside the trolley (Figure 2).

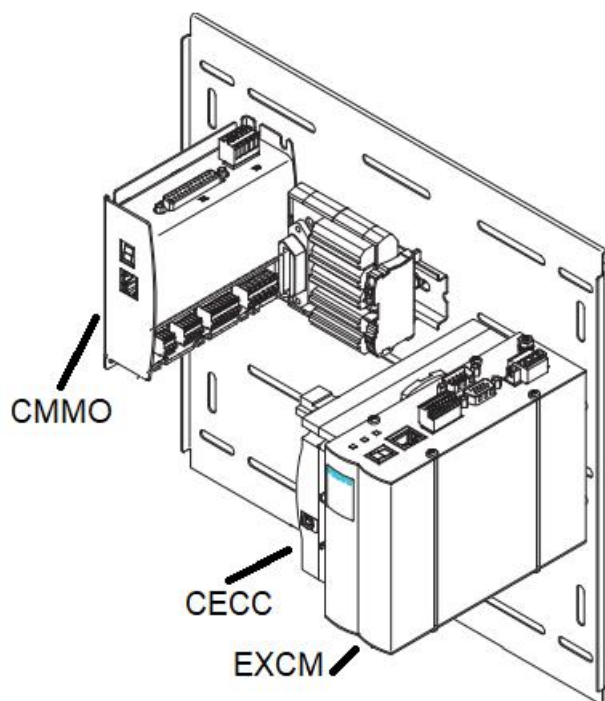


Figure 2. Control units and digital I/O terminal inside the trolley (Festo Didactic SE)

2.2 Planar surface gantry with a spindle axis

Planar surface gantry is operating at a pressure of 6 bars, consuming 1 l/min of air. It is powered from the upper air system in the laboratory by plastic tubing with a 6 mm outside diameter. There is an air switch in the corner of the profile panel to control the flow. The

gripper is 60 mm wide in open conditions and 40 mm wide in closed conditions. (Festo SE 2022.)

The identity code of the device is EXCM-30-600-210-KF-SB-T2-ES-DE. The kinematic mechanisms of the gantry are driven by 2 stepper motors with an integrated optical encoder (closed loop) and a suitable 2-axis controller.

The slide is moved in two dimensions (X axis/Y axis) using a toothed belt. The system is driven by 2 position-controlled stationary motors (closed loop). The motors are connected to a toothed belt. The belt is guided by pulleys so that the slider can move to any position in the working space when the motors are actuated (Figure 3). (Planar surface gantries EXCM 2021, 2.)

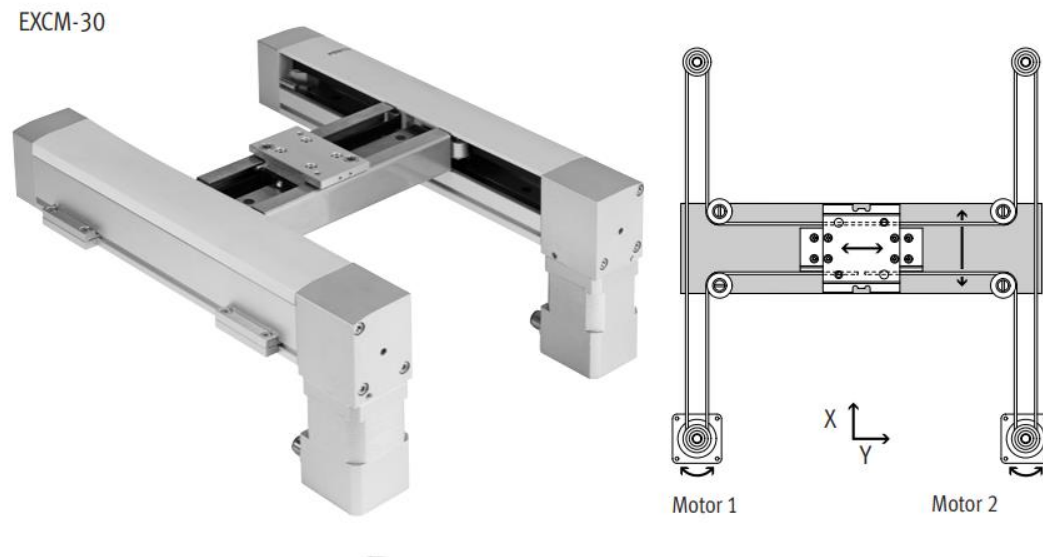


Figure 3. EXCM 30 appearance and functional principle (Festo Didactic SE)

The storage station uses a unique spindle axis in the system. It is marked as "Iigus 4775223001 006 13.07.2017" but searching the Iigus website by this number did not result in finding the correct part. Nevertheless, the motor, the pneumatic valve, and the gripper in the spindle axis are manufactured by Festo, thus it is easy to find the manuals for them. Pneumatic elements of the spindle axis are (Circuit diagrams 2018, 14.):

- G2MM1 (Gripper DHPS-10-A part no. 1254040)
- G2QM2 (5/3 pneumatic drive)
- G2QM1 (3/2 pneumatic drive)
- G2MB1 (Valve L1-1VK8-LP part no. 735441)

The motor rotates the thread so that the gripper module attached to the thread would move along the spindle axis (Z axis). The parallel gripper DHPS-10-A jaws are controlled with a

valve. External fingers are mounted to the gripper jaws to give it additional reach. The valve is located at the rear part of the spindle axis and supplied by a pipe with pressured air of 6 bars going through the Igus cable chain “E2.159.18.5PZ”. (Parallel gripper DHPS 2022, 3.)

The cable connected to the z-axis sensor (B2BG1), and the cable connected to the stepper motor are also going through the chain. The sensor is a z-axis reference switch, it sends a signal to stop the retraction of the gripper module to avoid collision with the rear part of the spindle axis.

2.3 Racking system

The high-bay racking system consists of 6 metal plates, each having 8 slots for storing the workpieces. Storing slots look like square-shaped grooves that perfectly fit 40 mm diameter round discs used by the LAB University in the laboratory.

The slots are made in 2 rows and 4 columns. The rack is filled in such a way that the gripper places the disc from the left side of the rack to the right, from the rear slot to the front slot (Figure 4).

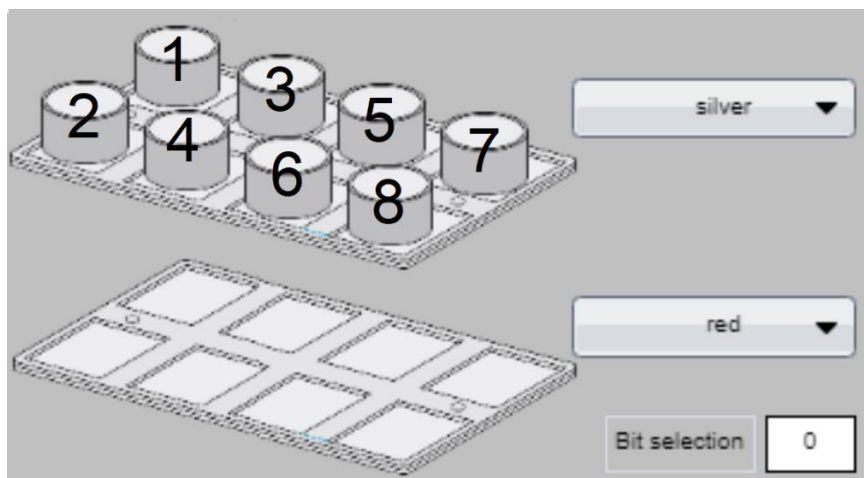


Figure 4. Empty and filled racks, with an order of filling (Webvisu control panel)

Each rack can store up to 8 discs of a certain color. The color may be red, black, silver, or transparent. The color is selected in the webvisu control panel, which will be introduced in the following chapters.

Each metal plate can be dismounted and removed. In the case of testing, it is recommended to do this with the top 5 racks, as the spindle axis may collide with the rack when the spindle is fully extended. When a collision is detected, the movement of the gantry stops, but it does not happen immediately, therefore the spindle axis can be damaged.

2.4 SPS EduTrainer

SPS EduTrainer is the PLC device connected to the main system block via SysLink cables. The cables are connected to the SysLink socket at the digital I/O terminal inside the trolley and the SysLink socket on the control console (Figure 5).

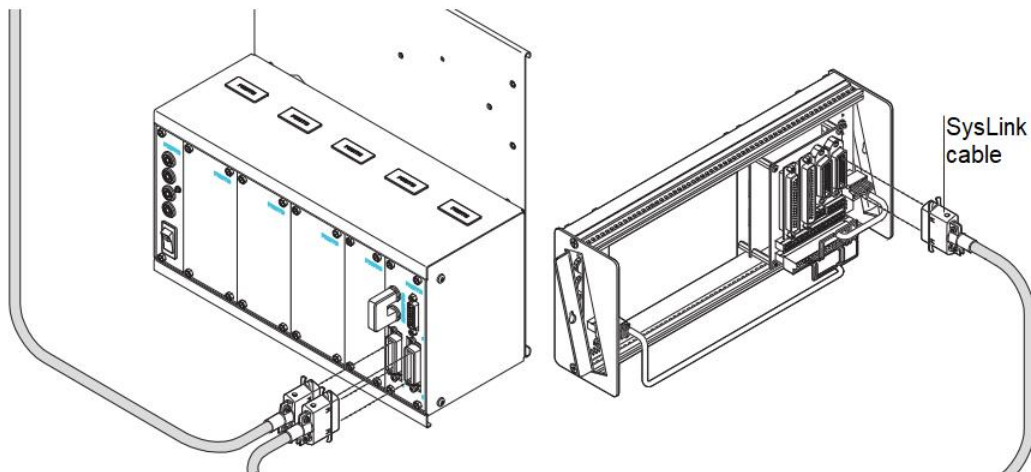


Figure 5. Syslink connection (Festo Didactic SE)

CPU of the SPS EduTrainer can be:

- Festo type – CoDeSys software;
- Siemens type – TIA portal software;
- Allen Bradley type – RSLogix500 software;
- Mitsubishi type – GX IEC Developer software;

In the case of the storage station in LAB University's laboratory, the CPU is Festo type. The current arrangement of the EduTrainer is very basic, as it has 4 blanking plates that can be replaced by different 19-inch modules. All available options can be checked from the manual, which also has commissioning instructions. (Eberhardt & Eggelhöfer & Haußmann & Jedelhauser 2020, 3.)

2.5 Feed unit assembly

The discs are fed through the detection module, which checks the workpiece's color and material with a photoelectric sensor and a reflex light sensor. Its dimensions are 120 mm x 73 mm x 155 mm.

The detection module detects the material or color of items using 3 proximity sensors with a digital output. One inductive proximity sensor and two optical proximity sensors are used (Circuit diagrams 2018, 11.):

- The inductive proximity sensor detects the metallic workpiece (B1G3).
- The diffuse light sensor detects the red and the metallic workpieces (B1G2).
- The fork light barrier detects all workpieces (B1G1).

The sensors are wired to the mini I/O terminal, order no. 8025740. It is attached to the left side of the detection module, which is riveted to the right side of the sliding module. The entire weight of the detection module and mini-terminal is concentrated on a thin metal plate, so special care must be taken when disassembling the feed unit. (8044527 Detection module 2016.)

The angle of the slide was adjusted so that Robotino could deliver the workpiece to the unit. This was done by detaching the two rivets on the metal plate in the middle of the slide. The bottom rivet has a movable position that makes the slide steeper or gentler.

There are two other sensors in the system, the types of which can be checked from the circuit diagrams. They are connected to another mini I/O terminal located under the gantry's left stepping motor. The first sensor is the z-axis reference switch sensor (B2BG1) on the spindle axis mentioned earlier. The second one is the pickup position sensor (B2BG2) located at the end of the slide. (Circuit diagrams 2018, 12.)

3 General definition of Festo Storage Station

3.1 Application

The station will be integrated into LAB University's laboratory assembly line. Finished workpieces will be transferred by Festo Robotinos and stored inside the station. Another use for the station will be to educate students and teach them how to use the CoDeSys software in a practical example.

The pre-installed program mostly uses the SFC and the FBD as the graphical programming language for PLC. In CoDeSys the PLC tags (or variables) are realized with ST, but they can also be displayed in a tabular view, to make them appear in the same way as in the TIA Portal. Automation studies at LAB University focus mainly on LD, thus this station can be a good practical example for students to learn and use other graphical languages.

Festo had also uploaded the program for TIA portal software to the public domain. Therefore, the station can be used as an addition to existing LAB University courses that explore that software. This also means that students can compare the code written in CoDeSys to the one in the TIA portal.

3.2 Operating principle

According to the manufacturer, the station must work as follows (Festo SE 2022.):

- A disc is fed into the system via the chute;
- The sensors in the chute detect the disc color;
- The disc reaches the holding unit;
- The "start" button on the control console is pressed;
- System automatically determines the available storage location for the colored disc;
- Planar surface gantry with spindle axis and pneumatic gripper travels to the holding unit to pick up the disc;
- The disc is gripped and transported to the storage level, where discs of the same color are stored;
- Planar surface gantry places the disc on the empty slot and returns to its start position.

When work with the station started, pressing the buttons on the control console did nothing. As it was later discovered the problem was with the program installed in the SPS EduTrainer.

4 Configuration

4.1 PLC program

The program for the Storage Station was made with CoDeSys V3.5 SP11. Currently, version V3.5 SP18 of this software is available online for free via CODESYS Store. It does not require any licenses, thus anyone may install it without any difficulty. Newer versions are compatible with the older versions, so using the newest version is preferred. (CODESYS GmbH 2018.)

The differences between TIA Portal and CoDeSys are rather subtle. Hence, it may be more appropriate to explain how the program works to students in a course related to the storage station via the TIA Portal version. The description here, however, followed the CoDeSys version.

Many of the variables used in the program are without comments and have names that do not imply the purpose they may carry. There is no official manual with all variable descriptions and instructions on how to use the program. Monitoring variables can give some idea, but this is often not the case as the program deals with many inputs and outputs.

All conclusions about how the code works were drawn during the testing of the device. Some statements about the allocation of certain variables are just speculation and need to be revised. A deeper understanding of the code is required to make major changes to the program, thus only the basic idea of the program structure was explored, and no further study is needed.

Festo product manager in Finland, Mr. Markku Lähetkangas, has made instructions in the Finnish language for the CoDeSys program. Finnish-speaking people can draw additional knowledge about the structure of the program from there. (Markku Lähetkangas a.)

The program was divided into three functional units, each serving a different purpose. The “main” function block contains all other function blocks and is used to transfer the signals they produce to specific inputs and outputs. Code utilizes instances only from the standard library, such as “SR” and “Blink”. The logic was done so that no addresses were set for the variables, which is common for CoDeSys programs.

The program operates with both global and local variables, meaning that the control system was distributed into several units. Therefore, the adjustments one could make to the PLC block are limited. Some improvements in the station work may require changes in the program of other units.

As an example, the “Station reference” output makes the gantry move to the XY-coordinates 0,0 in a way that the gantry collides with the rack frame to ensure proper positioning. This cannot be edited in the PLC program since it only appears there as an output variable that is triggered by a signal from the FB_OpMode function block.

The changes in the movement of the gantry can only be done by commissioning the EXCM and CMMO-ST controllers and making the adjustment with the FCT. In other words, the PLC program manages the signals of the control units and puts all the parts together.

Nevertheless, providing a manual for reading the PLC program is essential to facilitate the modification of the station. Each function block’s code will be discussed and described.

FB_BitCode

This function block is used to issue the workpieces. The code is done with SFC, so the signal goes from the top to the bottom “step” blocks. When a block is active it does the action described in the branch to the right from the block, e.g., the “Init” block resets output variables “xProcessBusy” and “xResetReady” and sets the “Act” subfunction to be active.

The qualifiers for actions in SCF used for storing are:

- S – The action is activated as soon as the step is active.
- N – The action is active as long as the step is active.
- R – The action is deactivated.

The transition element between the step blocks defines the condition to transfer the signal down. This way, to move from “Init” to “Step0”, the variable “R_TRIG_CntUp.Q” must be triggered. To do so, as described in the ACT subfunction, the variable “xCntUp” must change its state. It can be done by giving a rising edge signal to input I4.

The "Step0" to "Step4" blocks trigger the variables "xBit0", "xBit1" and "xBit2", which send signals to the memory outputs "xMBit0", "xMBit1" and "xMBit2". The combination of these signals allows the program to determine which rack to empty.

These memory outputs are global variables, so it is impossible to define the internal logic within the bit-signal combination just from the CoDeSys program. The variables are assigned to "Flags for the Main prg", which does not give a clear idea of where the signal is going.

However, these several bit signals are later converted into a single bit value. This value can be monitored through the webvisu interface. The meaning of each number that the value takes is described in the following chapter.

After triggering the variable "R_TRIG_CntUp.Q" for the fifth time, the value is set back to zero. The signal is fed back to the "Init" step block using the "Jump" element at the end of the function block.

FB_OpMode

The function block is used to monitor the state of the station. It is written in 18 networks, each having its purpose. Some of them are needed for some internal logic of the code, so it is difficult to assess what each network does.

Many variables are missing descriptions and figuring it out based purely on the name is impossible in some cases. However, the functions of some networks are easy to determine, for example, network 2 resets all modules when the reset button is pressed, and the process is not running.

It also activates the "xclock_Yellow" variable. Festo uses variables of this kind to show the status of the station by turning on the light indicators of different colors on the control panel. The red light indicates that the station is not ready, yellow – is when it is resetting, and green – is when it is ready.

From the example of "xclock_Green", it is seen how this function is usually coded. Activating this variable will activate the variable "GreenStatus", which then activates the global variable "indLightYellow". However, "xclock_Yellow" is not used anywhere in the code outside network 2. In the main function block, the "YellowStatus" variable can be seen.

The storage station does not need these variables and there are no such indicators on the control console. Taking this into account, two possibilities can be assumed. Either the coding of the yellow indicator is not made, because it is not needed, or the coding is made in another, not yet discovered place.

The reason why this was done for the green indicator and why these variables are present in the program may be to make the code more flexible and customizable. Or perhaps it is a standard for Festo to add these variables and make code for the green indicator. Further research will be needed to fully understand this function block.

FB_SeqTransport_ST

The function block is used to store the workpieces. The basic cycle of the code in this block is written in SFC, while the more specific functions are executed using the FBD in the "ACT" subfunction.

The code begins at the "Init" step element, which sets the subfunction "ACT" to be active and resets variables "xProcessBusy" and "xResetReady". This way, the code realizes that the storage process has not yet started, and it waits for the reset to be pressed.

When the reset button on the control console is pressed, the fault is cleared and in 200 ms station is reset. If an error is detected, the cycle returns to the "Init" step, otherwise, the program proceeds to step2, which makes output variables "xResetReady" activated and "xProcessBusy" deactivated respectively.

This step2 stays active when the station is in the idle position and changes to step3 when the workpiece is detected at the fed module. At the step3 element, the storing process is in order, thus "ProcessBusy" output is activated. Gantry moves around the positions specified in EXCM and CMMO-ST.

The "ACT" subfunction is used to exchange bit data in the system. It can only be guessed what purpose it serves, as most of the variables are missing comments. It may be assumed that it is needed for the code to understand how to fill the rack.

It is defined as how the program should react when a store is full and what to do next. Store Bit numbers might represent the positions of the slots on the rack. More accurate conclusions can be drawn by testing the station with monitoring enabled.

FCT

FCT is a PC-based software package for electrical drive configuration and commissioning. It is a menu-driven environment that allows all parameters and motion control profiles to be defined, checked, and loaded into the controller via the integrated RS232 interface with minimum effort. (FCT Software: Standard Tool for Configuring and Commissioning Electrical Drives, 1.)

Several powerful commissioning features are provided in the software, including reference motion, diagnostics, and an interactive "teach-in" operation mode that allows direct control of system components from a PC.

The Festo support portal contains FCT plug-ins for most of its devices, which should be downloaded for configuration. No other system setup is required since all key characteristics such as a mechanical actuator, moving loads and external bearing friction are known in the internal FCT library. (Rice, 6.)

The controllers in the storage station are configured in FCT as described in the following instructions:

- Firstly, plug-ins for the devices are downloaded
- Secondly, FCT is opened, and a new project is created
- Thirdly, the device is selected by name for a component to be configured
- For CMMO-ST “OK” is pressed; For EXCM “30” is selected and “OK” is pressed
- Then, the PC is plugged into the ethernet switch to which both controllers are connected
- The FCT interface is found in the component menu on the top bar
- Next, the IP address is entered manually, or the scan button is pressed, and the device is selected from the pop-upped menu
- After that, the “Offline – IP address” button on the top bar is clicked to go online
- Subsequently, “Upload” is pressed to upload the device configuration to your PC
- Finally, once the configuration is uploaded, the bottom bar menu is used to operate the device

Pressing "Download" will download the device configuration made on the PC to the device, and "Synchronize" will compare the configuration data entered on the PC with the configuration on the device.

Fully set up controllers, as soon as an online connection is made, will start sending statistics to the PC immediately, which can be found in the “Monitoring” menu in the FCT. Manual jogging of the gantry is done by going online for the EXCM controller and selecting "FCT" and “Enable” under Device Control in the Manual Move menu (Figure 6).

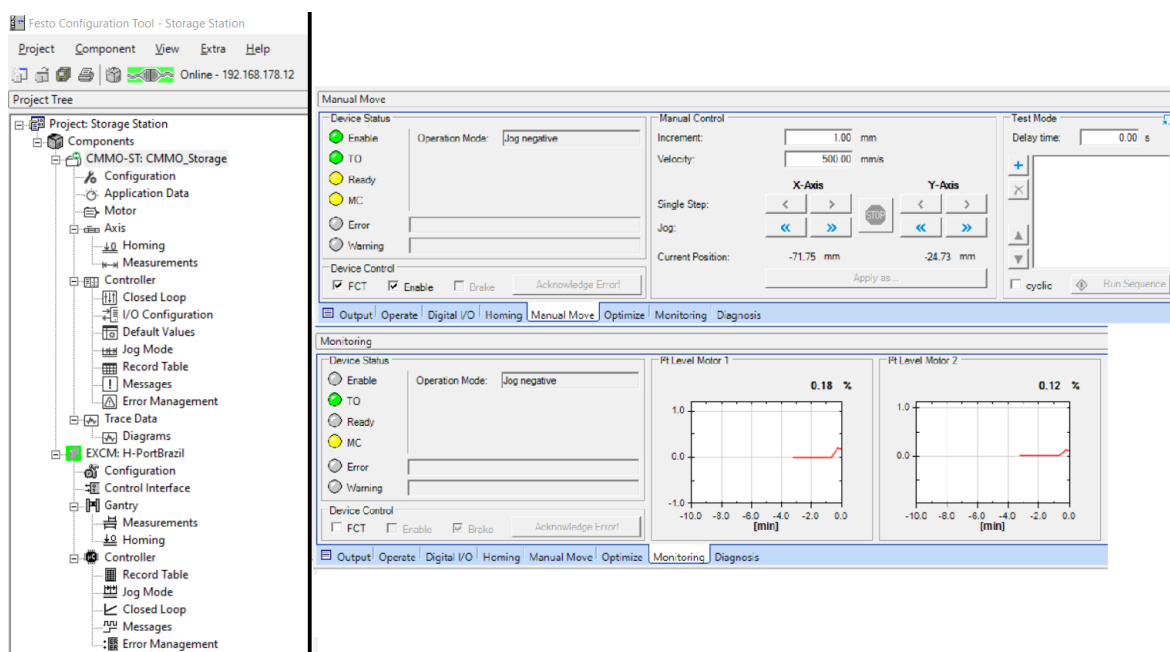
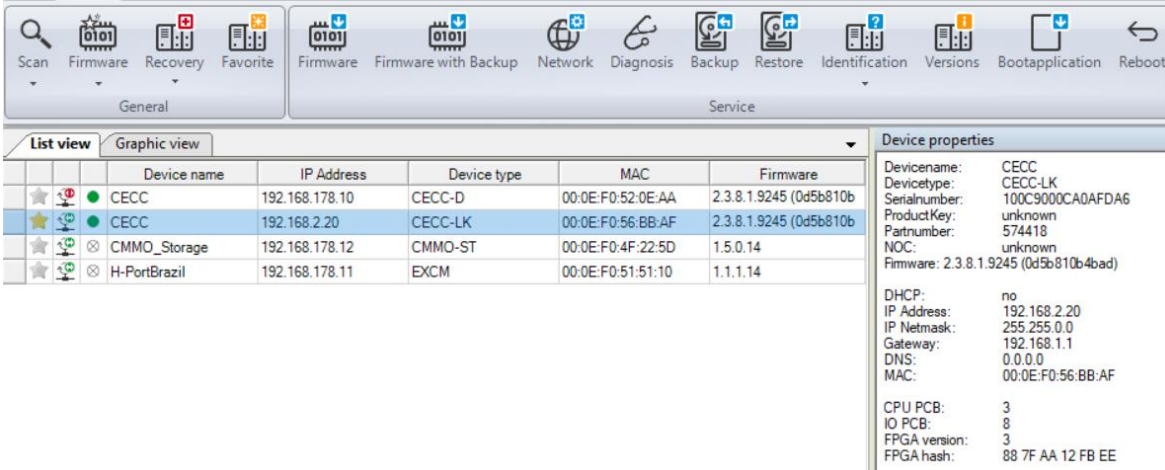


Figure 6. Project Tree, Manual Move, and Monitoring (FCT)

FFT

FFT is software for the service, commissioning, and maintenance of Festo devices. The software will discover all the devices connected to the PC via ethernet. A large list of specifications will be provided for each connected device, including the full device name, network settings, and firmware version. This information was crucial for fixing the problem and understanding how the system works. (Festo Field Device Tool 2018.)

It allows the user to find the serial number, which can be used to find devices faster in the FCT. FFT gives the IP address, subnet mask, and DNS server required to connect to a device via ethernet without checking the manuals or labels on the device, which can be difficult to access (Figure 7).



The screenshot shows the FFT software interface. At the top, there are two tabs: 'General' and 'Service'. The 'General' tab is active, showing a toolbar with icons for Scan, Firmware, Recovery, Favorite, Firmware with Backup, Network, Diagnosis, Backup, Restore, Identification, Versions, Bootapplication, and Reboot. Below the toolbar, there are two views: 'List view' and 'Graphic view'. The 'List view' is selected, displaying a table of devices. The table has columns for Device name, IP Address, Device type, MAC, and Firmware. The 'Device properties' panel on the right shows detailed information for the selected device, including Device name, Device type, Serial number, Product Key, Part number, NOC, Firmware, DHCP status, IP Address, IP Netmask, Gateway, DNS, MAC, CPU PCB, IO PCB, FPGA version, and FPGA hash.

Device name	IP Address	Device type	MAC	Firmware
CECC	192.168.178.10	CECC-D	00:0E:F0:52:0E:AA	2.3.8.1.9245 (0d5b810b)
CECC	192.168.2.20	CECC-LK	00:0E:F0:56:BB:AF	2.3.8.1.9245 (0d5b810b)
CMMO_Storage	192.168.178.12	CMMO-ST	00:0E:F0:4F:22:5D	1.5.0.14
H-PortBrazil	192.168.178.11	EXCM	00:0E:F0:51:51:10	1.1.1.14

Device properties:

```

Device name: CECC
Device type: CECC-LK
Serial number: 100C9000CA0AFDA6
Product Key: unknown
Part number: 574418
NOC: unknown
Firmware: 2.3.8.1.9245 (0d5b810b4bad)

DHCP: no
IP Address: 192.168.2.20
IP Netmask: 255.255.0.0
Gateway: 192.168.1.1
DNS: 0.0.0.0
MAC: 00:0E:F0:56:BB:AF

CPU PCB: 3
IO PCB: 8
FPGA version: 3
FPGA hash: 88 7F AA 12 FB EE

```

Figure 7. Device properties (FFT)

4.2 Network settings

To monitor the program flow, one must connect the PC with the pre-installed program to the CECC-LK device via an ethernet cable. The network settings on the PC must be:

- IPv4 address: 192.168.2.1
- Subnet mask: 255.255.0.0
- IPv4 DNS Server: 0.0.0.0

A storage station can be commissioned by connecting the PC to the open-loop control (CECC-D), the motor controller (CMMO-ST), and the drive package comprising a controller (EXCM) via an ethernet switch (Figure 8).

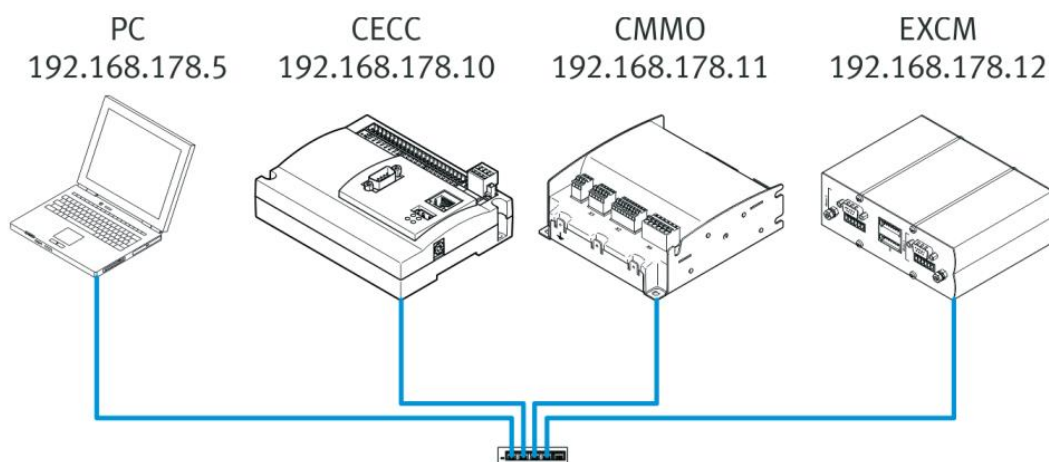


Figure 8. Ethernet connection of the devices with IP addresses (Festo Didactic SE)

Network setting on the PC must be:

- IPv4 address: 192.168.178.5
- Subnet mask: 255.255.255.0
- IPv4 DNS Server: 0.0.0.0

After the connection is established, one may control the storage station with the web interface found at the following URL: <http://192.168.178.10:8080/webvisu.htm>. The webvisu is a visual interface with which the user can manually control the station. (Christian & Remo 2018, 61.)

4.3 Webvisu navigation

Webvisu can do the following operations with the station:

- Move the gantry
- Open and close the gripper
- Select which color discs will be stored on the rack
- Check which disks are to be issued from the rack
- Clear the store from the discs
- Reset and set a global reference for the station

The webvisu is available in German and English, which can be selected in the central-bottom part of the interface (Figure 9).

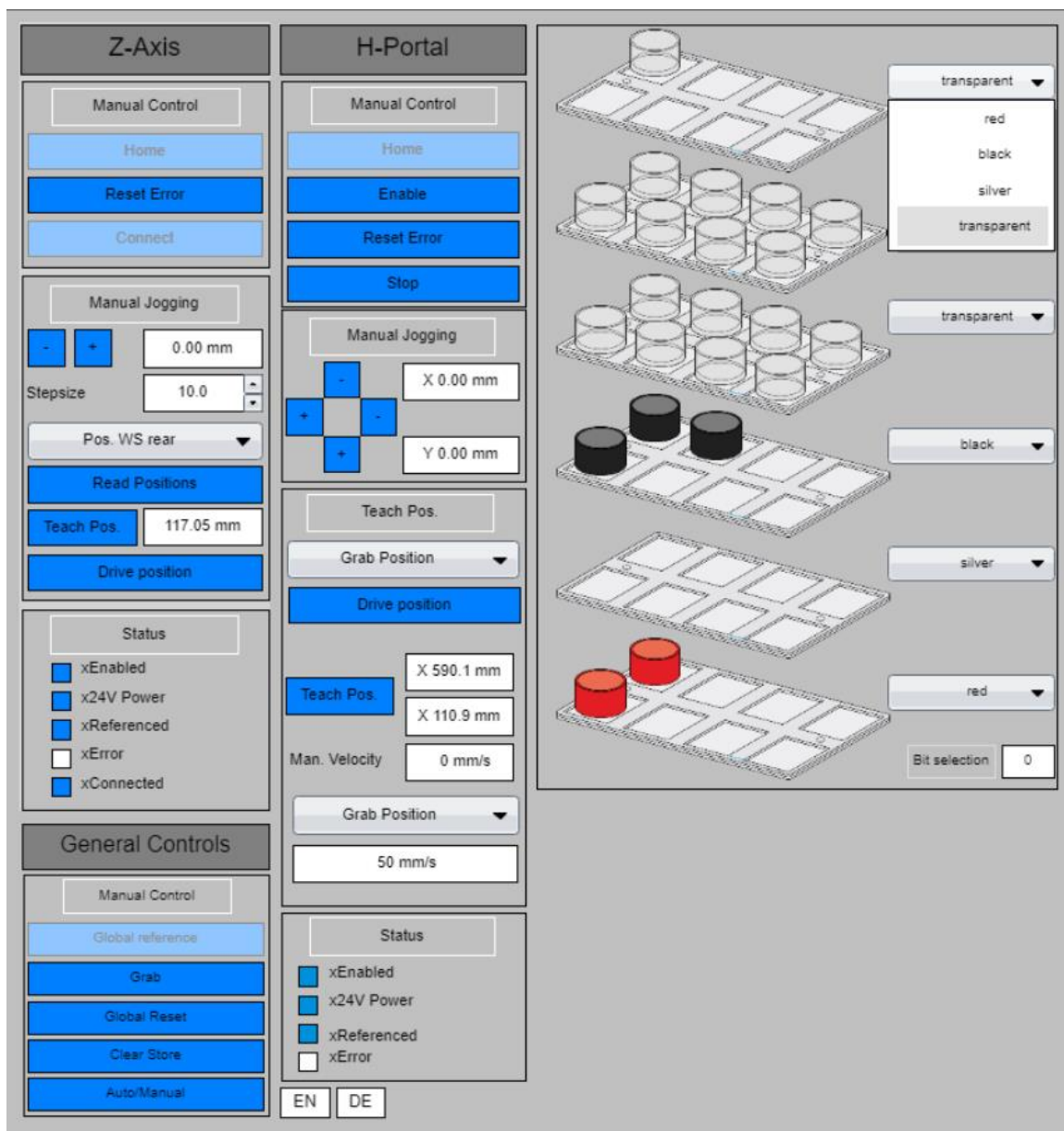


Figure 9. Webvisu interface (Festo Didactic SE)

General Controls

The commissioning of the station starts with the “General Controls” panel at the bottom-left corner of the interface. The station must be referenced to operate, which can be done by first pressing the "Global reset" button on the panel that will reset the reference and then pressing the "Global reference" button that will cause the planar surface gantry to move to the zero coordinates at the top right of the racking system.

Pressing the “Grab” button will result in the closing or opening of the gripper. The "Clear shop" button will clear the racks from the discs in the interface. The “Auto/Manual” button will switch between the automatic and manual modes for the station. If the buttons at the “Manual jogging” do not work, the station is in automatic mode.

Z-Axis

The “Z-Axis” panel is responsible for the gripper movement on the z-axis. The gripper has 3 positions on the z-axis: “Grab position”, “Pos. WS front”, and “Pos. WS rear”. “Grab position” always has zero z-coordinate and is used to grip the workpiece and move between the racks. “Pos. WS front” is the position on the first row of the rack and “Pos. WS rear” is the position on the second row of the rack about the initial position.

Since the gripper location on the z-axis is controlled by a stepper motor, the connection to the motor must be ensured and, if commissioned, a step size must be selected for manual jogging. Clicking the "+" and "-" buttons once will move the gripper towards and away from the rack respectively by the distance selected in the step size.

The current gripper location can be seen below the "Read Positions" button and pressing the "Teach Pos." button will assign the current z-coordinate to the position selected above the "Read Positions" button. Pressing the "Drive Position" button will move the gripper from its current position to this selectable position.

H-Portal

The "H-Portal" panel is used to navigate the planar surface gantry in the XY plane. The arrangement of the "+" and "-" buttons in the manual jogging menu corresponds to the direction in which the gripper will move when any of them is pressed.

The current x and y coordinates of the planar surface gantry can be assigned to the position selected under the “Teach Pos.” menu by clicking the “Teach Pos.” button. There are 4 teachable positions: “Grip position”; “Idle position”; “Transfer position”; and “Pos. Workpiece”. The purpose and description of these positions will be given later.

Users can command the planar surface gantry to move to these positions by selecting one from the drop-down list, entering the velocity in the “Man. Velocity” input box, and clicking the “Drive position” button. It should be noted that clicking this button when the velocity is set to zero will cause an error, which must first be reset by pressing the “Reset Error” button in the manual control menu to proceed with commissioning the device.

The planar surface gantry movement can be interrupted at any time by pressing the "Stop" button in the manual control menu. The “Home” button functions in the same way as the global reference button and allows setting the reference for the “Z-Axis” and the “H-Portal” separately.

Rack menu

A menu on the right side of the webvisu manages the storage of the discs by color on the racks. Users may select one of the colors from the drop-down list to indicate which discs will be stored on the rack. Each counter has a separate list, and the location of the rack in the menu corresponds to its location in the real station.

The "Bit selection" textbox at the bottom-right corner of this menu is used to show which workpiece will be issued. Issuing is realized through a counter that takes values from 0 to 5, each representing a specific color or rack. The textbox contains the current value of the counter.

4.4 Workpieces issue

The station must be in manual mode for the removal of the discs from storage. The counter specifies which disc should be issued. The station was made in such a way that the counter value can only be incremented by the rising edge signal coming to input I4.

The removal sequence can be started by pressing the "Start" button on the control console. This will make the gantry remove the workpiece and transport it to the output slide. After that, the gantry will move back to the idle position.

When digital output Q7 is set to 0, the user can specify which color workpiece should be removed from storage. When Q7 is set to 1 the user can select the storage level from which the workpiece will be removed. The bit numbers in the range 0-5 were assigned to specific workpiece colors for Q7=0 and specific racks for Q7=1 (Table 1). (Christian & Remo 2018, 56.)

Table 1. Bit numbers and descriptions

Bit number (Q7=0)	0	1	2	3	4	5
Description (Q7=0)	Red	Black	Silver	Transparent	N/A	N/A
Bit number (Q7=1)	0	1	2	3	4	5
Description (Q7=1)	Bottom rack	Rack 2	Rack 3	Rack 4	Rack 5	Rack 6

Festo did not provide the device that could give a rising edge signal to input I4, thus self-made small circuit powered by EduTrainer was realized. When a button in the circuit is pressed, it blinks a light once and the switch closes, sending a signal to I4 (Figure 10).

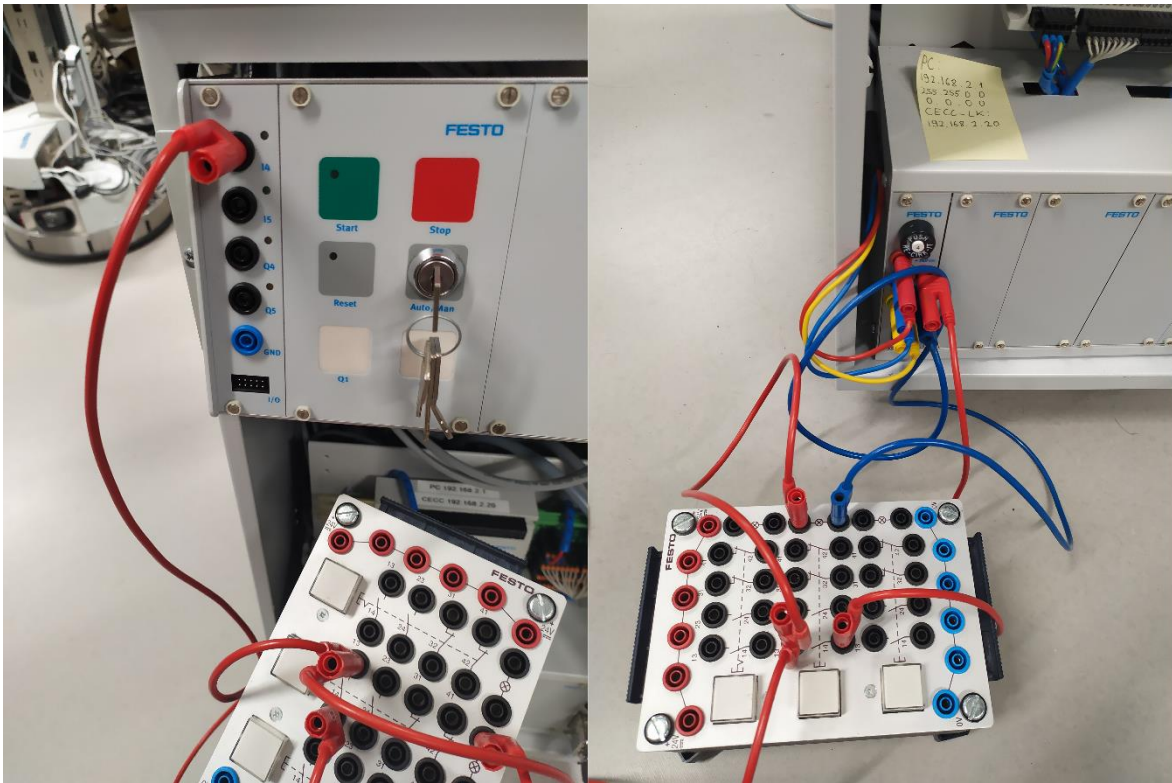


Figure 10. Self-made small circuit (Image: Danila Goncharenko)

5 Problem solving

5.1 Position teaching

Positions can be changed and adjusted if one so desires. The reference coordinates and description of the positions were not provided in the Festo manual, therefore the latest parameters set on the station were documented for future commissioning (Table 2).

Table 2. Position names and coordinates

Grab Position	A position where the gripper can grip the workpiece	X	590.1 mm
		Y	110.9 mm
Idle Position	A position, from which the gripper safely moves to the other positions by linear interpolation	X	445.2 mm
		Y	110.9 mm
Transfer Position	A position where the workpiece will be dropped on the outgoing slide	X	448.4 mm
		Y	18.8 mm
Pos. Workpiece	A position at the first (most left) slot on the bottom rack	X	462.2 mm
		Y	185.8 mm

The gripper also travels on the z-axis to reach the rack position for the front and rear slots. The initial coordinates for those positions are listed below (Table 3).

Table 3. Position names and z-axis coordinates

Position Grab	0.00 mm
Position WS front	63.03 mm
Position WS rear	117.05 mm

5.2 Network configuration (DNS)

An ethernet switch with 8 ports was placed inside the carrier and connected to the control units of the storage station for easier commissioning of the device. Three ethernet cables in different colors were used to connect the switch to the devices: EXCM via a light green cable plugged into port 3; CECC-D via a yellow cable plugged into port 6; CMMO-ST via a dark-green cable plugged into port 8.

PC can be connected via a spare light-green cable plugged into port 1. The paper sticker with the PC network settings and webvisu URL address was attached to the ethernet switch to make the commissioning of the device easier for students (Figure 11).

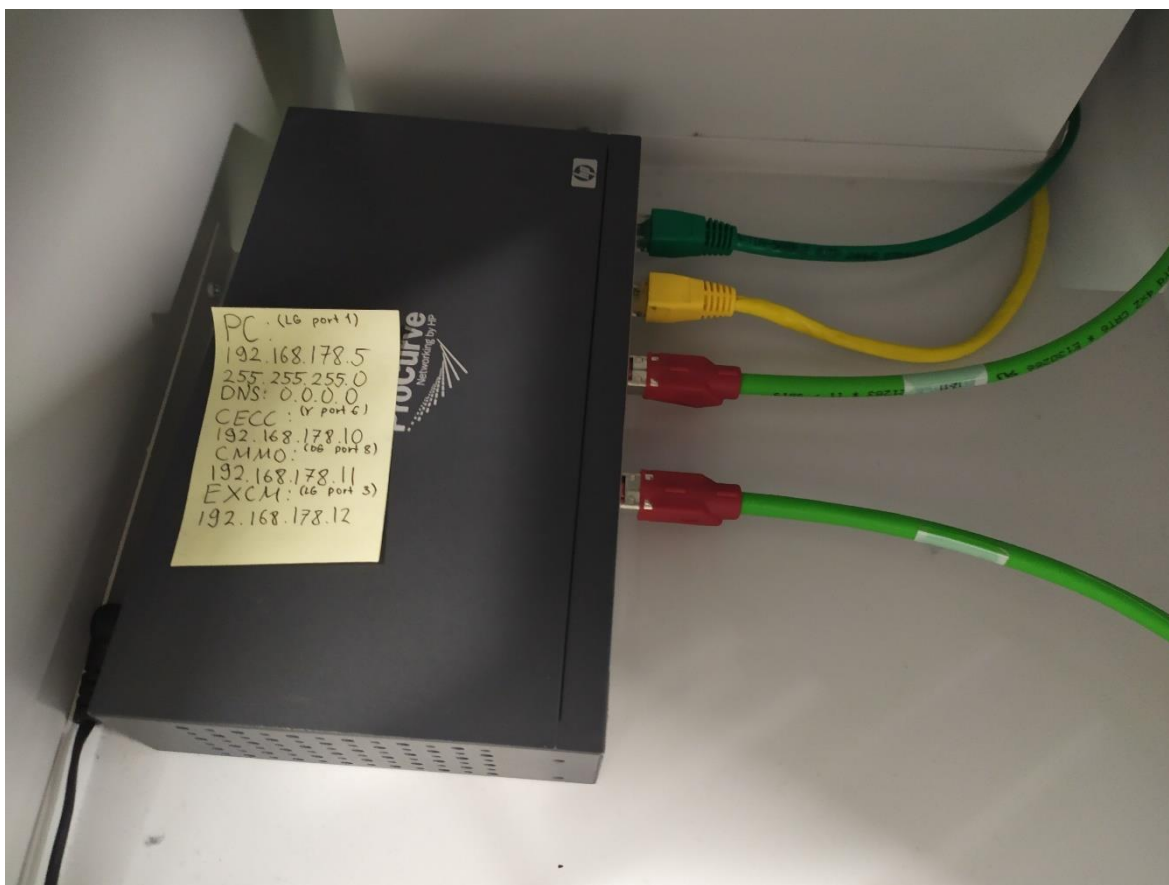


Figure 11. Ethernet switch inside the carrier (Image: Danila Goncharenko)

The spare light-green cable can also be used to connect the PC to the CECC-LK and monitor the program flow. One may unplug this cable from the ethernet switch and put it into the PLC device and PC ethernet ports. The cable has a sticker with the needed PC network settings attached to it.

5.3 Program uploading

The PLC program can be uploaded to the CECC-LK device using a USB-memory stick. It is recommended to first check the device properties, which can be done with the FFT. The specifications found can be then compared to the following prerequisites, which must be met before uploading the program to the CECC-LK (CoDeSys USB-Bootproject MPS Storage Station Manual, 1.):

- Firmware version is 1.3.4.0 or later
- USB memory stick is formatted: file system FAT or FAT32 only

- "Device Description in Project" and "CECC Runtime System" versions are the same
- "Load Project Data from USB Memory" function in the USB configuration of the CECC-LK is activated (default setting)
- PLC shell commands are "usbsetconfig" and "usbgetconfig"
- CECC-LK is switched off

The firmware version can be updated directly in FFT. Other settings can be changed by commissioning CECC-LK as instructed in the manual for the device. The program and USB-boot project can be downloaded from the Festo Didactic InfoPortal website found under "Software > PLC > MPS D".

The needed files can be obtained by pressing "Festo CECC" and "USB-Bootproject MPS Storage Station". These files will be the CoDeSys project archive and the "root" folder with the manual.

- Firstly, the CoDeSys project and "root" zip folder are unarchived
- Secondly, A USB memory stick is plugged into a PC
- Thirdly, the CoDeSys project is opened
- Next, « Application [Storage: PLC Logic] » is selected
- After that, in CoDeSys « Online > Create boot application » is selected
- Then, the old application found under « ... > root > ffx > codesys > prj » is replaced
- Subsequently, the root folder is moved to the USB memory stick
- Finally, the USB memory stick is unplugged from the PC

The USB drive now has all the necessary files, and by plugging it into the PLC device, the program will be installed on it. The step-by-step process for uploading the program is shown below:

- Firstly, the USB memory stick is plugged into a CECC-LK
- Next, the CECC-LK is switched on
- Then, the CECC-LK detects the project data on the USB memory stick and uploads it to the flash memory (non-volatile memory) of the CECC-LK
- Subsequently, the uploaded project is automatically started
- Finally, the USB memory stick is removed so that this process is not repeated the next time the CECC is switched on

The "Run" indicator light on the CECC will be green if the program was uploaded correctly and no further action is required. It will be yellow if something is missing in the program, thus it is stopped. It will be red if the device could not find the program or if it causes an

error. All the LED indicator descriptions can be found in the CECC-D/LK/S manual. (Controller CECC-D/LK/S 2018, 5.)

The CECC controller manual contains all commissioning instructions and if any error appears again, it is recommended to start with this manual as it will describe the error message that appears.

5.4 Possible expansions of the station

PC network settings need to be reconfigured every time one connects to the station or the PLC device. The network in the LAB University laboratory was set to be 198.168.195 meaning that students must either use their own computers or ask permission from the university IT technicians to change the settings on the university PCs.

Webvisu simplifies the station control dramatically, thus making LAB PCs connectable to an ethernet switch would make commissioning a lot easier. A router can be used as a transition point between the PC and the ethernet switch, reconfiguring the settings to put the devices into the same network area.

Full documentation of the PLC program could be a great asset to the course, as it would allow the students to further adjust the CoDeSys program. In this thesis, it was explained how changes in the states of the variables with the monitoring on can be used to find out variables' designation.

It might be a good idea to make this task a team project work, as it is easier to be done by two people: one person works with the station, second person monitors the state change of the variables in the program. It will be useful work that introduces students to CoDeSys and makes further changes to the storage station code possible.

Another good improvement would be a modification of the webvisu interface, which can be done through the CoDeSys software. New objects, such as a button that increases the BitCode value directly from webvisu, can be added this way (Figure 12).

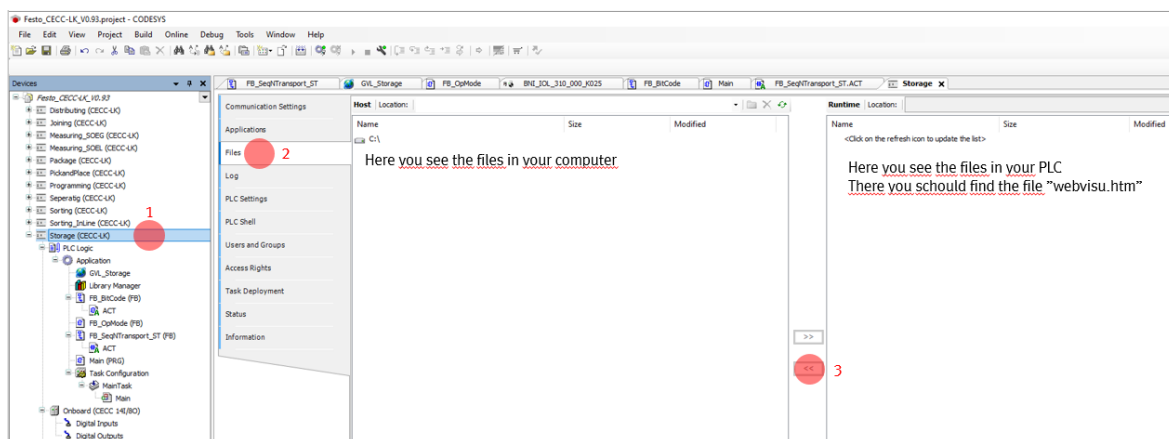


Figure 12. Webvisu modification (Screenshot: Markku Lähetkangas)

It can be beneficial to add a table with the explanation of each BitCode value to the webvisu so that students would not need to check it from the manual every time. Instead, the table with bit values could be added as a paper sticker on the control console, since it is required to switch the key for issuing and students will use the console anyway.

Reflecting deeper in this direction, the small self-made circuit could be made differently. As of now, it is unreasonably large and poorly integrated into the station. The only purpose it serves is to increment the bit value. The only requirement for the circuit is to be able to send the signal via a 4 mm safe cable to the I4 input on the control console.

This leads to a large variety of solutions, one of which could be seen in this thesis. The perfect way to integrate the pushbutton into the system could be to add the 19-inch module 8DIN into the SPS EduTrainer. This plate both has the needed cable socket and the push button switch. The biggest concern of this solution is the price, as there are cheaper ways to implement it with the same level of integration.

To be able to connect a university PC to the CECC-LK, its IP address should be changed. It can be done with FFT by connecting to the controller via ethernet and selecting the "Network properties for the device" in the software. Festo has given detailed instructions on how to do this in the CECC controller manual.

6 Summary and conclusions

As a result of the performed diagnostics, Storage Station 8049013 has returned to operating condition. The reason for the malfunction of the Festo Storage Station has been identified and eliminated. Measures were given to resolve the same error in the future. The conducted research on the station components has provided an in-depth understanding of the system's operating cycle.

The station and the ethernet switch are electrically supplied from a cable switch behind the carrier. The workpieces are stored in the station when they are delivered by Robotino and fed through the Detection Module. The gantry will move and deliver the workpiece when the station is ready.

The stored workpieces are issued and delivered by the gantry into the holding unit when the station is in issue mode. Holding the "Stop" button for 3 seconds will allow a user to restart the station and reference the gantry by holding the "Restart" for 3 seconds. Pressing the "Start" button once will bring the station into ready status.

Switching the key to a vertical position will set the station into store operating mode. The key in a horizontal position will set it into issue operating mode. In the issuing mode, the user will need to press start for every workpiece to be removed from the rack. The workpiece can be selected by the color or level of the rack by triggering the rising edge at input I4 on the control console.

The additional system, a small self-made circuit, was added to the station for those purposes. Pressing the middle button in the circuit will make it blink and increase the bit value by 1. The current value can be checked from the webvisu visual interface or CoDeSys program, thus it is recommended to always make sure the value is set back to zero after students are done working with the station.

The values range from 0 to 5, and the colors are in the order red; black; silver; transparent. Bit values 4 and 5 are not used. If the workpiece is selected based on the rack level, as the bit value increases, the rack level goes up from the bottom to the top. This information is represented in chapter 4.4, Table 1.

As of now, there is no way to connect to the station via ethernet through university computers and students will need to use their own personal PC to access the deeper settings of the station. It can be done by connecting the PC to an ethernet switch stored in the back compartment of the metal trolley.

The network settings on the PC must be changed to the ones indicated on the sticker attached to the switch. Then, webvisu is found by putting <http://192.168.178.10:8080/webvisu.htm> into the search bar of the browser on the PC. In webvisu, students may clear the store and arrange racks by colors. These actions can only be done from there.

In addition to that, the visual interface has such features as manual control of the gantry and spindle axis, which otherwise could be accessed from EXCM and CMMO controllers respectively. Webvisu allows setting 4 positions for the gantry and 3 positions for the spindle axis. The station operates with a much larger number of positions that can only be checked or modified from the before-mentioned controllers.

To do so, one must first configure the EXCM and CMMO in FCT by downloading the plugins and uploading the device data from the controller to the PC, which can be done with the ethernet connection. It should be noted that the network settings on the PC are not important for this connection, unlike the connection to the webvisu and the PLC program.

The PLC program is stored in the CECC-LK controller attached to the SPS EduTrainer. It can be accessed by connecting the device via ethernet to the PC with network settings written on the paper sticker attached to the device. When the gateway is configured and an online connection is secured, the user can monitor the program flow in real-time.

A CoDeSys project corresponding to the program stored in the controller must be installed on the PC. This means that changes to the program must first be made on the PC, then an application file must be made from the project. This file is later uploaded to the root file on the USB stick, which is afterward plugged into the CECC-LK.

The modification of the webvisu is also done with the CoDeSys project, but the files of the virtual interface can only be accessed when the PC and the controller are connected, thus no USB stick uploading is required.

All the files needed in the commissioning or improvements, such as FCT plugins, FFT setup file, root folder for program uploading with a USB stick, and the CoDeSys project program are uploaded to OneDrive.

In conclusion, an understanding of the Festo Storage Station working principle was achieved. Components of the station were commissioned, diagnosed, and described for future use. Documentation of all device features and tools needed in repairing or modification was gathered and put together. Future expansions of the station and a way to implement it into LAB University's studies were discussed. All the set objectives were accomplished.

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Appendices

Appendix 1. Overview of the Storage Station program

