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Innovation Fostering in Accelerator Science and Technology

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MILESTONE REPORT

Magnet constructed and tested

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ABSTRACT

IFAST Task 11.3 has designed and built a prototype permanent magnet-based dipole-quadrupole magnet, referred to as the HEPTO magnet, as an energy saving alternative to an equivalent electromagnet. This report summarises the construction characteristics of the prototype that will be tested within the same framework at the Daresbury Laboratory, and the results will be reported in deliverable 11.3.

For more information on IFAST, its partners and contributors please see https://ifast-project.eu/

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Delivery Slip

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TABLE OF CONTENTS

1. INTRODUCTION 5
2. MECHANICAL DESIGN REPORT AND MANUAL 6
3. CONCLUSIONS 48

Executive summary

This report presents Milestone MS56 of I.FAST Work Package 11, dedicated sustainable concepts and innovative technologies.

Within Task 11.3, the realization of PM-based combined function magnet with dipole and quadrupole fields, aimed towards the magnets used in the Diamond-II lattice have been successfully designed and manufactured.

Dimensional checks and the related activities confirm overall compliance with project specifications. Although a few deviations from nominal tolerances were identified, they are minor, non-critical, and manageable in the final magnet assembly.

The completion of this milestone provides validated components for the next phase of the WP11.3, enabling the measurement of this new Permanent Magnet Quadrupoles & Combined Function Magnets for Ultra Low-Emittance Rings at Daresbury Laboratory (Deliverable 11.3).

1. Introduction

Within the framework of I.FAST Work Package 11, dedicated to sustainable concepts and innovative technologies, Task 11.3 focuses on the construction of a Permanent Magnet -based combined function magnet with dipole and quadrupole fields.

These are second-stage prototypes; the basic concept has already been demonstrated, and this work considers the requirements for cost-effective series production of reliable magnets for an operational science facility.

The first part of the project was to assess the requirements in terms of field, field quality, magnetic length, overall magnet dimensions, and tuning range. A magnetic design and a mechanical design have been produced. Parts has been procured and magnet assembled. Finally, the completed magnet will undergo a programme of magnetic measurements at Daresbury laboratory (see Deliverable 11.3) to ensure that the specifications are met.

This milestone (MS56) documents the completion of the magnet within the KYMA company confirming the overall compliance with the project specifications.

2. Mechanical design report and Manual

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MECHANICAL DESIGN REPORT AND MANUAL

Hybrid Electromagnet-Permanent magnet Tuneable Optics (HEPTO Prototype) combined function dipole-quadrupole

Kyma project 2162b

Rev. 01 – October 8th, 2025

KYMA	MECHANICAL DESIGN REPORT AND MANUAL HEPTO Prototype	UKRI Science and Technology Facilities Council

Table of Contents

1 Introduction ... 5
1.1 Overview of this document ... 5
1.2 Disclaimer ... 6
1.3 List of abbreviations ... 6
1.4 Document symbols ... 6
1.5 Signs on the prototype device ... 7

2 Mechanical design and manufacturing ... 9
2.1 Main components and materials ... 9
2.2 Interface tray plate ... 10
2.3 Thermal shunts ... 11
2.4 Shimming design ... 12
2.4.1 Bottom main pole – reference ... 13
2.4.2 Top main pole adjustment design ... 14
2.4.3 Bottom auxiliary pole adjustment design ... 16
2.4.4 Top auxiliary pole adjustment design ... 17
2.5 Trim coils ... 17

3 Handling ... 19
3.1 Receiving and unpacking the device ... 19
3.1.1 Receiving the insertion device ... 19
3.1.2 Unloading the wooden box ... 20
3.1.3 Visual inspection ... 21
3.1.4 Unpacking ... 21

4 Instructions ... 28
4.1 Alignment instructions ... 28
4.2 Adjustment instructions ... 30
4.2.1 Top main pole vertical adjustment ... 31
4.2.2 Top main pole horizontal adjustment ... 33
4.2.3 Bottom auxiliary pole vertical adjustment ... 34
4.2.4 Top auxiliary pole vertical adjustment ... 36
4.2.5 Auxiliary poles horizontal adjustment ... 37
4.3 Connecting the trim coils ... 38
4.4 Maintenance instructions ... 39

5 Conclusions ... 40

6 Attachments ... 41

Table of Figures

Figure 1: HEPTO Prototype. 5
Figure 2: Magnetic design (left) and mechanical design (right) of the HEPTO prototype. 9
Figure 3: Main parts of assembly. 10
Figure 4: Interface plate 3D (left) and during magnet insertion (right). 10
Figure 5: Main pole mounted on the interface plate. 11
Figure 6: Type A magnet with glued thermal shunt (main). 12
Figure 7: HEPTO shimming design. 13
Figure 8: Top main pole vertical adjustment. 14
Figure 9: Enabling of top main pole vertical movement (loosening the yoke screws). 14
Figure 10: Top main pole horizontal adjustment. 15
Figure 11: Enabling top main pole horizontal movement (loosening interface plate screws). 15
Figure 12: Bottom auxiliary pole vertical adjustment. 16
Figure 13: Enabling auxiliary pole vertical movement (loosening the screw connections). 16
Figure 14: Auxiliary pole horizontal adjustment. 17
Figure 15: Cross section of main coil (left) and auxiliary coil (right). 18
Figure 16: HEPTO prototype as shipped. 19
Figure 17: Markings on the boxes, if transported by crane. 20
Figure 18: Shock indicator (left) and tilt indicator (right). 21
Figure 19: After removing the wooden box cover. 22
Figure 20: Wrapped device, after removing box walls. 23
Figure 21: Partially unwrapped device with spare permanent magnet boxes. 23
Figure 22: Remove the wooden blocks around the device. 24
Figure 23: Detaching the device from the wooden base. 24
Figure 24: DIN580 – C15E M12 lifting eye bolts. 25
Figure 25: Example – lifting the prototype device via forklift. 26
Figure 26: HEPTO alignment system (3D model). 29
Figure 27: HEPTO alignment system. 30
Figure 28: Slightly loosen the screws (1) and (2) prior to main pole vertical adjustment. 31
Figure 29: Rotate the adjustment screws (3) in the clockwise direction to lift the top main pole. 32
Figure 30: Insert / remove brass shims (4) between the main pole spacers (5) (6). 32
Figure 31: Top main pole horizontal adjustment screws. 33
Figure 32: Loosen the 30x M8 screws prior to main pole horizontal adjustment. 34

Figure 33: Bottom auxiliary pole vertical adjustment. 34

Figure 34: Bottom auxiliary pole vertical adjustment. 35

Figure 35: Enabling auxiliary pole vertical movement (loosening the screw connections). 35

Figure 36: Top auxiliary pole vertical adjustment. 36

Figure 37: Auxiliary poles horizontal adjustment. 38

Figure 38: Terminal blocks of main and auxiliary trim coils. 38

Table of Tables

Table 1: Safety and notice signs on the prototype device. 7

Table 2: Attachments. 41

1 Introduction

1.1 Overview of this document

The main purpose of this document is to provide extensive information on the correct use of the HEPTO prototype, manufactured for STFC Daresbury Laboratory, as part of the I.FAST project. The contents of the manual cover crucial protype lifecycle aspects, including transport, handling, setup, and maintenance. Chapter 2 is dedicated to explaining the mechanical design and the thought process behind it, focusing mainly on the adjustment process. The fully assembled prototype is presented in **Figure 1**.

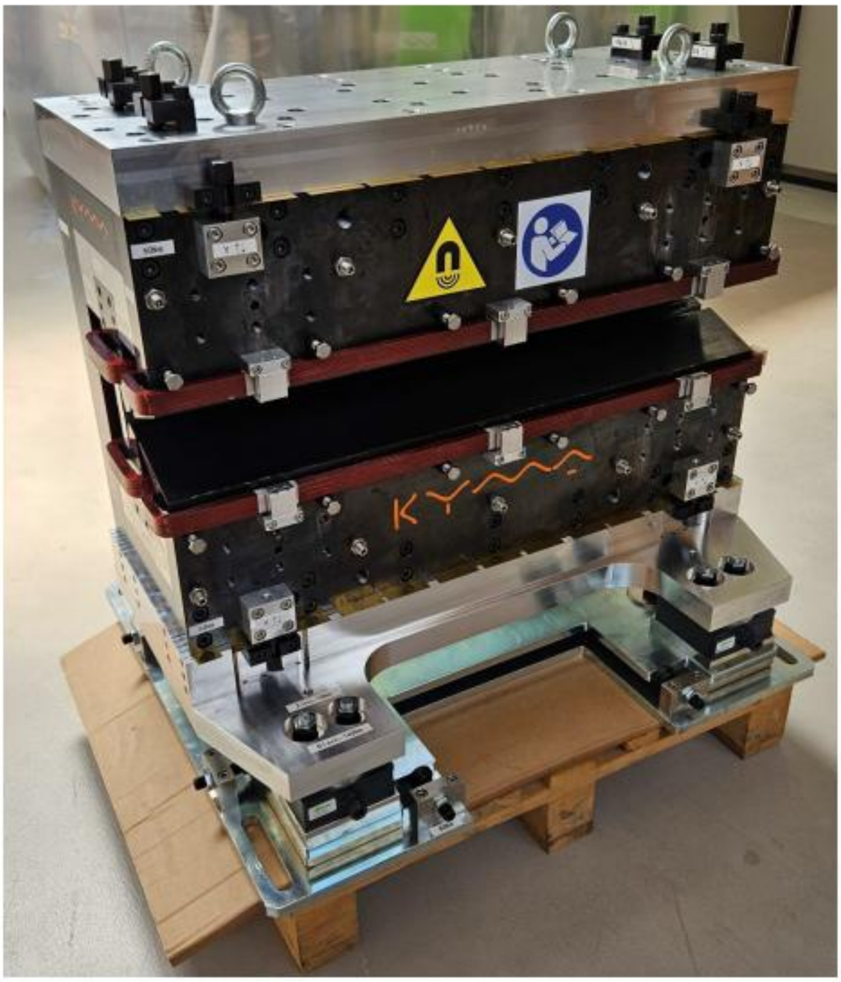


Figure 1: HEPTO Prototype.

1.2 Disclaimer

Information given in this manual is accurate, but due to the nature of prototype development, be aware that specifications and features of this product can change without notice. Kyma SpA accepts full responsibility for the information supplied in this manual, but no liability for loss, damage, or injury, caused by omissions from the information supplied in this manual. In case of uncertainties or mistakes found in the manual, contact Kyma to resolve the matter.

NOTE!
The HEPTO prototype has no commercial value and its intended use is for testing purposes only! Kyma will not take responsibility for any other potential uses of the device.

1.3 List of abbreviations

HEPTO	Hybrid Electromagnet-Permanent magnet Tuneable Optics
I.FAST	Innovation Fostering in Accelerator Science and Technology

1.4 Document symbols

The following symbols are used throughout the document to point out important information concerning proper handling, transport, adjustment, and maintenance of the prototype, with special emphasis on conformity with human health and safety regulations and preventing damage to the device.

IMPORTANT INFORMATION (WARNING)!
Contains crucial information on potentially hazardous areas and situations during various steps of the prototype's lifecycle, with the emphasis on human health and safety and preventing damage to the device.

NOTE!
General information and recommendations when dealing with the prototype device.

1.5 Signs on the prototype device

There are various notice and warning signs, each containing information about the hazards involved in dealing with the prototype device. These signs, presented in **Table 1**, are located at various locations on the prototype.

IMPORTANT!
Any personnel dealing with the prototype device in any way, must always consider all the safety and notice signs! The signs must never be removed!

Table 1: Safety and notice signs on the prototype device.

Warning: Strong magnetic field permanently present!

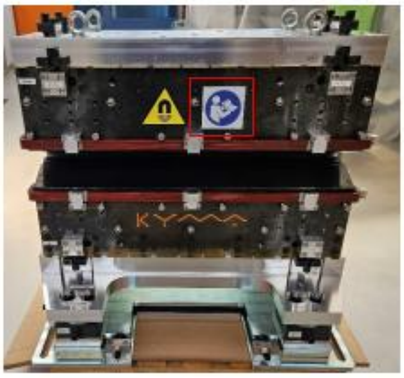
- Location: front and back side

Warning: Potentially hazardous to pacemaker wearers!

- Location: back side

Note: Read the user manual.

- Location: front side



2 Mechanical design and manufacturing

The mechanical design of the HEPTO prototype is based on the magnetic design (**Figure 2**), provided by STFC Daresbury Laboratory. The main restriction, affecting the final mechanical design, was the predetermined size of the permanent magnet blocks, installed in the prototype. Special interface plates were designed to accommodate and appropriately position the magnets relative to the yoke and poles. Tuneability of permanent magnet devices is generally limited, that is why a lot of focus was directed in reaching sufficient adjustability of the main and auxiliary poles of the HEPTO magnet. This process is also called shimming. Adjustability of the pole positions was achieved by a series of adjustment screws and standard brass shim plates. Assembly of the prototype device was carried out with the use of specially designed tools, which were necessary due to high magnetic forces involved.

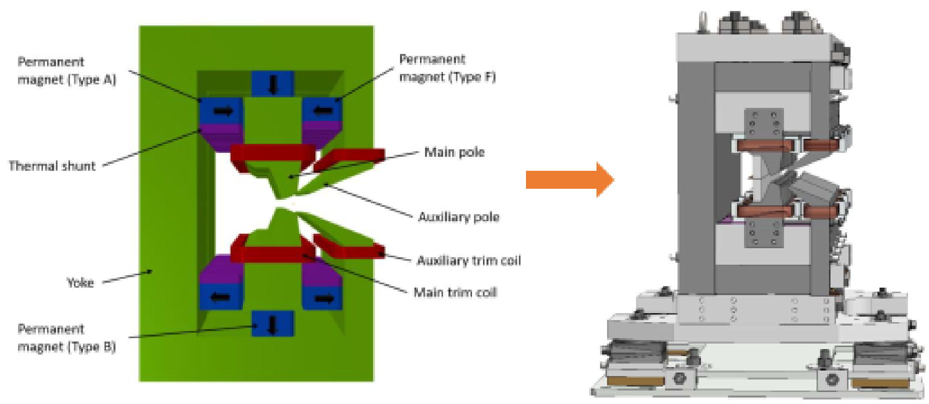


Figure 2: Magnetic design (left) and mechanical design (right) of the HEPTO prototype.

2.1 Main components and materials

Magnetic design is expanded with some additional components for transportation, alignment, and installation. Magnet assembly is mounted on top of the feet assembly (**1**), which allow horizontal and vertical alignment. Top adjustment assembly (**2**) and bottom adjustment assembly (**3**) give rigidity to whole magnet and enable shimming of magnet poles. Yoke consists of yoke back plate assembly (**4**) with top and bottom yoke plates (**5**). Permanent magnets are inserted inside interface tray plate (**6**). On the other side of magnet, auxiliary pole assemblies (**7**) are mounted. Main (**8**) and auxiliary trim coils (**9**) are mounted to main and auxiliary poles.

Material used for poles and the yoke is ARMCO® Pure Iron, which is specifically designed for magnetic devices. All the parts and plates (apart from some steel screws) in proximity of the magnets and the yoke are made from aluminium alloy 5083. The alignment system at the bottom has a couple of zinc plated steel plates (1.0045) with a bronze sliding interface.

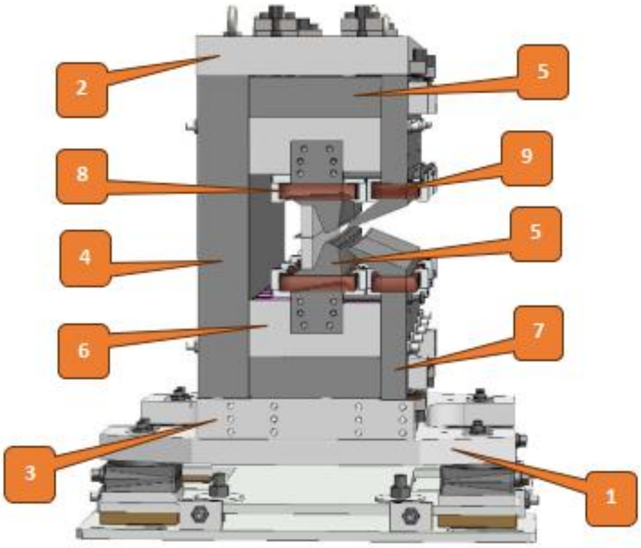


Figure 3: Main parts of assembly.

2.2 Interface tray plate

As mentioned, the permanent magnet blocks were predetermined in size and were not part of mechanical design. Building around that, an interface tray plate was designed and manufactured to accommodate the magnets. With limited space available for securing the magnets via reversible method like clamping screws, a decision was made to glue the magnets inside the slots in the interface plate with epoxy resin. The downside is the irreversibility of the method, as the magnets are permanently attached to the interface plate. This would pose a big problem in a hypothetical case of needing to disassemble the magnets.

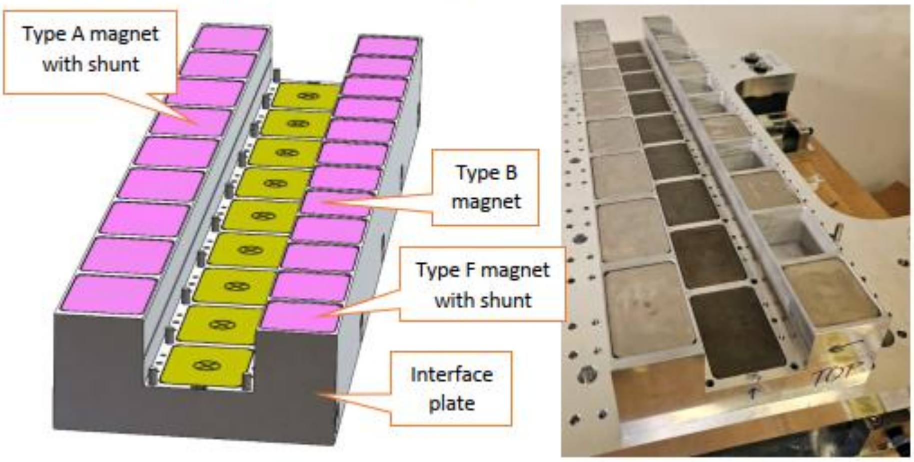


Figure 4: Interface plate 3D (left) and during magnet insertion (right).

Another important function of the interface plates is for the main poles to have a stable position and to protect the type B magnets from damage. The height of the interface plate in the middle part is designed to be slightly larger than the type B magnets, to prevent unnecessary loading.

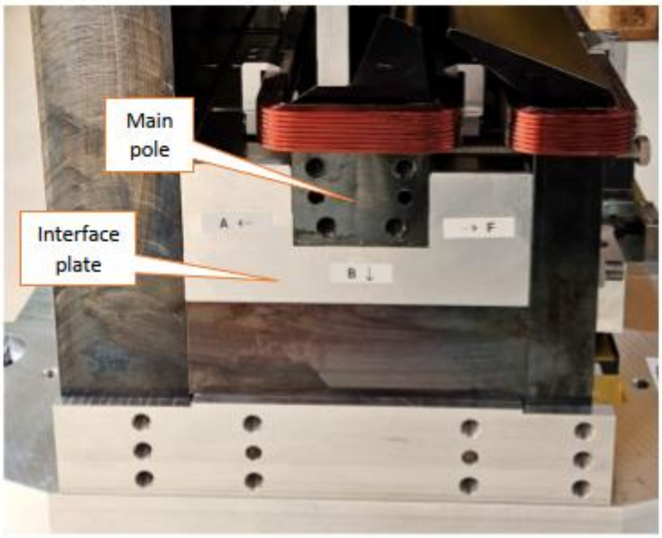


Figure 5: Main pole mounted on the interface plate.

2.3 Thermal shunts

Apart from mechanical adjustment, additional tuneability of the HEPTO prototype is achieved with the use of trim coils. Depending on the required adjustment (current through the coils), these can heat up the nearby magnets, affecting their remanent magnetic field and overall performance of the device. With the aim of counteracting this negative effect, thermal shunts are mounted on the side magnets (type A and F). These are made from an Iron-Nickel alloy in the form of stacks. The raw plates of 0.5 mm thickness were water-jet cut to the shunt final dimension and glued into stacks with epoxy resin.

The actual thermal compensation possible needs to be tested, as the actual shunt material volume is lower than what was initially planned. The initial specification required stacks of 32 shunt plates, but due to insufficient material and the manufacturing process, this was not possible. In the final design, for the main and auxiliary shunts, the achievable number of stacks was 25 and 24 respectively.

Figure 6: Type A magnet with glued thermal shunt (main).

2.4 Shimming design

Generally, the main downside of permanent magnet devices is low tuneability, as permanent magnets employ a static magnetic field. Manufacturing tolerances and errors, magnetising errors, temperature changes, and other factors can have a detrimental impact on the overall performance of permanent magnet devices. It has been shown that mechanical shimming has a great impact on overall performance. Small positional changes of the magnets or the poles can greatly improve magnetic field strength and quality of the device. That is why during the design, a lot of focus was directed at achieving this tuneability. Positional adjustment of the poles is achieved by a series of adjustment screws, which enable movement of the individual poles in both horizontal (transversal) and vertical directions. Longitudinal positioning of the poles and the yoke is ensured by dowel pins and is not adjustable.

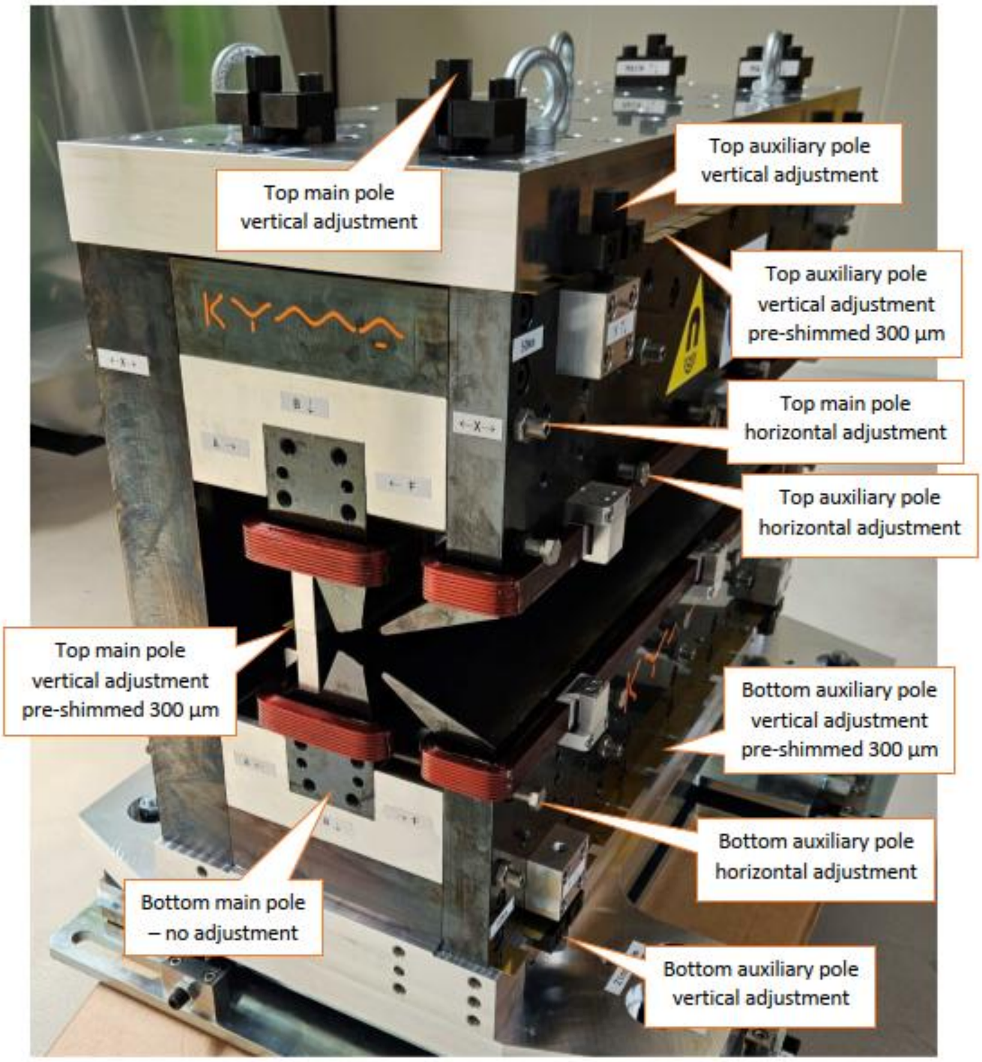


Figure 7: HEPTO shimming design.

2.4.1 Bottom main pole – reference

During the design phase, it was decided that the bottom main pole and the surrounding magnets on the interface plate can have a fixed position, i.e. serve as reference, relative to which other poles can be positioned accordingly.

2.4.2 Top main pole adjustment design

Vertical movement of the top main pole is achieved via four adjustment screws, located at the top of the device. These are mounted on the aluminium plate, which also provides structural support during adjustment. This support is necessary, as some screws need to be loosened before the main pole structure can be moved. These are shown in **Figure 9**. There are two aluminium spacers, mounted on the main poles. These provide additional structural support, reducing the deformation of the structure under magnetic load. The spacers are also used for shimming, i.e. controlling the vertical distance between the two main poles. The pre-shimming amount at the main pole spacers is 300 µm.

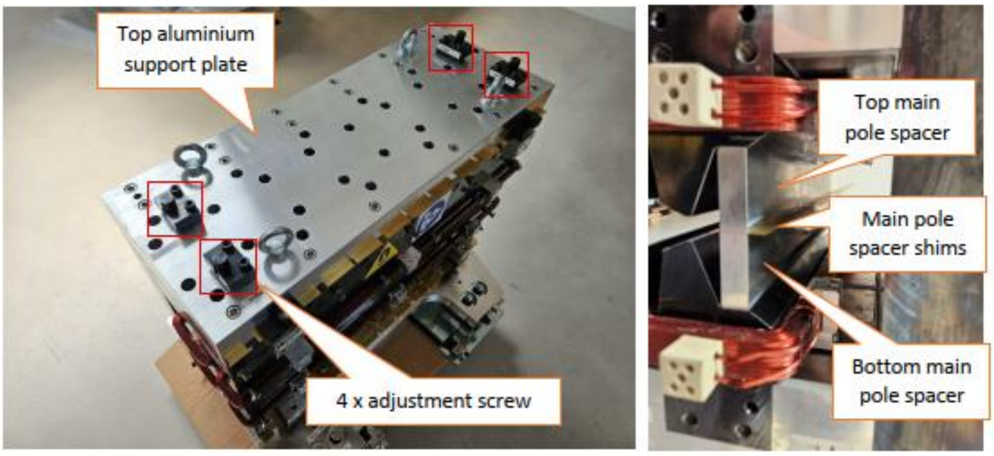


Figure 8: Top main pole vertical adjustment.

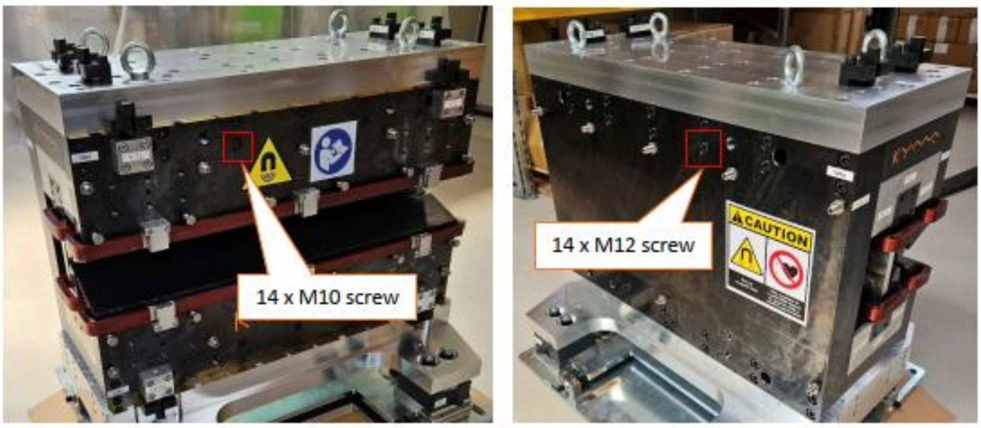


Figure 9: Enabling of top main pole vertical movement (loosening the yoke screws).

Horizontal (transversal) movement of the top main pole is enabled by ten fine adjustment screws, five per each side, allowing direction reversal. These screws are in principal pushers, acting on the interface plate, which holds the top side magnets and main pole.

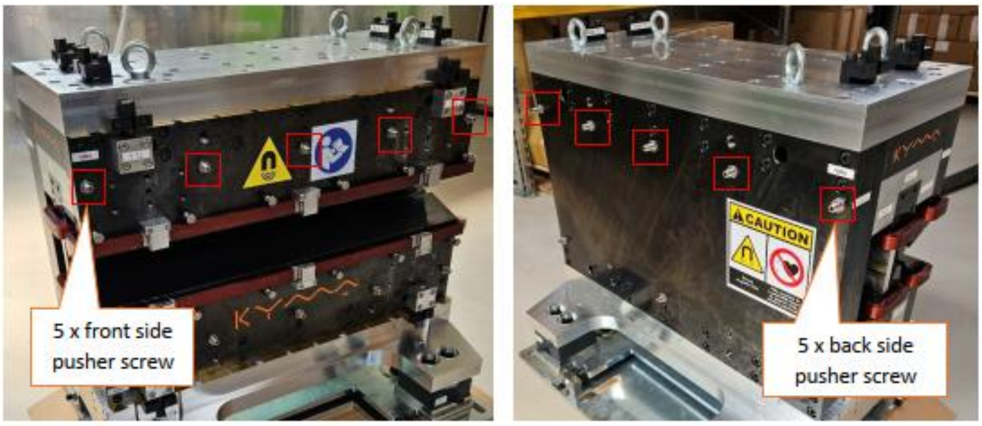


Figure 10: Top main pole horizontal adjustment.

To enable horizontal movement of the top main pole structure, the screw connection between the interface plate and the top yoke plate needs to be loosened. These are accessible through the drilled holes in the top aluminium plate.

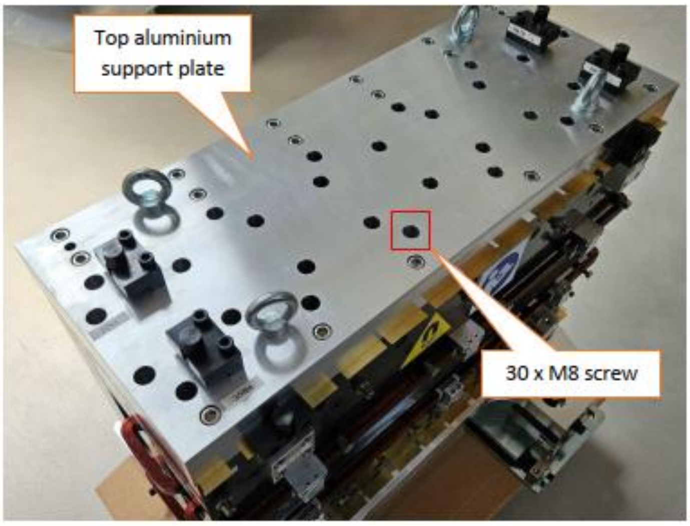


Figure 11: Enabling top main pole horizontal movement (loosening interface plate screws).

2.4.3 Bottom auxiliary pole adjustment design

Vertical adjustment of the bottom auxiliary pole is enabled by two fine adjustment screws, which are meant for slightly opening the gap between the auxiliary pole bottom surface and the bottom aluminium support plate. Pre-shimming of 300 µm is applied at this location along the length of the device, using standard brass shims. Opening this gap allows insertion or removal of shims, depending on the desired adjustment direction.

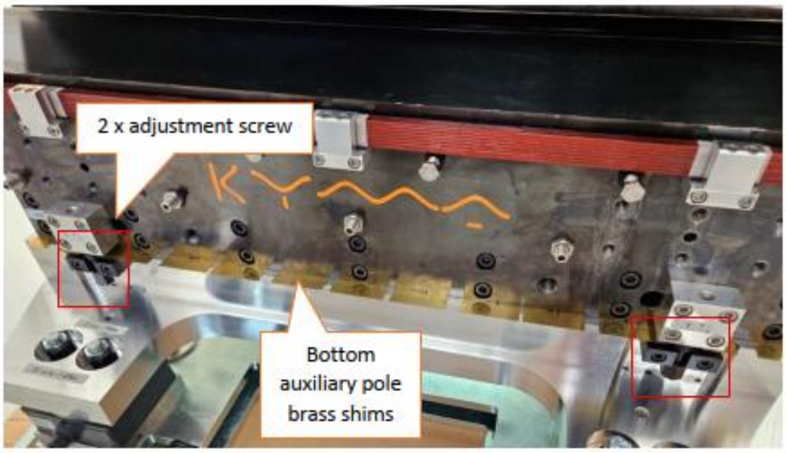


Figure 12: Bottom auxiliary pole vertical adjustment.

To enable vertical movement of the bottom auxiliary pole, some screw connections need to be loosened. These are shown in **Figure 13**. Firstly, the M10 screws, that connect the auxiliary pole to the bottom yoke plate and afterwards the M12 screws, which are accessible from the bottom. Acting on the adjustment screws will move the pole upwards, opening the gap at the location of the brass shims. After shimming, the M12 screws must be tightened first, to press the bottom surface of the pole against the shims, ensuring good position repeatability. Afterwards, the M10 screws need to retightened.

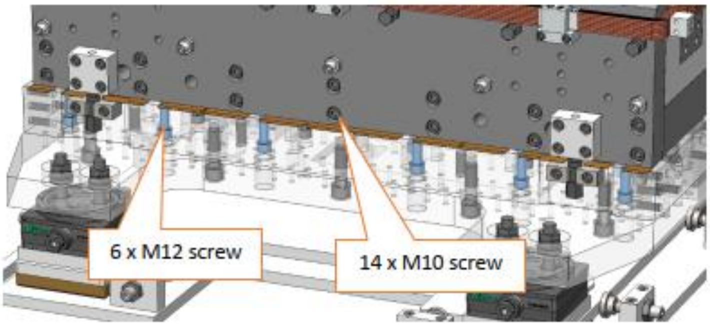


Figure 13: Enabling auxiliary pole vertical movement (loosening the screw connections).

Finding an elegant solution for the horizontal adjustment of the auxiliary poles proved difficult with the current mechanical design of the HEPTO prototype. The final design for this functionality is based on the attractive force between the main poles and adjacent auxiliary poles, meaning the auxiliary poles can be adjusted only in the direction away from the main pole. This is achieved by acting on the M10 screws, shown in **Figure 14**.

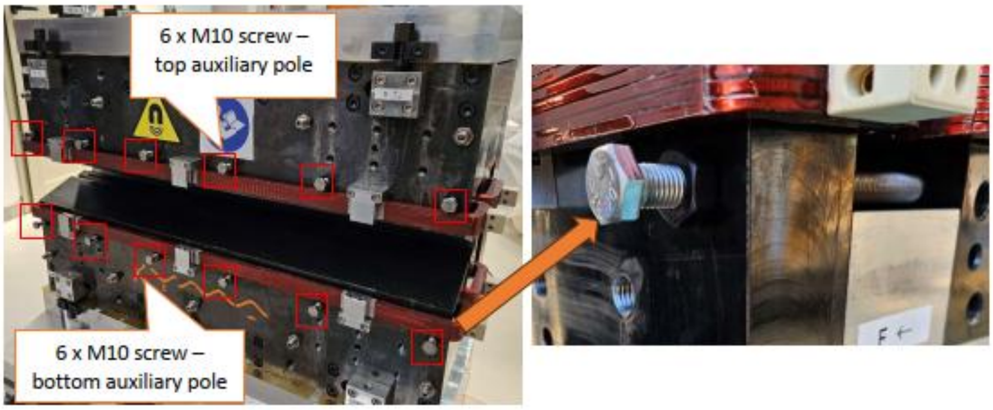


Figure 14: Auxiliary pole horizontal adjustment.

WARNING!
Auxiliary pole horizontal adjustment should be used for very small movements (± 10 µm), as it is inducing stress and deformation in the material. If larger adjustments are required, other options need to be explored. Contact Kyma in this case.

2.4.4 Top auxiliary pole adjustment design

For the top auxiliary pole, the process of adjustment is the same as for the bottom auxiliary pole.

2.5 Trim coils

There are four trim coils mounted directly to main and auxiliary poles, which allow some magnet field adjustments. Copper wire used has cross section of 2.8 x 1.6 mm. Main coil has resistance of 0.6 Ω, auxiliary coil resistance is 0.37 Ω. Coil cross section is presented in **Figure 15**.

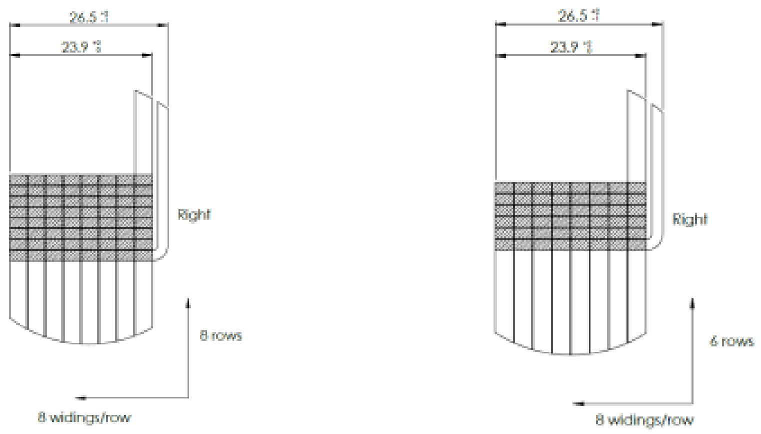


Figure 15: Cross section of main coil (left) and auxiliary coil (right).

3 Handling

3.1 Receiving and unpacking the device

IMPORTANT!
All lifting and handling procedures of the device must be carried out by trained and experienced personnel, with forklift or crane and with chains or belts with adequate lifting capacity.

WARNING!
Unloading the box containing the device with an under-dimensioned forklift, crane or any other lifting accessory could result in severe threat and safety risk for the driver/operator and other people involved.

WARNING!
Never stand below the boxes when lifted or transported by forklift or crane. Only professional operators, adequately skilled and supplied with all necessary safety protection shall participate in these operations.

3.1.1 Receiving the insertion device

The HEPTO prototype along with spare permanent magnet blocks is carefully packaged in protective plastic wrapping and secured inside a wooden box, as shown in **Figure 16**.

WARNING!
There is important information, provided on the wooden boxes, which must be taken in account during any handling of the units, e.g. lifting capacity, lifting locations and others.

Figure 16: HEPTO prototype as shipped.

3.1.2 Unloading the wooden box

The wooden box is constructed in such a way that it can be lifted with a forklift or a crane.

IMPORTANT!
All lifting equipment, whether forklift or crane, must have sufficient lifting capacity. Based on the gross weight of the packaging, the lifting capacity of the equipment should be at least 2000 kg.

IMPORTANT!
Avoid any kind of shock while unloading the wooden box! Always assure a soft landing when lowering the boxes to the ground.

The boxes are appropriately marked in correspondence of the points where they can be hanged, if transported by crane. See **Figure 17**.

Figure 17: Markings on the boxes, if transported by crane.

In order to record any improper handling, shock and tilt indicators are attached at the front and back side of the wooden box, as shown in **Figure 18**.

Figure 18: Shock indicator (left) and tilt indicator (right).

3.1.3 Visual inspection

Once unloaded, the wooden boxes must be carefully inspected for any kind of visible damage. Any damage must be carefully described and recorded by taking appropriate pictures. Pictures with descriptions must be submitted to Kyma prior to proceeding with any other operations. Tilt and shock indicators must be inspected and relevant statuses reported to Kyma (also when in negative state). In case any indicator has turned on (red status), the relevant position must be photographed and documented. This material must be submitted to Kyma for further analysis.

3.1.4 Unpacking

WARNING!
Only experienced and properly trained personnel and supplied with all necessary safety equipment, shall participate in this operation.

Transfer the wooden box in a roofed and dry hall with flat floor. The HEPTO prototype along with spare permanent magnet blocks is wrapped in protective plastic and secured tightly inside the wooden box, as shown in **Figure 19**.

To unpack the device, proceed as follows:

- Unscrew the screws of the top wooden cover and remove it, paying attention to the following:
    - The wooden cover does not support the weight of a person (not a walkable surface).

- Remove the screws with care because they are in carbon steel; keep them away from the device, which is magnetic.
- The wooden cover can be quite heavy. If possible, use a forklift or crane to remove and lower it to the ground.

Figure 19: After removing the wooden box cover.

- Carefully remove the wooden walls by first removing the nails, which connect the walls. Collect and dispose all the nails immediately. Being in carbon steel, they could be attracted to the device, which is magnetic. After removing all the walls, the device will remain as wrapped, as shown in **Figure 20**.

Figure 20: Wrapped device, after removing box walls.

- Carefully remove the wrapping and plastic around the device, exposing the prototype, as shown in **Figure 21**. Boxes containing spare permanent magnet blocks are located on the front and back side of the HEPTO prototype. Remove the boxes and store them accordingly.

Figure 21: Partially unwrapped device with spare permanent magnet boxes.

- Remove all the wooden blocks around the device, shown in **Figure 22**.

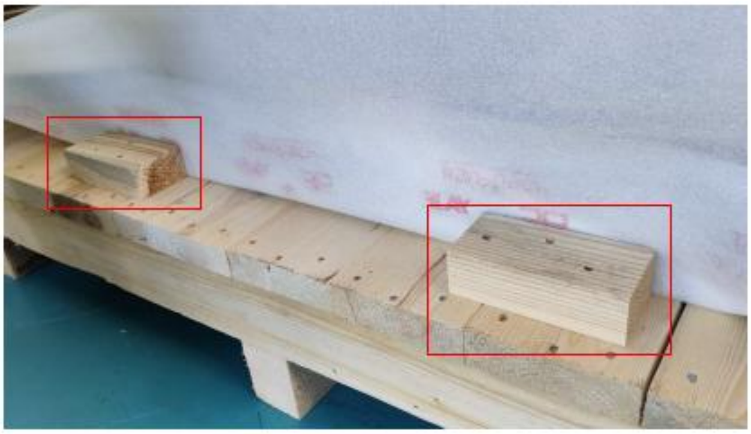


Figure 22: Remove the wooden blocks around the device.

- Detach the prototype from the wooden base by unscrewing the four screws shown in **Figure 23**.

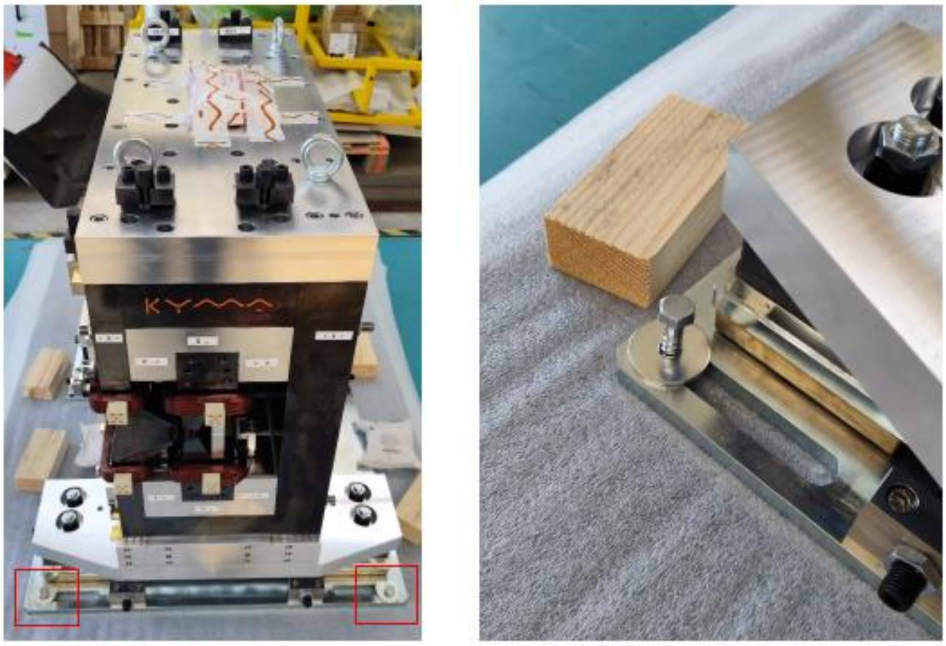


Figure 23: Detaching the device from the wooden base.

NOTE!
Humidity absorbers have been placed at various locations inside the packages, to protect the equipment from humidity during transport.

- Before lifting the device from the wooden base, pay attention to the following aspects:
  - Make sure there are no obstructions potentially interfering with the procedure.
  - Locate the four lifting eye bolts, mounted on top of the device (**Figure 24**). Make sure that the eye bolts are fully screwed in the aluminium plate.
  - The device can also be lifted via forklift, as shown in **Figure 25**.
  - Use lifting equipment suitable for the weight (without box), i.e. with minimum lifting capacity of at least **1500 kg**.
  - See the general assembly drawing for additional lifting instructions.

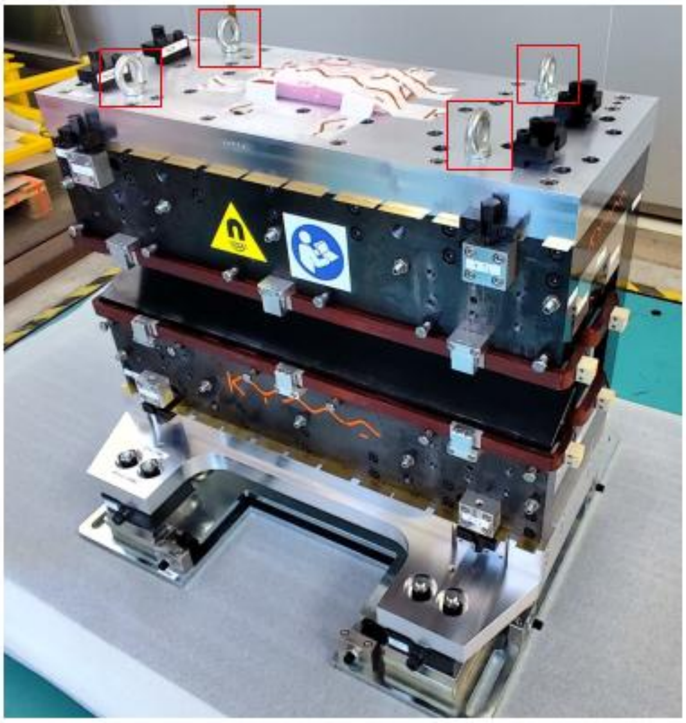


Figure 24: DIN580 – C15E M12 lifting eye bolts.

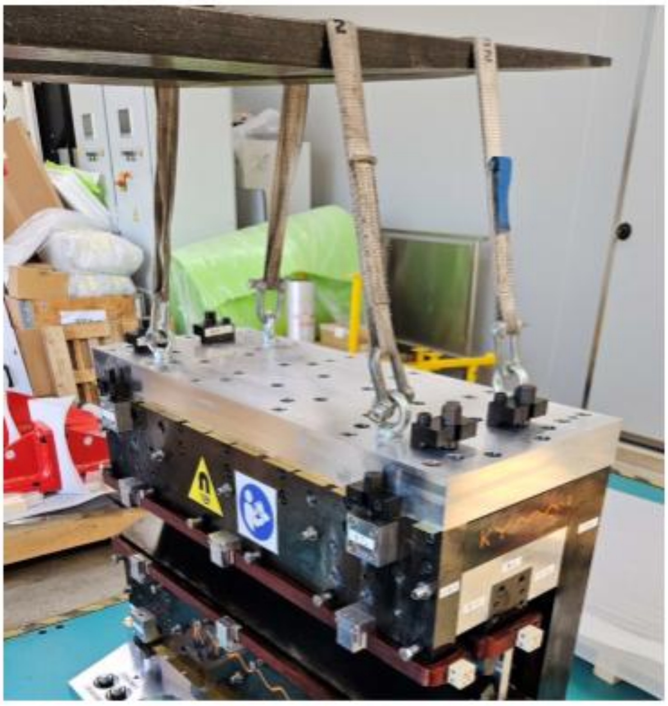


Figure 25: Example – lifting the prototype device via forklift.

IMPORTANT!
All lifting and handling procedures of the machine must be carried out by trained and experienced personnel, with forklift or crane and with chains or belts with adequate lifting capacity!

WARNING!
Lifting and transporting the device with an under-dimensioned forklift, crane or any other lifting accessory could result in severe threat and safety risk for the driver/operator and other people involved.

WARNING!
Never stand below the payload when lifted or transported by forklift or crane. Only professional operators, adequately skilled and supplied with all safety protection shall participate in these operations.

WARNING!
Regardless of lifting via crane or forklift, be careful not to damage the device in any way.

- Lift the device from the wooden base:
  - Hoist with care and gently lower the device to the ground. When placing the device to the ground be careful not to apply any lateral force that would damage the alignment mechanism.

NOTE!
All the remaining packaging material should be disposed in an environmentally friendly way to minimize pollution and environmental impact.

4 Instructions

This chapter contains information and instructions for alignment of the HEPTO prototype on the measurement bench and adjustment of the poles. This is generally an iterative process with multiple measurements taken, optimising the relative positioning along the way. The initial alignment can be executed with the precision alignment system, on which the HEPTO magnet is supported.

WARNING!
The alignment and leveling of the device must be carried out by experienced and properly trained personnel.

NOTE!
During initial alignment, keep in mind that the bottom main pole is used as reference and is not adjustable relative to other poles. Therefore, the bottom main pole should be aligned relative to the bench with the precision alignment system. Afterwards, other poles can be adjusted accordingly, based on the measurements.

4.1 Alignment instructions

The HEPTO prototype is equipped with a precision alignment system, as presented in **Figure 26** and **Figure 27**. The bottom base plates (**1**) need to be fixed to a stable reference surface.

IMPORTANT!
In the current design, the nominal vertical distance from the reference surface to the beam center is 475 mm.

The top part of the alignment system, on which the HEPTO body is supported, allows for horizontal and vertical adjustment of the device. The horizontal adjustments are enabled via sliding plate interface between the bottom base plate (**1**) and the top plate (**2**), which holds the wedge levelers (**3**). The vertical adjustments are provided by four wedge levelers (**3**).

WARNING!
Before horizontal alignment, make sure the M20 nuts (**8**) are completely loose. Adjusting while the nuts are tightened could cause damage to the mechanical components.

IMPORTANT!
For horizontal alignment of the machine, use the adjustment screws (**5**). There are two adjustment screws for each leveling foot, so the machine can be properly secured after alignment. When adjusting the screws, make sure other screws are properly loosened, to allow movement. After reaching desired position, rotate the screws until they press on the plate and tighten all the M16 nuts (**6**) with a torque wrench (60 Nm).

WARNING!
Before vertical adjustment, loosen the M16 nuts (**7**) for all wedge levelers. Adjusting while the nuts are tightened may damage the wedge leveler mechanism (**4**). While adjusting, make sure that there is enough space between the M16 nuts (**7**) and aluminium mounting plate (**9**) for vertical movement.

IMPORTANT!
Vertical alignment is achieved by acting on the wedge leveler mechanism (**4**). Wedge leveler adjustment range is +4 / -5 mm. After reaching the desired position, tighten the M16 nuts (**7**) with a torque wrench (140 Nm for the black oxide nut, 70 Nm for the zinc plated nut).

IMPORTANT!
When adjusting the wedge leveler, especially near the final position, make sure there is no looseness in the wedge mechanism, to prevent sinking over time.

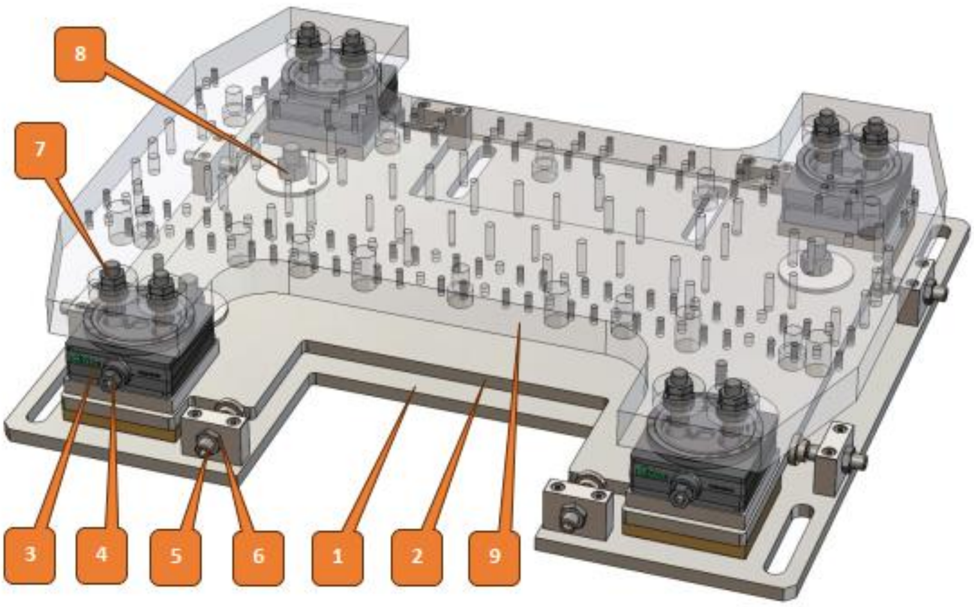


Figure 26: HEPTO alignment system (3D model).

NOTE!
After alignment, the M20 nuts (**8**) should not be fully tightened, as this would slightly deform the system. They should be only slightly tightened, having a snug fit.

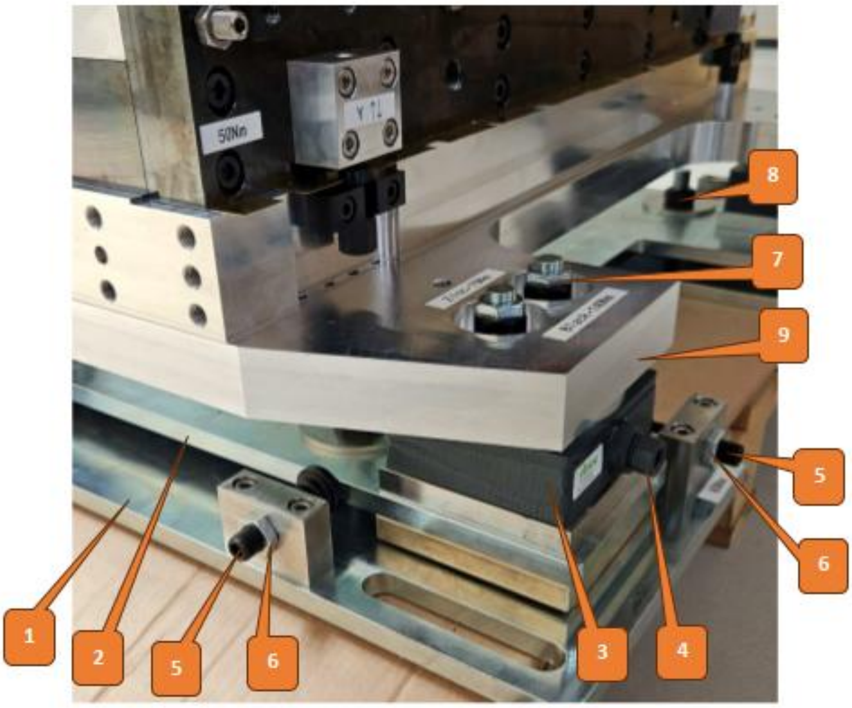


Figure 27: HEPTO alignment system.

4.2 Adjustment instructions

After initial alignment on the measurement bench, the poles of the HEPTO magnets must be adjusted, to reach optimal position and measurements. The top main pole is adjustable in the vertical and horizontal (transversal) direction. Both auxiliary poles are adjustable in the vertical direction. Horizontal (transversal) adjustment of the auxiliary poles is only slightly adjustable. The bottom main pole is not adjustable relative to other poles.

WARNING!
The alignment and leveling of the device must be carried out by experienced and properly trained personnel.

4.2.1 Top main pole vertical adjustment

Vertical movement of the top main pole is enabled by four adjustment screws, located at the top of the device. Final vertical position should be defined by the amount of brass shim plates between the main pole spacers, along the length of the HEPTO magnet.

WARNING!
Before vertical adjustment of the top main pole, loosen all the screws connecting the top yoke plate to the top auxiliary pole and to the yoke back plate. This will allow the top main pole structure to slide vertically in between the top auxiliary pole and the yoke back plate. First loosen 14x M10 screws (**1**) that connect the top yoke plate to the auxiliary pole. Then loosen 14x M12 screws (**2**) that connect the top yoke plate to the yoke back plate. These screws do not need to be loosened fully, but just enough to enable movement.

IMPORTANT!
Vertical adjustment of the top main pole is achieved by acting on the four adjustment screws (**3**), located at the top of the device. Slightly rotate each adjustment screw in the clockwise direction to lift the top main pole structure and open the gap at the brass shim location between the main pole spacers. Try to rotate each screw by the same amount (e.g. quarter turn), until brass shims can be inserted / removed.

Figure 28: Slightly loosen the screws (1) and (2) prior to main pole vertical adjustment.

Figure 29: Rotate the adjustment screws (3) in the clockwise direction to lift the top main pole.

IMPORTANT!
Insert / remove brass shims (4) as needed, between the main pole spacers (5) (6). Afterwards rotate the adjustment screws (3) counter-clockwise, to lower the main pole structure. Rotate each screw equally in small increments, until brass shims are sufficiently pressed between the spacers and cannot be moved.

WARNING!
Use protective gloves when working the shims, as they have very sharp edges and can cut the skin easily!

Figure 30: Insert / remove brass shims (4) between the main pole spacers (5) (6).

IMPORTANT!
After shimming, retighten all the yoke screws (**1**) (**2**) with a torque wrench.
Tightening torque:
M10 (**1**) – 50 Nm
M12 (**2**) – 90 Nm

4.2.2 Top main pole horizontal adjustment

Horizontal (transversal) movement of the top main pole is enabled by ten adjustment screws (**7**), located at the top auxiliary pole and the yoke back plate.

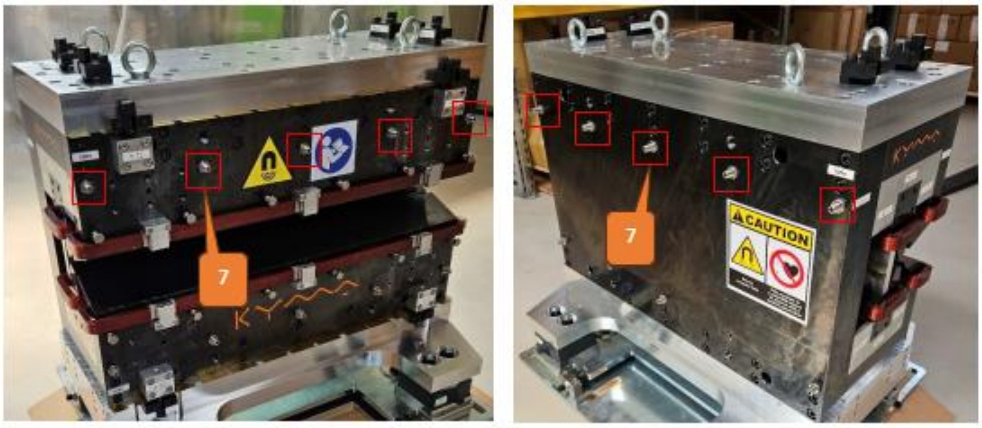


Figure 31: Top main pole horizontal adjustment screws.

WARNING!
Before horizontal adjustment of the top main pole, loosen all the screws that connect the top interface plate to the top yoke plate. This will allow the interface plate with the main pole to slide horizontally. The 30x M8 screws (**9**) can be loosened through the holes in the top aluminium plate. The screws do not need to be loosened fully, but just enough to enable movement.

IMPORTANT!
Horizontal adjustment of the top main pole is achieved by acting on the ten adjustment screws (**7**). Slightly rotate each adjustment screw to move the main pole structure. Make sure that the adjustment screws on the other side do not block the movement.

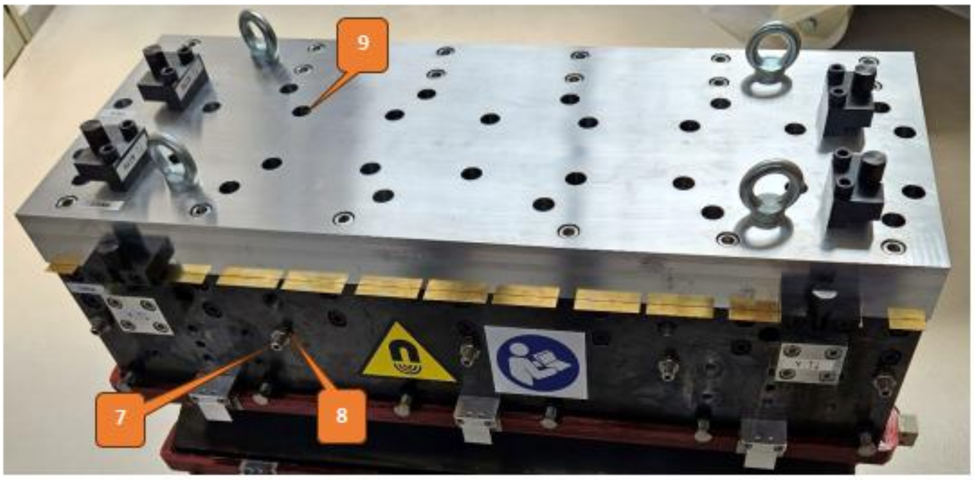


Figure 32: Loosen the 30x M8 screws prior to main pole horizontal adjustment.

IMPORTANT!
Upon reaching the desired horizontal (transversal) position, slightly tighten all the nuts (**8**) of the adjustment screws. Afterwards, retighten the 30x M8 screws (**9**) with a torque wrench (20 Nm).

4.2.3 Bottom auxiliary pole vertical adjustment

Vertical movement of the bottom auxiliary pole is enabled by two adjustment screws (**10**), shown in **Figure 33**. Final vertical position should be defined by the amount of brass shim plates (**11**) at the bottom mounting surface of the auxiliary pole.

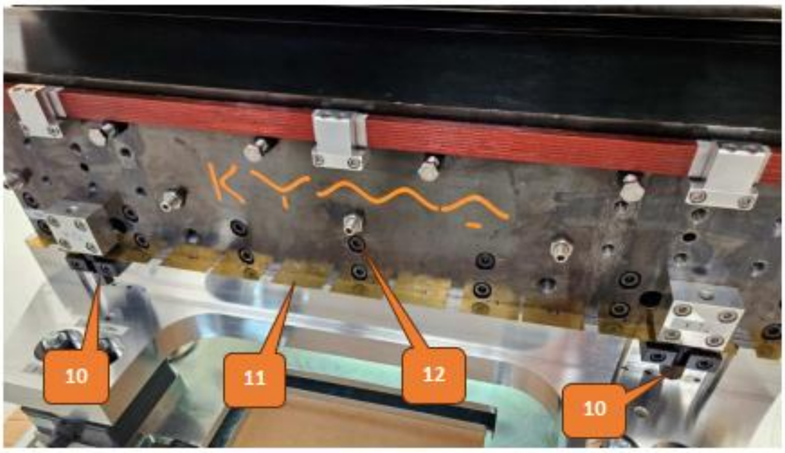


Figure 33: Bottom auxiliary pole vertical adjustment.

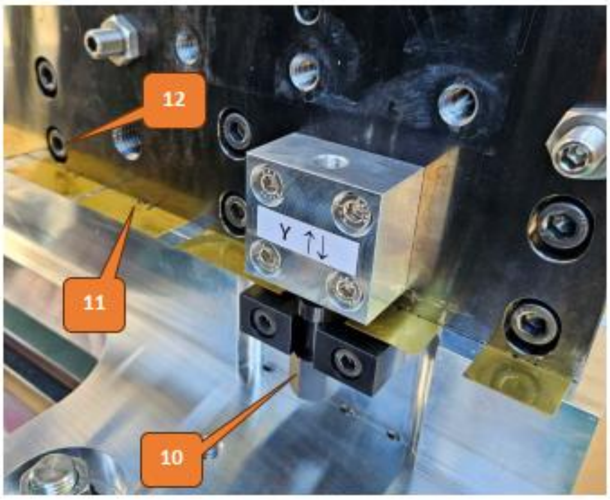


Figure 34: Bottom auxiliary pole vertical adjustment.

WARNING!
Before vertical adjustment of the bottom auxiliary pole, loosen all the M10 screws (**12**) that connect the bottom auxiliary pole to the bottom yoke plate. These screws do not need to be loosened fully, but just enough to enable movement. Then unscrew the six M12 screws (**13**) from the bottom.

IMPORTANT!
Vertical adjustment of the bottom auxiliary pole is achieved by acting on the two adjustment screws (**10**). Slightly rotate each adjustment screw in the counter-clockwise direction to lift the auxiliary pole and open the gap at the brass shim location (**11**). Try to rotate each screw by the same amount (e.g. quarter turn), until brass shims can be inserted / removed.

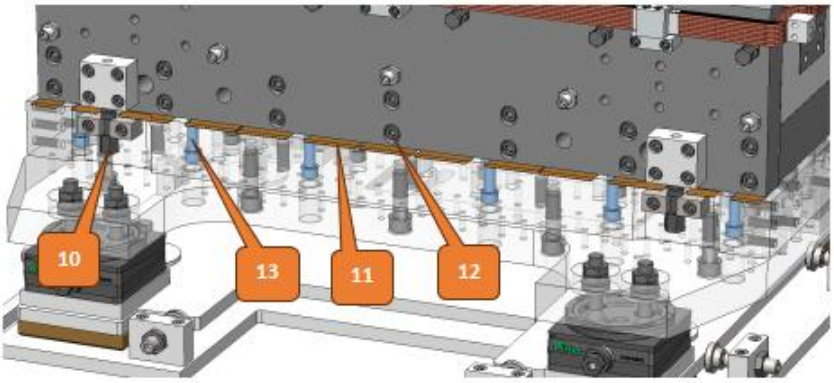


Figure 35: Enabling auxiliary pole vertical movement (loosening the screw connections).

IMPORTANT!
Insert / remove brass shims (**11**) as needed. Afterwards rotate the adjustment screws (**10**) clockwise, to lower the auxiliary pole. Rotate each screw equally in small increments, until brass shims are sufficiently pressed between the spacers and cannot be moved.

WARNING!
Use protective gloves when working the shims, as they have very sharp edges and can cut the skin easily!

IMPORTANT!
After shimming, first retighten the bottom M12 screws (**13**) to ensure good contact at the shimming location. Then retighten the M10 screws (**12**) to connect the yokes.
Tightening torque:
M12 (**13**) – 35 Nm
M10 (**12**) – 50 Nm

4.2.4 Top auxiliary pole vertical adjustment

The process of vertical adjustment for the top auxiliary pole is practically the same as for the bottom auxiliary pole. Vertical movement of the top auxiliary pole is enabled by two adjustment screws (**14**), shown in **Figure 33**. Final vertical position should be defined by the amount of brass shim plates (**15**) at the top mounting surface of the auxiliary pole.

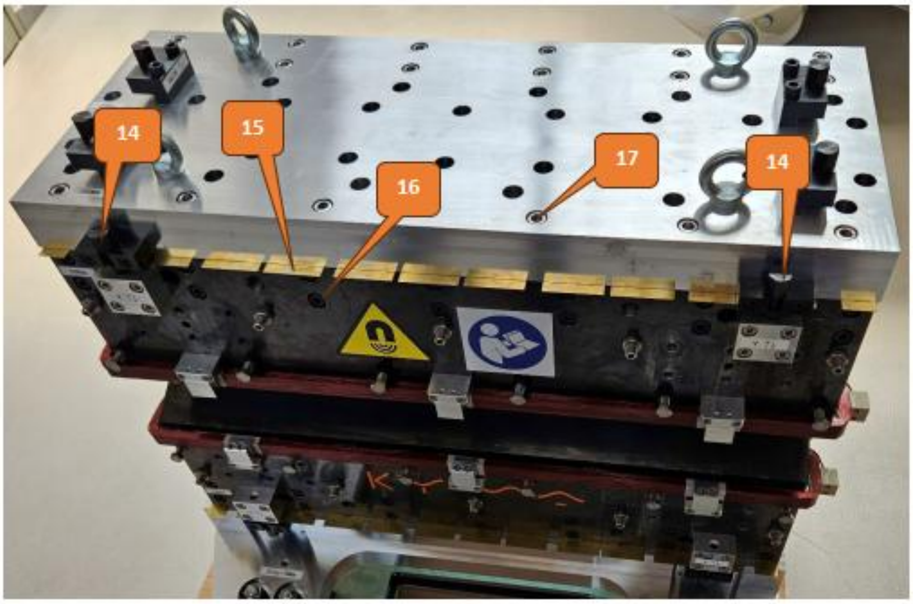


Figure 36: Top auxiliary pole vertical adjustment.

WARNING!
Before vertical adjustment of the top auxiliary pole, loosen all the M10 screws (**16**) that connect the top auxiliary pole to the top yoke plate. These screws do not need to be loosened fully, but just enough to enable movement. Then unscrew the six M12 screws (**17**) at the top.

IMPORTANT!
Vertical adjustment of the top auxiliary pole is achieved by acting on the two adjustment screws (**14**). Slightly rotate each adjustment screw in the counter-clockwise direction to lower the auxiliary pole and open the gap at the brass shim location (**15**). Try to rotate each screw by the same amount (e.g. quarter turn), until brass shims can be inserted / removed.

IMPORTANT!
Insert / remove brass shims (**15**) as needed. Afterwards rotate the adjustment screws (**14**) clockwise, to lift the auxiliary pole. Rotate each screw equally in small increments, until brass shims are sufficiently pressed and cannot be moved.

WARNING!
Use protective gloves when working the shims, as they have very sharp edges and can cut the skin easily!

IMPORTANT!
After shimming, first retighten the top M12 screws (**17**) to ensure good contact at the shimming location. Then retighten the M10 screws (**16**) to connect the yokes.
Tightening torque:
M12 (**17**) – 35 Nm
M10 (**16**) – 50 Nm

4.2.5 Auxiliary poles horizontal adjustment

The final design for this functionality is based on the attractive force between the main poles and adjacent auxiliary poles, meaning the auxiliary poles can be adjusted only in the direction away from the main pole.

IMPORTANT!
Horizontal adjustment of the auxiliary poles is achieved by acting on the M10 (**14**). Very slightly rotate each adjustment screw in the clockwise direction to push the auxiliary pole away from the respective main pole.

WARNING!
Auxiliary pole horizontal adjustment should be used for very small movements (± 20 µm), as it is inducing stress and deformation in the material. If larger adjustments are required, other options will need to be explored. Contact Kyma in this case.

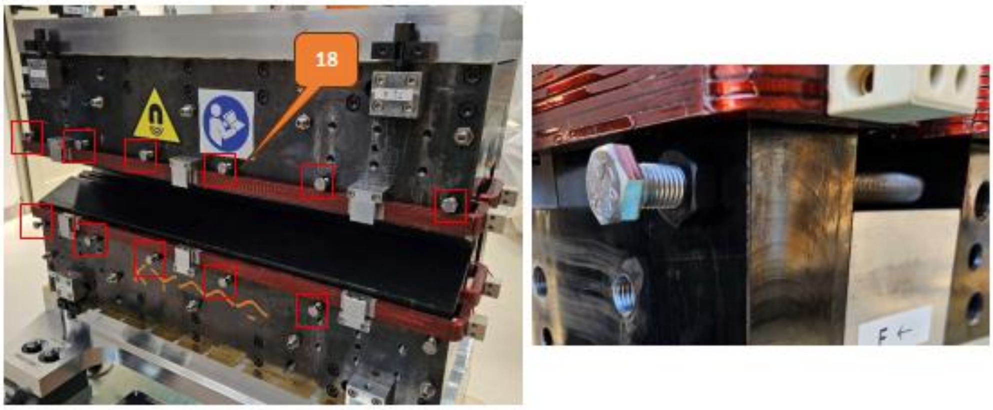


Figure 37: Auxiliary poles horizontal adjustment.

4.3 Connecting the trim coils

Trim coil screw terminal blocks are located on the upstream side of the machine (**Figure 38**). Be sure to turn off power of coil power supply before connecting cables. Loosen the screw of terminal blocks and insert uninsulated ends of cables in desired configuration. Tighten the screws.

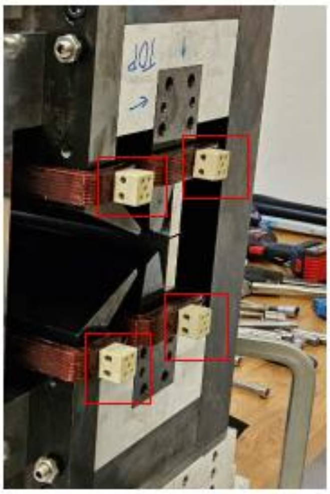


Figure 38: Terminal blocks of main and auxiliary trim coils.

WARNING!
Do not connect any cables while the coil power supply is on.

4.4 Maintenance instructions

The HEPTO prototype is a passive device and does not have moving parts in the general sense. The adjustment screws can be occasionally lubricated with grease.

5 Conclusions

The HEPTO prototype was successfully assembled and shipped to STFC Daresbury for magnetic performance evaluation.

In terms of mechanical design, there are a few areas which could be improved in future designs. In the current design, the main limitation was in the horizontal adjustment of the auxiliary poles. The horizontal adjustment range of the auxiliary poles is very limited because it relies on the elasticity of the material. A different solution should be explored to achieve sufficient adjustment range.

Another important aspect is regarding alignment, namely providing fiducial points on the device and carry out the fiducialisation, which would help greatly with final alignment.

Positional adjustment of the poles is functional, but is rather complex as it requires multiple operations. This increases the likelihood of human error. Future design should aim to simplify this process as much as possible.

Some form of mechanical measurement should be carried out after shimming, especially regarding the gap between the main poles and the auxiliary poles. The gap after shimming should be sufficiently large to accommodate the vacuum chamber without any interference.

6 Attachments

The list of relevant attachments is presented in **Table 2**.

Table 2: Attachments.

No.	File name	Description
1	2162b-TDA-000-R01-GeneralAssembly.pdf	Main assembly drawing
2	2162b-TDA-001-R01-MagnetAssembly.pdf	Magnet assembly drawing
3	2162b-TDA-011-R01-FeetAssembly.pdf	Support structure assembly drawing
4	2162b-TDA-000-R01-GeneralAssembly.STEP	General assembly STEP model
5	2162b-MainPoleMeasurement-1.pdf	Main pole measurement report 1
6	2162b-MainPoleMeasurement-2.pdf	Main pole measurement report 2
7	2162b-AuxiliaryPoleMeasurement-1.pdf	Auxiliary pole measurement report 1
8	2162b-AuxiliaryPoleMeasurement-2.pdf	Auxiliary pole measurement report 2

3. Conclusions

The construction of the HEPTO Permanent Magnet -based combined function magnet with dipole and quadrupole fields in the I.Fast framework (Task 11.3) has been successfully completed and verified through dimensional inspection at KYMA, magnet has been shipped to STFC Daresbury for magnetic performance evaluation.

In terms of mechanical design, there are a few areas which could be improved in future designs. In the current design, the main limitation was in the horizontal adjustment of the auxiliary poles. The horizontal adjustment range of the auxiliary poles is very limited because it relies on the elasticity of the material. A different solution should be explored to achieve sufficient adjustment range.

Another important aspect is regarding alignment, namely providing fiducial points on the device and carry out the fiducialisation, which would help greatly with final alignment.

Positional adjustment of the poles is functional, but is rather complex as it requires multiple operations. This increases the likelihood of human error. Future design should aim to simplify this process as much as possible.

Some form of mechanical measurement should be carried out after shimming, especially regarding the gap between the main poles and the auxiliary poles. The gap after shimming should be sufficiently large to accommodate the vacuum chamber without any interference.

These are not critical aspects and can be managed without impact. The manufactured magnet will be therefore validated to STFC Daresbury , representing a key step toward the realization of Deliverable D11.3.