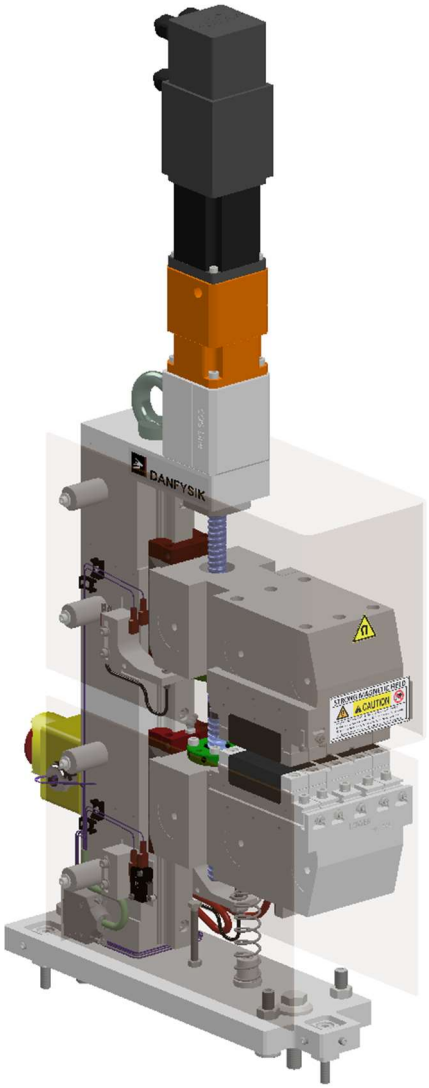
Magnet type: **Phase Shifter**
Magnet designation: **SXR**
Assembly drawing: **7103050653**

OPERATING AND SERVICE MANUAL



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Date:	12/03/2024	14-03-2024

HISTORY

Document History

Revision Status	Date of Issue	Author	Change and reason for change
A	2024/03	Daniel Ancher	1st issue

List of contents

1 Read this first

1.1 About this document

This document is intended for service engineers responsible for the installation, maintenance and repair of the magnets supplied by Danfysik A/S. External cabling and power supplies are outside the scope of this manual. Regular preventive maintenance is necessary to ensure a high uptime of the installed equipment.

1.2 Intended Use of Equipment

The supplied magnets are a component to be installed in a particle accelerator built according to industrial standards. Their primary function is to control the beam in a particle accelerator.

The magnets are controlled from an external power supply that provides the current for the magnet to control the beam. All magnets provide interlock signals to the power supply in the event of overheating.

They receive cooling water from an external water system.

The magnets are designed as fixed equipment and must be permanently connected. They must be installed in an enclosed operating area.

Only skilled personnel are allowed to install the equipment and only instructed personnel are allowed to operate it.

Should the magnets fail to control the beam, the accelerator system must be able to detect and shut down the accelerator in a safe manner.

1.3 Requirements

1.3.1 Qualifications

The installation, service and maintenance of equipment described in this manual may only be performed by qualified personnel.

In this context, “qualified” signifies that the technician has been trained and has had practical experience in the required routines so that he/she is capable of performing service work on the system.

1.3.2 Personnel

Certain maintenance procedures may require the assistance of two people.
Where relevant this will be indicated in the instructions.

1.4 Reference documents (See Appendix)

- Magnet assembly drawing 7103050653

Including relevant sub drawings according to BOM

1.5 Acronyms and Abbreviations

ACS	Accelerator Control System
BOM	Bill of Materials
DF	Danfysik A/S
LCLS-II	Linac Coherent Light Source II
PS	Phase Shifter
SLAC	Stanford Linear Acceleration Center

1.6 Note Conventions

WARNING	A *warning* label indicates potential risk of injury or loss of life to personnel if safety guidelines and instructions are ignored or circumvented.

CAUTION	A *caution* label indicates potential damage to equipment if the necessary precautions are not heeded.

NOTE	A *note* label provides practical information that can be helpful in various maintenance situations.

1.7 Safety Precautions

Installation of these magnets presupposes that they will be installed in an enclosed operating area clearly marked as such (signs, restricted access etc.)

Care must be taken during and after installation of vacuum chamber or equipment near the pole gap. See. Section

1.7.2 Electric and Magnetic Field Hazards for further information.

Only use certified lifting equipment (e.g. H-beam and round slings).

WARNING	Failure to observe the warnings specified in this document may lead to serious injury or loss of life. The guidelines contained in this document must be strictly followed.

WARNING	In operation, there is a risk for accident and injury when magnets need to be moved out of the beamline.

1.7.1 Radiation Hazards

WARNING	**Risk of radioactive contamination!** Parts located in the radiation-controlled area might be activated. Contact the local radiation officer for authorization prior to access, removing parts or bringing parts out of the controlled area.

WARNING	**Risk of exposure to radiation!** Staying inside the accelerator area during operation might result in exposure to radiation. Always comply with your location's safety and security regulations.

1.7.2 Electric and Magnetic Field Hazards

WARNING	**Magnetic fields present. Risk of accident and injury!** Electric and magnetic fields can damage or interfere with active implants. Risk of death or severe injury to staff working in this area! With an active or magnetic implant, avoid working in this area during operation.

WARNING	**Magnetic fields present. Risk of accident and injury!** Permanent magnets are present. Do not use magnetic tools, equipment etc. unless it is strictly necessary. Only trained personnel are allowed to work on the magnet.

1.7.3 Environmental Hazards

CAUTION	**Environmental Protection** Hazardous materials must be properly disposed of by an authorized waste management company. Risk of environmental pollution! Dispose of hazardous materials in accordance with local regulations.

2 System Description

2.1 General

NOTE	To identify the magnet type, look at the Danfysik A/S identification label attached to the support structure.

Figure 1 - Identification label.

The purpose of the mechanical structure is to provide support for the magnets and make it possible to move and position the magnets symmetrically above and below the electron beam.

The support structure is L-shaped. A linear rail with a runner block for each girder guides the girders. A ball spindle with a left-hand thread in one end and a right-hand thread in the other end moves the girders. The two girders carry the magnets.

The phase shifter can be lifted using the lifting eyebolt at the top of the carriage. It is necessary to remove the cable for the limit switches from the motor before lifting the device.

CAUTION	Turn off the power supply for the motor before removing the cables. Both connection cables between motor and controller as well as cable to limit switches shall be removed for lifting.

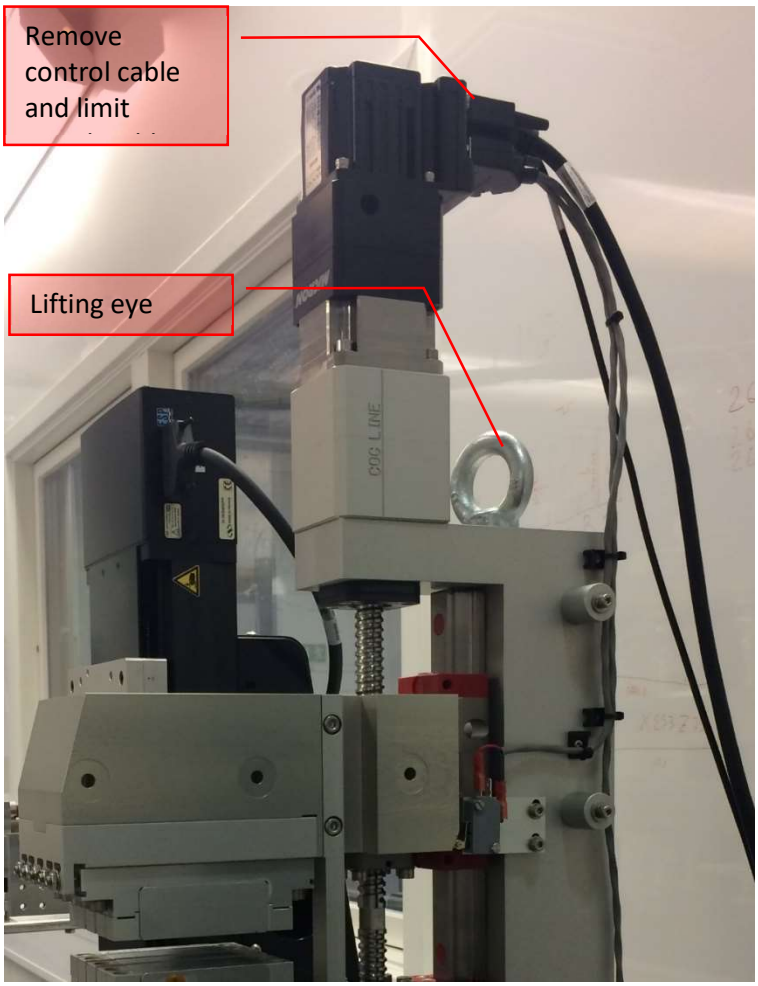


Figure 2 - Cables that shall be removed before lifting + lifting eye.

2.2 Gap Motion

A linear motion rail on the mechanical structure obtains the vertical linear motion of the girders. A roller block carries each girder.

A ball spindle secures the opposite movement (vertically) of the girders. A right-hand ball thread for the upper girder and a left-hand ball thread for the lower girder obtain this. The ball spindle is connected to a stepper motor through a gearbox.

An absolute linear encoder measures the gap.

Two sets of switches, named 'limit' switches and 'power' switches, are installed on the phase shifter, and shall be connected to the motor controller. Each set contains a switch at open gap and a switch at closed gap. If activated, the switches will stop the motion and only allow for movement in the opposite direction. The purpose of the power switches is to secure against over-travel. The limit switches employ switches made by Omron, which have excellent reproducibility characteristics. These switches may be used to set the gap with micron accuracy in case the encoder has to be replaced. The power switches are made by Honeywell and Metrol.

A hard stop is installed for closed gap for final protection of the vacuum chamber (not included) as well as for open gap should the electrical safety not stop the motion.

2.3 Rigid Frame

The frame for the phase shifter is constructed in aluminum to minimize the magnetic permeability of the device. The frame supports the magnets through the rail, the ball spindle, and girders.

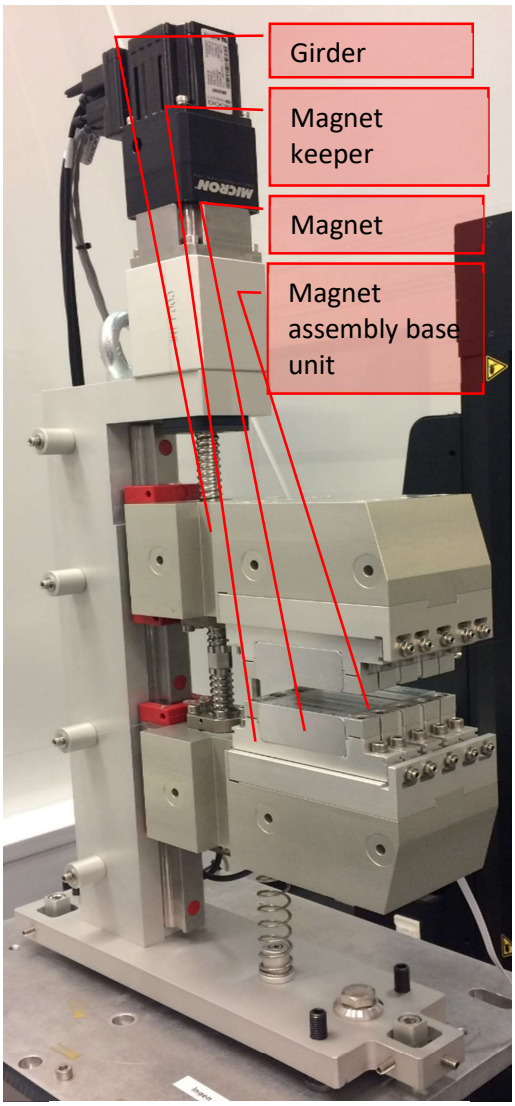


Figure 3 - Girder and magnet assemblies.

2.4 Girders

The girders are constructed in aluminum to minimize magnetic permeability. The girders support the magnets through the magnet keepers on the magnet assembly units.

2.5 Magnet Assemblies

The magnet arrays are built from magnets magnetized in alternating directions. All magnets are glued into aluminum keepers that are secured to the aluminum magnet assembly unit base.

3 Installation and Operation Instructions

3.1 General

WARNING	**Radiation Area!** The magnets will be installed in an enclosed operating area with restricted access. Warning signs should therefore be visible on doors and near the entrance area.

Certain basic conditions are necessary to ensure safe and responsible installation of the equipment:

- The place of installation must be a weather protected area (against rain, wind and dust, etc.)
- The installation area must be kept free from dirt and dust particles.
- The installation area must allow an operating temperature of 15 - 30°C, with a relative humidity of 0 - 70%.
- Access ways must be kept clear.
- Warning signs and barricades must be in place to prevent unauthorized access to the working area

3.1.1 Tools and Auxiliary Materials

- Ordinary assembly tools
- Forklift
- Crane
- Pallet jacks
- Protective equipment according to local regulations, for instance hard hats, safety glasses, and/or goggles, safety shoes with toecap protection

3.1.2 Unpacking and Installation

WARNING	**Risk of injury from fall!** Safety shoes must be always worn during installation of the magnets.

3.1.3 Instructions for Unpacking

The phase shifters are delivered in a wooden crate. The crate is on the outside equipped with 2 tilt sensors and a drop indicator. Check if any of the 3 sensors are activated as well as the outside of the crate for signs of damage. Activated (or missing) sensors or signs of damage must be noted on the dispatch note before signing possible insurance claims. The crate can be handled by a pallet truck or forklift.

Figure 4 - Wooden crate.

CAUTION	Be careful when handling the phase shifter and the loose magnetic array. There is a strong magnetic field from the magnets in both. Be careful with tooling.

WARNING	The strong magnetic fields can be dangerous for people with implants. People with implants should stay at least 35 cm (1.2 ft.) from the magnet array and phase shifter.

Remove the screws from the lid and open the crate. Remove the beams that keep the phase shifter from moving inside the crate. Carefully cut the bag inside the crate. Remove the limit switch cable from the motor and lift the phase shifter out of the crate. Please note that the phase shifter and loose arrays must be kept a minimum of 25 cm (10 inches) apart. Please note that the carriage will tilt approximately 20 degrees during lifting. The carriage is equipped with an irreversible temperature indicator on the back. Please check that the device has not experienced temperatures higher than 54°C (130°F) maximum immediately after removing the phase shifter from the crate. If the device has experienced higher temperatures, please note the temperature. The magnetic field of the device might need checking if the temperature has been too high.

3.1.4 Internal transportation of the phase shifter

The phase shifter should be transported with an overhead crane using the eyebolt. When the device is not carried by the eyebolt, it shall always be secured to the item it is standing on. Due to the height/width relationship there is a risk of the device falling over if exposed to even relatively small forces or accelerations. Always take precautions against the dangers from the magnet array.

3.1.5 Installing phase shifter around beam

The phase shifter is delivered with the gap set to approximately 10mm. Should another gap be necessary for installation, the device can be connected to a suitable control system as described in 3.1.6 Electrical Connection and the gap changed.

Screw the two “Base fixture for horizontal alignment” (item 7103051152) into the support plate where the device shall be installed. Carefully lift the device into position. Install the two “Washer for Tie down screw” (item 7103026921) and the two “ISO 4017 - M12 x 55” (item 5200803150) with the tightening torque = 6 Nm. Align the device relative to the nominal beam axis considering the fiducialization data obtained during mechanical and magnetic measurements at Danfysik and stated in the measurement report.

3.1.6 Electrical Connection

Connect the emergency switch, motor, and encoder to a suitable control system. The controls are not included in the delivery.

WARNING	When the device is connected to a control system, the magnet arrays can be moved. The device is prepared for being installed around a vacuum chamber with a minimum height of 9mm. When the vacuum chamber is not installed, the shields do not give sufficient protection against crushing injuries from the moving girders. It is necessary to be very careful while working with the device without suitable vacuum chamber installed.

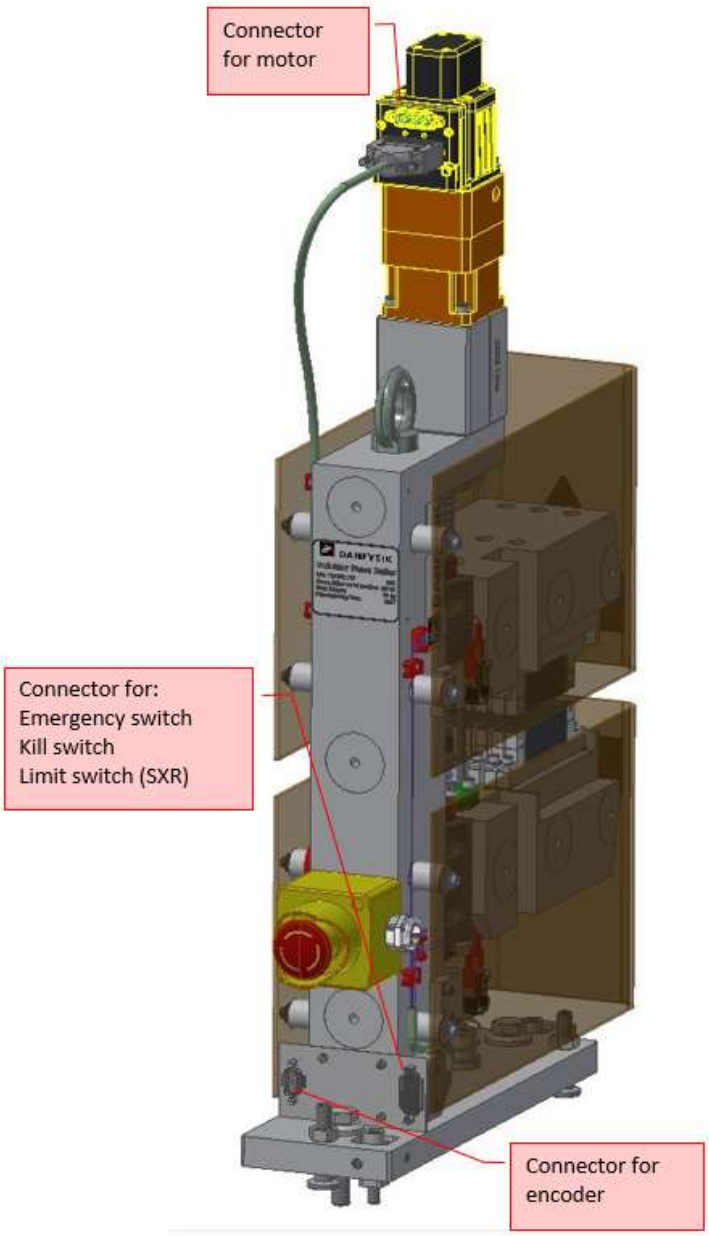
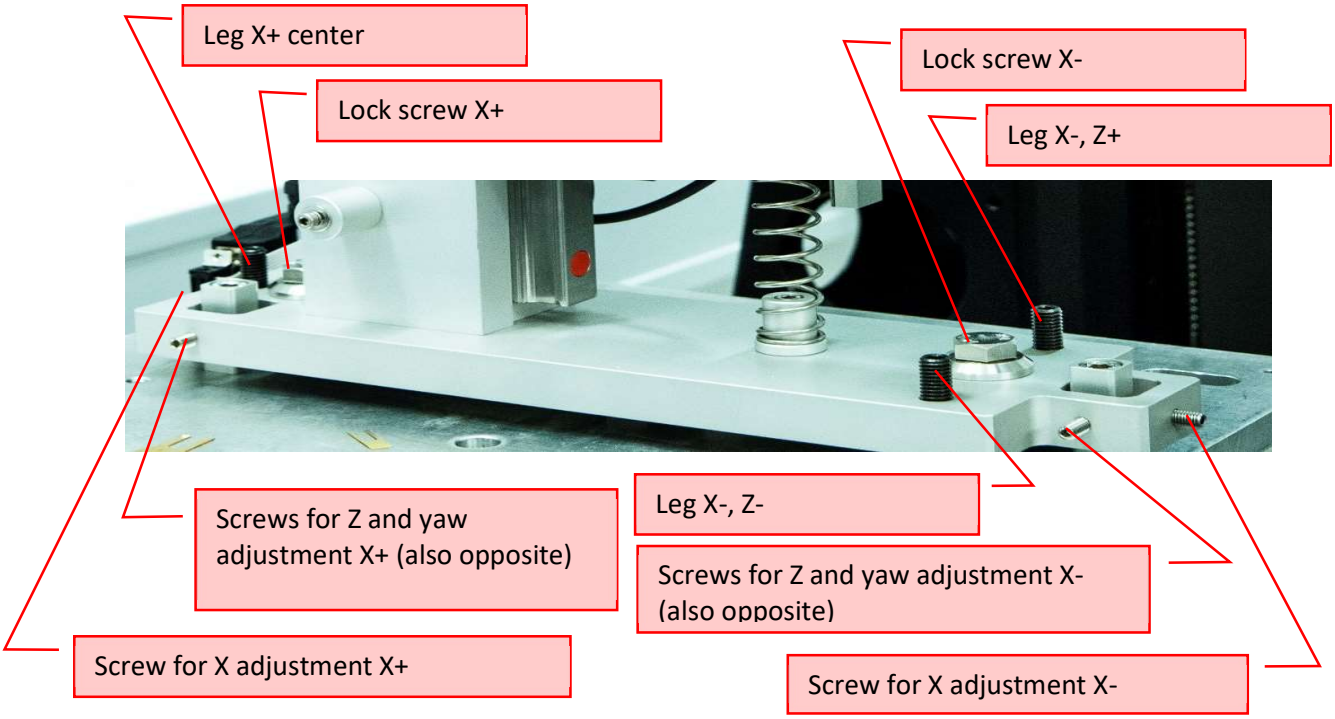


Figure 5 - Electrical connections.

3.1.7 Alignment

There are 15 alignment fiducial holes on the device. Three on each side of each girder and three on the back of the device. The target positions can be found in a separate report.



Manual adjustment of the X, Y and Z position as well as roll, pitch and yaw for alignment can be adjusted with the screws around the feet. The following steps is proposed for aligning the phase shifter:

- Adjusting the pitch angle: loosen the lock screw in the x- side. Turn the leg screw in the end of the device that shall be adjusted until the pitch angle is correct. Tighten the lock screw.
- Adjusting the yaw angle: Loosen both lock screws. Loosen the screw for Z and yaw adjustment at the position that shall be changed at the side that the device needs to be adjusted towards. Adjust the opposite screw until the device is positioned correctly. Tighten the screw that was initially loosened. Tighten the lock screw.
- Adjusting the roll angle: loosen the leg lock screw on the X+ end. Adjust the X+ leg center until device is horizontal. Tighten the lock screw.
- Adjusting the X position: Loosen both lock screws. Loosen the screw for x adjustment in the end corresponding to the direction the device shall be moved towards. Tighten the x adjustment screw in the opposite end of the device until the alignment is correct. Tighten the first x adjustment screw. Tighten the lock screw.
- Adjusting the Y position: Loosen both lock screws. Adjust all 3 legs the same amount until the device is in the right height. Tighten the lock screw.
- Adjusting the Z position: Loosen both lock screws. Loosen the screws for z adjustment in the end corresponding to the direction the device shall be moved towards. Tighten the z adjustment screw in the opposite end of the device until the alignment is correct. Tighten the first z adjustment screw. Tighten the lock screw.

3.1.8 Setting of limit and power switches

The limit switches and power switches are set from the factory. The following method can be used for resetting. Please note that the Omron limit switches are intended for resetting encoders. If the limit switches are reset, it is important to update the documentation of the encoder offsets. Also note that it is important that the limit switch activates before the corresponding power switch, and that the activation point of the power switch is located within the over-travel movement distance of 1.5 mm from the activation point of the limit switch. This ensures that the limit switch cannot be damaged.

CAUTION	Changing the setting of limit switches without updating encoder offset documentation will remove the possibility to use the limit switches for reference for encoder offset.

Remove the polycarbonate shield by the limit switch that needs resetting. Move the gap to the position the switch shall be activated. Loosen the two screws holding the limit switch bracket to the phase shifter carriage. Move the bracket and limit switch until the switch just activates. Tighten the screws for the bracket. Move the gap until the switch has been deactivated a couple of millimeters. Change the gap setting until the switch activation stops movement. Check that the setting is correct or re-adjust following the same procedure.

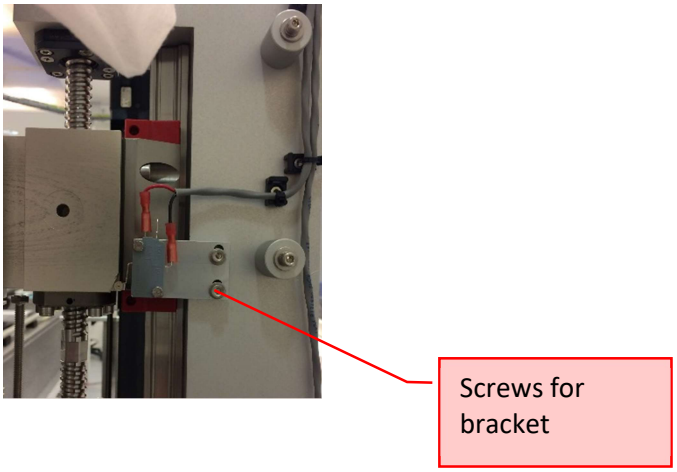


Figure 6 - Screws for limit switch brackets.

3.1.9 Setting of hard stop

The hard stop is preset from the factory. To readjust the hard stop position, loosen the hard stop lock nut. Set the gap to required stop position (this might require pre-adjustment of the hard stop screw and possibly readjustment of the limit switch). Tighten the hard stop screw until it hits the upper girder. Tighten the lock nut.

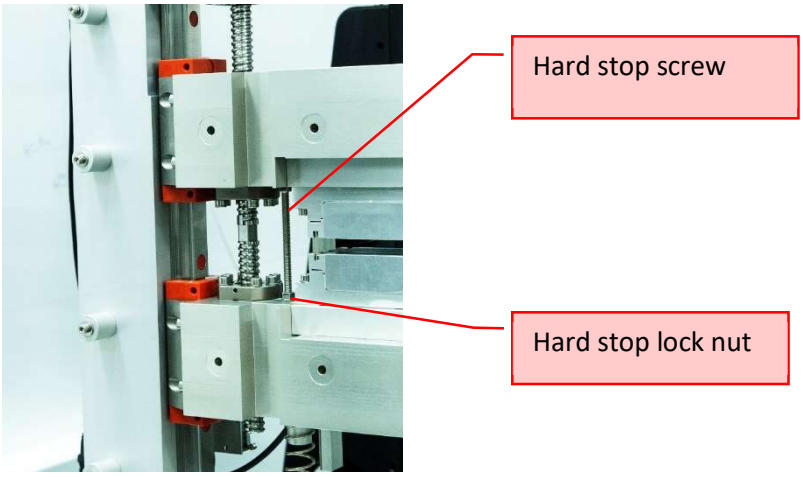


Figure 7 - Setting of hard stop

3.1.10 Shields

The phase shifter is equipped with two shields, an upper and a lower. Remove the four screws securing the shield that need removing. Always re-install the shield as soon as possible. The shield both shields the magnets towards magnetic materials coming from outside the shield as well as protect people against the mechanical movement of the device.

WARNING	The shields should preferably always be installed while the device is connected to a control system.

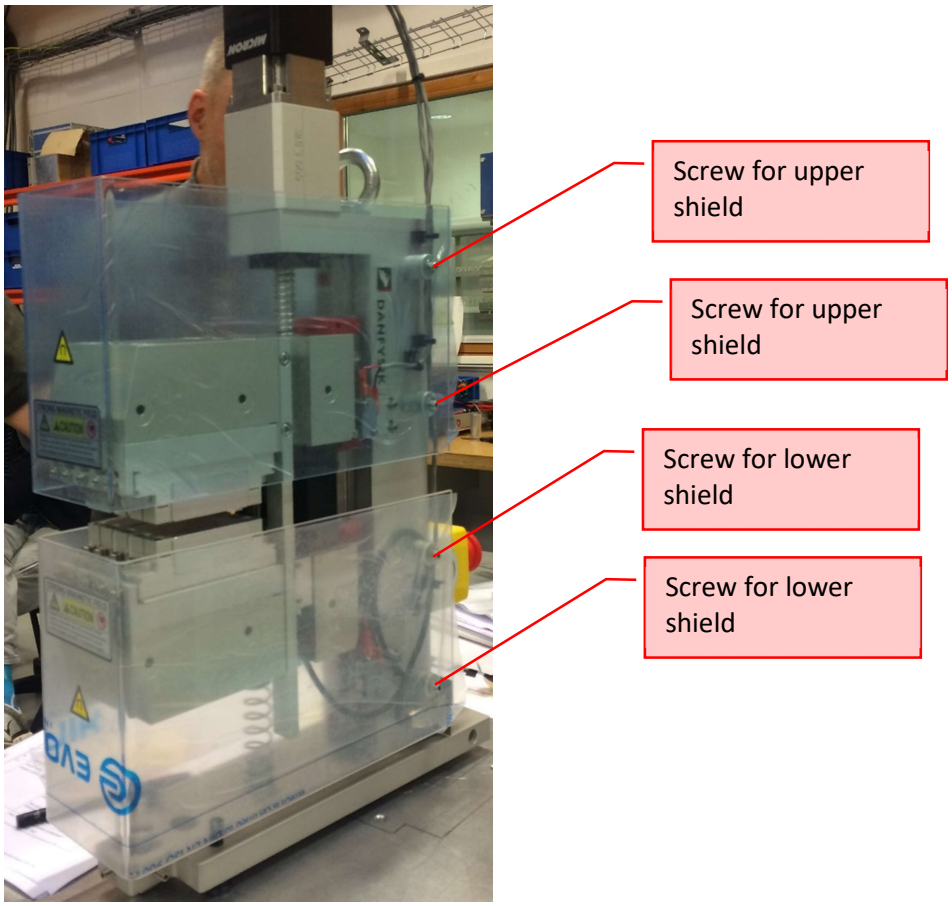


Figure 8 - Shield removal and refitting.

3.1.11 Storage environment requirements

Do not store the magnets in places where they are exposed to large temperature ranges and resulting moisture. The storage area must be frost free and with a relative humidity less than 80%. Condensed water on the surfaces of the magnet will result in corrosion

4 Maintenance

Before attempting any work on the phase shifter, make sure you are familiar with the safety procedures outlined in Chapter 1, “Read this first”.

4.1 General Maintenance

When delivered, all unprotected steel surfaces are treated with oil. This can be removed using white spirit if wished. It is recommended that all surfaces subject to oxidization should be covered one way or another if possible. It is recommended that unprotected surfaces that are used for motion (i.e. linear motion rails and ball-spindle threads) be treated with thin oil free from acid. All surfaces that are not required for movement (not protected and of steel) should be covered with oil (or another corrosion protective substance). All oiled surfaces should be re-oiled at least once a year.

4.2 Motion System

4.2.1 Motor

No Maintenance required. Refer to the motor manual for details.

Changing of the motor:

The motors are equipped with a brake that prevents the shaft from turning unless the brake is released electronically. Therefore, before disconnecting the phase shifter from the control system, set the gap so that the lock screw for the motor bushing is in line with the hole in the gearbox. The spindle has flats that may be used to turn the spindle manually if the motor is dismounted or the motor brake is released.

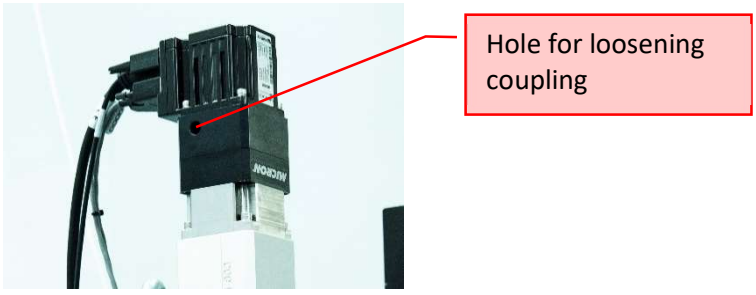


Figure 9 - Hole for loosening coupling, same on opposite side.

Lock the ball spindle with a vice to prevent the gap from accidentally moving. Turn off the control system. Disconnect the connectors for the motor and brake. Loosen the lock screw through the hole in the gearbox. Remove the 4 screws securing the motor to the gearbox. Re-assemble in opposite sequence.

4.2.2 Gear

No maintenance required.

4.2.3 Bearing

No maintenance required.

4.2.4 Ball spindle

Re-grease once every year.

Grease: STABURAGS NBU 12/300 KP

Rotating speed range up to 5000 rpm

Working temperature -35C° to +150C°

Alternatively, any ball bearing grease of quality NLGI 2 with relatively good resistance to radiation can be used.

4.2.5 Roller Blocks

Re-grease once every year.

Grease: STABURAGS NBU 12/300 KP

Rotating speed range up to 5000 rpm

Working temperature -35C° to +150C°

Alternatively, any ball bearing grease of quality NLGI 2 with relatively good resistance to radiation can be used.

4.2.6 Rail

Oil the surface of the rail with a thin oil (Castrol Everyman or similar) once each year.

4.2.7 Absolute linear encoder

No maintenance required. If the encoders operate in a dusty environment, it might be necessary to clean the ruler and possibly also the read head glass with a soft, lint-free cloth wetted with a little isopropanol.

4.2.7.1 Changing the encoder head

In case the encoder head must be changed, the following procedure should be used:

- Open the gap to approximately 85mm.
- Turn off the power to the encoder controller.
- Remove the encoder connector from the small bracket.
- Carefully remove the two screws holding the encoder head.
- Make sure not to scratch the encoder scale on the rail.
- Remove the encoder head.
- Insert the new encoder head and the two screws that carry it.
- Insert the small encoder head adjustment piece that is delivered with the encoder head between the encoder head and the scale.
- Push the encoder head gently towards the adjustment piece. Lock the encoder head screws with 0.8 Nm torque.
- Connect the encoder and turn on the encoder controller.
- Check the color of the diode on the encoder head (it can be seen mirrored on the girder behind the encoder head).
- The diode color needs to be blue or green over the entire working range. If this is not the case, loosen the encoder head screws and adjust until the requirement is fulfilled.
- Verify that the motor settings are Velocity = 5 mm/s; Acceleration =500 mm/s2.
- Set the gap to approximately 10 mm from the point where the closed-gap limit switch activates.
- Set the gap to a smaller value so the motor closes the gap and is stopped by the closed-gap limit switch. Write down the encoder read-out value.
- Set the gap to approximately 10 mm from the point where the open-gap limit switch activates.
- Set the gap to a larger value so the motor opens the gap and is stopped by the open-gap limit switch. Write down the encoder read-out value.
- Based on the two encoder read-out values, determine the encoder offset parameter in the control system so the encoder values at the closed-gap and open-gap limit switch positions correspond to the values determined at Danfysik and listed in the phase shifter ATP.

4.2.7.1 Changing the encoder scale

In case the encoder scale must be changed, the following procedure should be used:

- Open the gap to approximately 85mm.
- Turn off the power to the encoder controller.
- Carefully remove the two screws holding the encoder scale bracket.
- Make sure not to scratch the encoder head.
- Remove the encoder scale bracket.
- Remove the encoder scale from the bracket with a sharp tool.
- Glue the new encoder scale on the bracket using the double-sided tape on the back side.
- Re-install the encoder bracket.
- Insert the small encoder adjustment piece between the encoder head and the scale.
- Push the encoder scale gently towards the adjustment piece.
- Lock the encoder scale screws. Tightening torque = 5 Nm.
- Connect the encoder and turn on the encoder controller.
- Check the color of the diode on the encoder head (it can be seen mirrored on the girder behind the encoder head).
- The diode color needs to be blue or green over the entire working range. If this is not the case, loosen the encoder scale screws and adjust until the requirement is fulfilled.
- Verify that the motor settings are Velocity = 5 mm/s; Acceleration =500 mm/s2.
- Set the gap to approximately 10 mm from the point where the closed-gap limit switch activates.
- Set the gap to a smaller value so the motor closes the gap and is stopped by the closed-gap limit switch. Write down the encoder read-out value.
- Set the gap to approximately 10 mm from the point where the open-gap limit switch activates.
- Set the gap to a larger value so the motor opens the gap and is stopped by the open-gap limit switch. Write down the encoder read-out value.
- Based on the two encoder read-out values, determine the encoder offset parameter in the control system so the encoder values at the closed-gap and open-gap limit switch positions correspond to the values determined at Danfysik and listed in the phase shifter ATP.

4.3 Magnetic Arrays

No Maintenance required.

4.3.1 Dismount and Remount of Magnet Array Cassettes

Dismount:

- Open the gap to approximately 85mm.
- Remove the acrylic covers.
- Place a block of non-magnetic material between the 2 arrays.

Remove the 6 x M6x40 screws (for each array).

The magnet array cassette can now be removed.

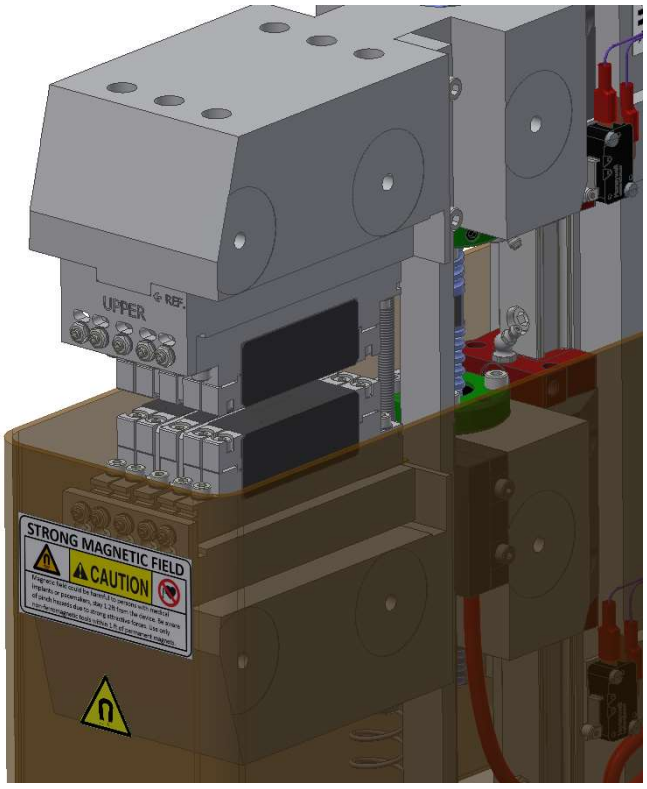


Figure 10 - Magnet Arrays

Remount:

- Press the magnet array cassette against the tower and the “Ref.” mark, while tightening the 6 x M6x40 screws. Tightening torque = 8 Nm.
- Remove the non-magnetic block.
- Remount the acrylic covers.

4.4 General tightening torque for screws and bolts

If nothing is stated on the drawings, the below values are to be used.

Dimension:	Torque:
M3	1 Nm
M4	2,5 Nm
M5	5 Nm
M6	8 Nm
M8	20 Nm

4.5 Preventive Maintenance Checklist

Use the “Preventive Maintenance Checklist” on page 31 as a guide when carrying out preventive maintenance.

Tools: vacuum cleaner, hex keys 5-14, adjustable spanner

4.6 Maintenance Overview

The magnet has no parts that require regular maintenance or calibration. The following are outlined to preserve the safety level of the magnet only.

Component	Recommended Interval	Time needed for review	Reference
Warning labels	12 months	1 min.	See “Check Warning Signs” on page 28.
Cleaning	12 months	30 min.	See “Cleaning” on page 28.
Greasing of non-painted areas	12 months	30 min.	See “Greasing” on page 28.

4.7 Every 12 Months

4.7.1 Visual and Mechanical Inspection

Please refer to Section 1, “Read this first” on page 5 before proceeding with any inspection.

— Check the magnet for excessive accumulation of dirt and dust.

- If necessary, clean dirty or dusty parts.

— Check for signs of corrosion on brackets and alignment surfaces.

— Inspect electrical connections for degradation and tightness.

— Check electrical connections for dust and debris.

— Check that all warning signs are legible and in place.

4.7.2 Check Warning Signs

— Check that all warning signs are visible and legible.

All warning signs must be present and legible. Missing or damaged signs must be replaced immediately, the safety of operating and service personnel could otherwise be endangered. Warning signs are placed on magnetic fields which can be harmful to pacemaker wearers.

4.7.3 Cleaning

— Vacuum clean electrical connections.

In dusty or dirty environments, the maintenance points listed should be performed more frequently. Dust particles on insulation become conductive when combined with moisture. This can lead to degradation of insulation, electric discharges and short-circuiting.

Please note that dust particles could be contaminated.

4.7.4 Greasing of non-painted areas

— Anti corrosion oil.

Non-painted areas, such as alignments surfaces and mounting surfaces on the support, should be checked for corrosion.

Apply anti corrosion oil, on the surfaces.

5 Deinstallation and disposal Instructions

This chapter describes how to deinstall the magnets and how to dispose of the individual components of the magnets.

Before attempting any work on the accelerator equipment, make sure you are familiar with the safety procedures outlined in Chapter 1, “Read this first”.

5.1 Local laws

Accelerator Magnets must be disposed of according to local laws. If there is a contradiction between the local laws and instructions in this document, the local laws should be adhered to.

5.2 General

Accelerator magnets consist mainly of electronic components that can be disposed of and recycled in accordance with current WEEE and RoHS standards. All components must be disposed of according to local regulations.

This disposal information is relevant when disposing of the system after disassembly and when replacing defective parts during operation. Defective parts should be recycled if they cannot be repaired.

5.3 Deinstallation

Ensure that all power has been turned off and that power cables have been disconnected before commencing any work on the magnets. Refer to documentation for magnet power supplies for power off procedures.

WARNING	Metal exposed to high levels of radiation can still be activated. Follow the precautions and procedures laid down by your safety and environmental authorities.

6 Appendix

6.1 Checklists

6.1.1 Installation Checklist

Device Name:		S/N:	
Inspection person:		Date	
Test Step	**Description**	**Accept Criteria**	**Result**
Inspection after unpacking			
	Check transport crate for visual damage	No visual damage	
	Inspection of Tilt Tester	Indicator not red	
	Inspection of Shock Tester	Indicator not red	
	Inspection of Irreversible Temperature Indicator	Highest temperature < 54°	
	Visual inspection	No visual damage	
Inspection after installation			
	Check that magnet is mounted on support girder with the appropriate bolts	Torque:	
	Visual inspection for collisions with other parts	No collisions	
Remarks:			

6.1.2 Preventive Maintenance Checklist, referring to chapter 4

Device Name:		S/N:	
Inspection person:		Date	
Test Step	**Description**	**Accept Criteria**	**Result**
Visual check			
	Visual and Mechanical Inspection	Everything according to chapter 4.7.1	
Label check			
	Label for strong magnetic field	Present and visible	
	Type plate on magnet	Present and visible	
Cleaning			
	Perform cleaning	Cleaning performed	
Greasing			
	Apply anti-corrosion oil to non-painted surfaces	Anti-corrosion oil applied	
Remarks:			

6.2 Drawings

- Magnet assembly drawings 7103050653 + 7103050895