Application Note

FESTO

Decapping with Festo products

This application note discusses the significance of the decapping process in laboratory automation. It outlines a decapping setup using Festo products, detailing hardware requirements, control mechanisms, and typical sequences for various cap types.

EHMD
CMMT-ST
EHAM-E20-40-Z
EHPS

Main topics:

- **Hardware setup:** Describes the necessary components for a decapping application, including grippers, z-movement mechanisms, and additional electrical components.
- **Control mechanisms:** Explains the use of Festo Automation Suite and PLCs for configuring and controlling the decapping setup.
- **Typical sequences:** Provides guidance for executing decapping operations for threaded and plug caps, along with tips for optimizing performance.

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1 The importance of decapping in laboratory automation

In the area of laboratory automation and diagnostics, precision and efficiency are important to achieve reliable results. One critical yet often overlooked step in the automated workflow is the decapping process. This essential procedure is about the removal of caps from sample vials or containers to be able to access the liquid inside for further analysis or processing. As laboratories increasingly adopt automation technologies to streamline operations, understanding the decapping process becomes crucial.

Knowing that there is a huge number of different analysis and processes in the labs, it is only logical that there are also many different vials and containers available in the market based on the type of (patient) sample, treats and the providing company. They differ in volume, size, color, inner surface, cap type, material and others.
For a mechanical decapping process the attributes

- diameter of the cap and vial,
- length of the vial with and without cap,
- type of the cap (threaded vs. plug cap),
- material

have an influence on the gripper design, the torques and forces required, and the motion sequences.

Figure 1: Selection of different types of vials

In some applications every tube is different, in others tube types do not change at all or just change from time to time. This requirement needs to be considered when designing and setting up the decapping setup and the gripper fingers. No matter how the application looks, with Festo catalogue products it is possible to setup a decapping functionality.

2 Example of a decapping setup with Festo catalogue products

Despite the huge number of different vials, containers and caps for analysis and processes in the labs, with the EHMD and other catalogue products from Festo it is possible to set up a decapping solution for different application needs. Based on the requirements the arrangement and exact type of products may change, but with the customizable mechanical interfaces, programmable processing parameters and sequences this modular system allows flexible solutions for different customer needs.

2.1 Hardware setup

For a decapping application in principle a gripper for the vial and a gripper for the cap is needed. For vials with threaded caps a rotational movement is mandatory. A z-movement is necessary to follow the movement in z direction based on the thread as well as for lifting the cap from the vial. In Figure 2 a scheme of a decapping setup is shown.

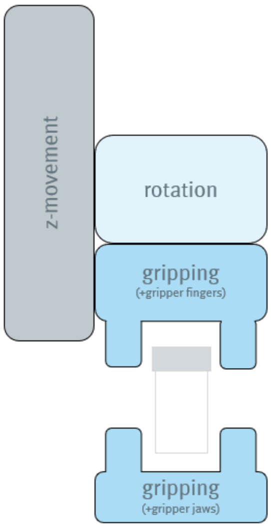
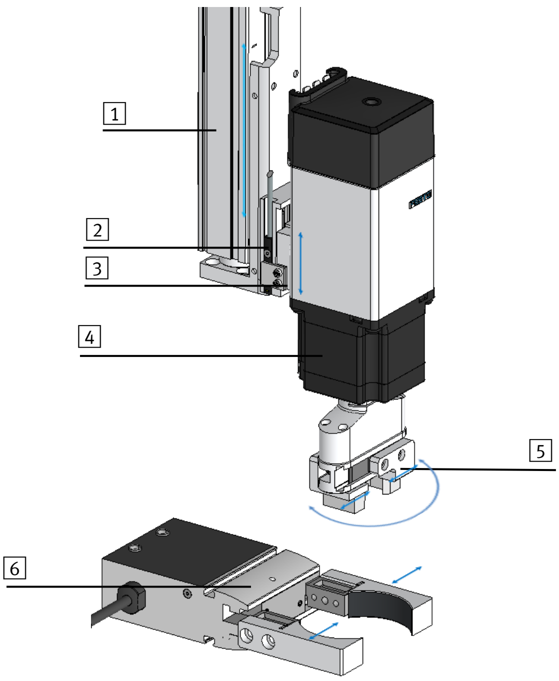


Figure 2: Scheme of a decapping setup with exemplary Festo catalogue products

Figure 3 shows an exemplary decapping system with Festo catalogue parts. The z-movement here contains a passive and an active component. For the passive z-movement based on the thread of a cap, a z-compensation module EHAM-E20 is used (see Chapter 2.2 for more details on z motion). For the active z-movement a Festo axis like an EGSC is shown. As rotary gripper the EHMD and as counter gripper the EHPS are used.



1 z-axis
2 sensor for z-compensation
3 passive z-compensation module
4 rotation-gripper-module EHMD
5 gripper fingers
6 counter gripper with gripper jaws for vial

Figure 3: Typical modular decapping system based on Festo catalogue products

Additional to the parts in the working space for decapping, there are other components needed like power supply, programmable logic controller (PLC) and motor controllers (see Figure 4).

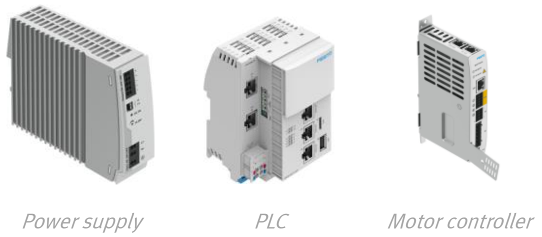


Figure 4: additionally needed components

Table 1 gives an exemplary overview of Festo components needed to realize a decapping application. To address the specific application needs, components such as axes, controls, etc. need to be varied, of course.

Table 1: Exemplary main catalogue parts

Designation	Name	Part no	Quantity
EHMD-50-RE-GE-15	Rotary gripper	8176191	1
EMMT-ST-42-L-RSB	Stepper motor	8156171	1
EAMM-U-45-V25-42A-63	Parallel kit	4825645	1
EGSC-BS-KF-32-100-8P	Mini slide	4356032	1
EHAM-E20-40-E19-25	Adapter	8080760	1
EHAM-E20-40-Z	Z-compensation module	5293408	1
SIES-8M-...	Sensor for z-compensation	551402	1
NEBM-M17G12-EH-5-Q6N-LE12	Motor cable axis		1
CMMT-ST-C8-1C-MP-S0	Motor controller	8163946	3
EHPS-20-A	Parallel gripper	8070831	1
CACN-3A-1-10-G2	Power supply	8149581	1
CPX-E-CEC-C1-EP	PLC	4252742	1

In addition to the catalogue products, specific gripper fingers for the EHMD and gripper jaws for the EHPS need to be designed and manufactured depending on the requirements for the vials to be decapped (and capped).

- Very often a tight fit between the gripper fingers and the cap is preferred.
- To be able to hold the vial at the bottom against the torque at the cap, in many cases a rubber part is added to the gripper jaws. This also helps to prevent damaging the barcode sticker on the vials.

To reach good decapping (and capping) results perpendicular forces should be avoided. Therefore, the EHMD rotary axis needs to be aligned properly with the center of the counter gripper and the vial.

2.2 Passive z-compensation

With the passive z compensation threads can be screwed up and down without the need of a synchronized movement of z-axis and rotation axis. The z movement is carried out passively as a reaction of rotation and pitch of the thread.

There are several advantages of a passive z-compensation:

- No need for path interpolation in PLC
- No need for real time capable bus connection between motor controller and PLC
- Low requirements for electrical hard- and software
- Pitch of thread doesn't need to be known
- Angle position of beginning of thread doesn't need to be known or can easily be detected
- No jamming if cap or vial is slipping a little bit

1 inductive switch (SIES- 8M-...)
2 switch lug
3 weight compensation
4 slide for z compensation

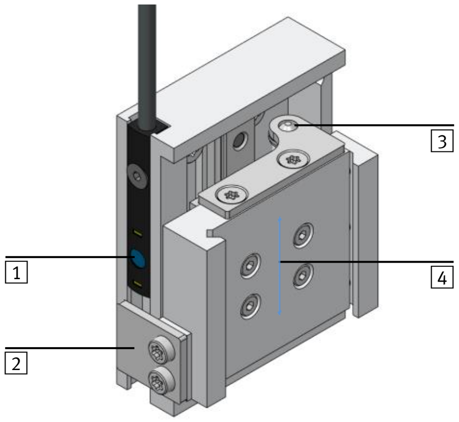


Figure 5: module for passive z-compensation (EHAM-E20-40-Z)

2.2.1 Weight compensation
There is a spring which pushes the slider upward to partially compensate the weight of EHMD. This ensures that only low forces act on the thread of the vial.

2.2.2 Sensor
There is a T-slot for an inductive switch sensor to detect a defined travel of the slider of the z-compensation. This signal can be used to compensate tolerances of the height of vials or to find the angular beginning of the thread. The switch position of the sensor can be adjusted by the clamping position within the t-slot.

3 System architecture and control options

3.1 System setup

The EHMD rotary gripper consists of two motors and needs two motor controllers (for example the Festo CMMT-ST) to be operated. The z-axis with its motor needs another motor controller to be operated. They are connected via EtherCat to the CPX-E PLC. The EHPS gripper only needs a digital signal to be opened or closed and could therefore be directly connected to the PLCs digital outputs. The PLC as well as the CMMT-ST motor controller and the EHPS need 24 VDC power supply. Figure 6 shows the data interfaces between the parts.

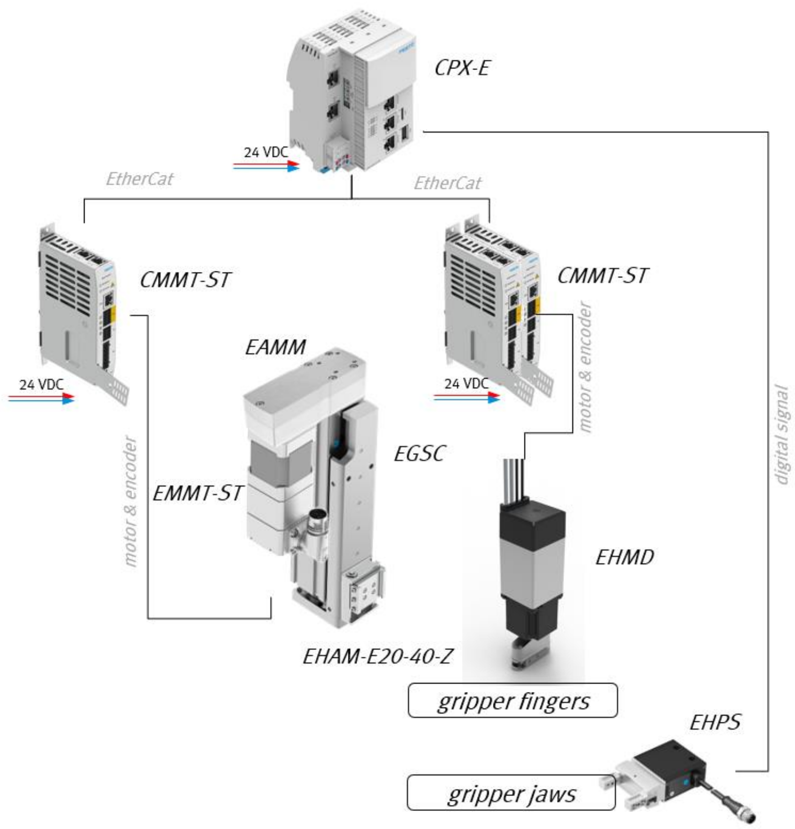


Figure 6: electrical connection and architecture

3.2 Controlling the decapping setup

There are different possibilities to operate the motors. For initial setup it is recommended to connect a computer with an ethernet cable directly to the CMMT-ST motor controllers via Festo Automation Suite. For the combined movement of the several actuators in the setup as well as the productive operation, a higher-level control like a PLC with Codesys is necessary.

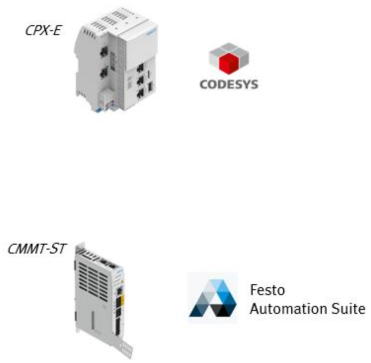


Figure 7: PLC and motor controllers

On CMMT-ST level with Festo Automation Suite it is possible to

- Configure the motor controllers for z-axis, rotation and gripper
- Move single motors
- Configure and run specific sequences and modes for a single motor
- Evaluate needed parameters during the setup of an application (speed, positions, torque,…)
- Use the diagnosis functionality to have a look on the parameters of the motor (position, current, torque,…)

For further information see ‘Application Note - EHMD Commissioning with CMMT-ST and Festo Automation Suite’, Festo Automation Suite instruction and CMMT-ST instruction.

On PLC level, for example with Codesys on a CPX-E, it is possible to

- Combine movements of different motors
- Run sequences based on library functions of CMMT-ST
- Trigger digital outputs for closing and opening counter gripper
- Read out digital inputs for different additional sensors

4 Typical decapping sequence

Once the setup is completed, different sequences can be executed, and parameters can be changed via software. Depending on the range of sizes of the vials and the gripper finger design, even the gripper fingers don't need to be changed for different vials.

4.1 Threaded caps

With the rotary gripper EHMD-40 vials up to 0.3 Nm torque could be processed, with the EHMD-50 version up to 1.0 Nm. Figure 8 shows a typical torque over time plot when decapping a threaded cap.

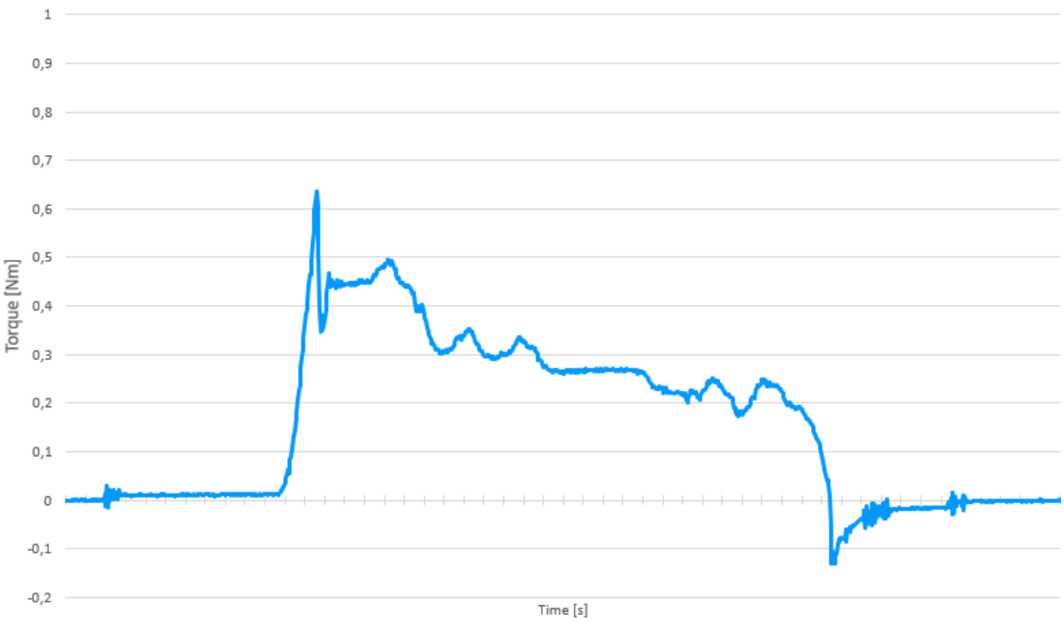


Figure 8: Torque over time while decapping a threaded cap

4.1.1 Sequence for decapping

Operation Mode

For decapping the rotation axis should be controlled in position mode. The position mode guarantees that the motor applies the required torque (up to the technical limits of the EHMD as described in the data sheet). The EHMD gripper needs to be controlled with torque mode to hold the cap properly.

Start situation

The vial with cap has been positioned and gripped with specific gripper jaws with the counter gripper manually or by an additional handling system.

1. Open the gripper of the EHMD.
2. Lower the z-axis slowly until the sensor of the z-compensation device is activated.

   When the gripper fingers hit the cap of the vial the z-axis carries on moving while the z-compensation travels until the sensor is activated.
   This also allows the check of height or the presence of vials as an in-process control.
   If the height of the vial is always the same, the z-axis can be positioned to an absolute position independent from the sensor signal.
3. Close the gripper fingers of the EHMD in torque mode.

   The torque must be set high enough to transfer the necessary torque to the cap without slipping. If it is chosen too high the cap is deformed and the friction between cap and vial increases. A tight fit between the gripper fingers and the cap may be helpful.
   Supervising the gripper position with the on-board encoder of the EHMD allows to check if the gripped caps are within the defined window.
4. Rotate the EHMD gripper counterclockwise to untighten and open the cap.

   The z-axis is standing still while screwing. The z-movement is done by the z-compensation device.
   The cap should be turned a little further than the thread ending to reliably unlock the thread.
5. Move the z-axis upward to lift off the cap from the vial.

The distance until the sensor signal changes can be monitored while moving the z-axis. If the process is successful, this distance should always be the same within a typical tolerance.

4.1.2 Sequence for (re)capping

Operation mode
For recapping it is recommended to use the torque mode of the rotation to close the caps with a defined torque. The EHMD gripper needs to be controlled with torque mode to hold the cap properly.

Start situation
A vial without cap is clamped in the counter gripper, while the cap is securely held between the gripper fingers of the EHMD.

1. Lower the z-axis slowly until the sensor of the z-compensation module is activated.
2. Look for the beginning of the thread if necessary (see next chapter).
3. Screw the cap by rotating the gripper clockwise in torque mode until a defined torque is reached.

The z-axis is not moved while screwing. The z-movement is done by the z-compensation module.

4.1.3 Sequence to find the beginning of the thread

Some threads have a critical zone where the beginning of the thread of vial and cap overlap only a little bit. If screwing is started from this position the cap might get jammed.

If the vial was decapped just before and there are no changes of the position of vial and cap, the beginning of the thread should be the same. If it is not known, it can be found by the following sequence.

1. Lower the z-axis slowly until the sensor signal of the z-compensation module is activated.

When the cap hits the vial, the z-axis carries on moving while the z-compensation module travels until the sensor is activated.

2. Slowly rotate the gripper counterclockwise until the sensor signal becomes low -> the beginning of the thread is found

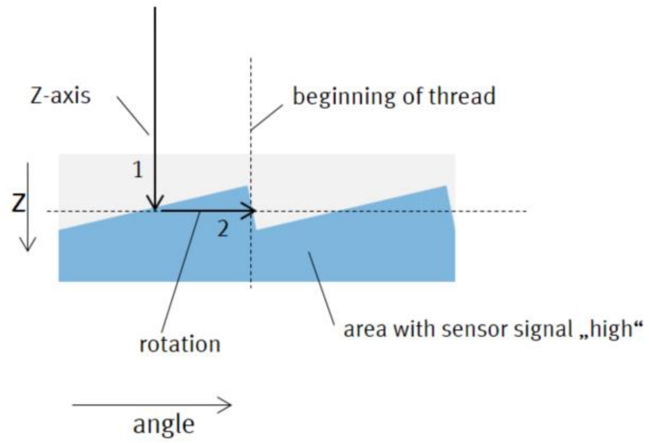


Figure 9: finding the beginning of the thread

3. If the signal doesn't become low within one turn of the gripper, the z-axis is moved up by the amount of about half the thread-pitch. Then step 2 is repeated.

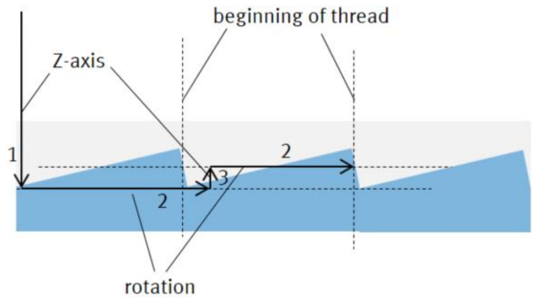


Figure 10: finding the beginning of the thread if first trial failed

4.2 Plug caps

4.2.1 Sequence for decapping

Operation Mode
For decapping plug caps, the rotation axis should be controlled in position mode. The EHMD gripper needs to be controlled with torque mode to hold the cap properly.

Start situation
The vial with cap has been positioned and gripped with specific gripper jaws with the counter gripper manually or by an additional handling system.

1. Open the gripper of the EHMD.
2. Lower the z-axis slowly until the sensor of the z-compensation device is activated.

   i When the gripper fingers hit the cap of the vial the z-axis carries on moving while the z-compensation travels until the sensor is activated.
   This also allows the check of height or the presence of vials as an in-process control.
   If the height of the vial is always the same, the z-axis can be positioned to an absolute position independent from the sensor signal.
3. Close the gripper fingers of the EHMD in torque mode.

   i The torque must be set high enough to transfer the necessary forces to the cap without slipping. If it is chosen to high the cap is deformed and the friction between cap and vial increases. A tight fit between the gripper fingers and the cap or an undercut may be helpful.
   Supervising the gripper position with the on-board encoder of the EHMD allows to check if the gripped caps are within the defined window.
4. Move the z-axis upwards while rotating the EHMD gripper at the same time to open the cap.

   i To overcome the static friction between the plug and the vial a rotational movement is recommended during active z-movement.

5. Move the z-axis further upwards to lift off the cap from the vial.

4.2.2 Sequence for (re)capping

Operation mode
For recapping of plug caps, the rotation axis can be controlled in position mode. Torque mode is not necessary. The EHMD gripper needs to be controlled with torque mode to hold the cap properly.

Start situation
A vial without cap is clamped in the counter gripper, while the cap is securely held between the gripper fingers of the EHMD.

1. Lower the z-axis slowly until the sensor of the z-compensation module is activated.
2. Start rotating the EHMD while moving further down with the z-axis until a defined z height is reached.

   i Because of the z-compensation module, the weight of the EHMD helps capping the plug on the vial again. In some cases, an additional force in z direction might be necessary. Therefore, the EHMD needs to be in contact with the upper limit of the z-compensation module that the z-axis can press the plug actively. Supervise the torque of the z-axis or the travelled distance in z to stop after completion of the capping process.