INSTRUCTION MANUAL

Ion irradiation facility *S*

Version: 1.1 25. 05. 2012

EN

Imprint

DREEBIT GmbH
Zur Wetterwarte 50
01109, Dresden
Germany

Website: http://www.dreebit.com

Content

Content

EC - Conformance Declaration

(Machine Guidelines: EG-RL 2006/42/EG)

Herewith the manufacturer

DREEBIT GmbH
Zur Wetterwarte 50, Building 301
01109, Dresden, Germany

declares, that the hereinafter described machine,

General Designation:	**Ion irradiation facility**
Function:	Production of highly charged ions
Model/Type	Ion irradiation facility *S* with Dresden EBIT
Product No.:	10003

is conform with the terms of the following guidelines:

- EMV-Guide Line (2004/108/EG)
- Machinery Directive 2006/42/EG
- Guide Line Electrical Equipment 2006/95/EG

This declaration becomes invalid if modifications are made to the product without consultation with the manufacturer.

Guidelines, harmonized standards, national standards in which have been applied:

EN ISO 12100-1, EN ISO 12100-2, EN 1012-2, EN 61010-1, EN 61326

The representative of the technical documentation:

Mike Schmidt
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Dresden, 06.11.2010

[CEO] | Dr.Ing. Frank Grossmann

Dresden, 06.11.2010

[CTO] | PD Dr. habil. Günter Zschornack

A User Instructions

A.A Use of this Instruction Manual

This important product information guide contains safety and handling, regulatory and warranty information for the Ion irradiation facility *S*.

To avoid injury and damage, read all operating instructions and safety information in this guide. If this instruction manual is lost, a replacement manual can be ordered from DREEBIT GmbH.

Please see www.dreebit.com for more detailed contact information.

A.B Warning Signs and Hazard Icons

Table 1: Overview of warning signs used in this instruction manual

	This symbol indicates a generic warning.
	This symbol indicates the presence of a high voltage hazard.
	This is the warning symbol indicating the presence of a magnetic field.
	This is a warning symbol indicating a hot surface.
	This is a warning symbol indicating an ionizing and radiation hazard.
	This is a warning symbol indicating a crushing hazard.
	This is a warning symbol indicating a heavy item.

A.C Symbols Used

Table 2: Overview of used symbols in this instruction manual

Notation	Meaning
>	You are requested to perform one action.
1. 2.	Perform these actions in the sequence described.
• -	List items

A.D Abbreviations Used

Table 3: Used abbreviations in this instruction manual

Abbreviation	Written
EBIS	Electron Beam Ion Source
EBIT	Electron Beam Ion Trap
EUV	Extreme Ultra Violet
HV	High Voltage
SHV	Safe High Voltage
UHV	Ultra High Vacuum
VUV	Vacuum Ultra Violet

A.E Structure of the Safety Notices

The following safety notices indicate the different danger levels.

Safety Notes

DANGER

DANGER indicates a hazardous situation which, if not avoided, will result in death or serious injury.

WARNING

WARNING indicates a hazardous situation which, if not avoided, could result in death or serious injury.

⚠CAUTION

CAUTION indicates a hazardous situation which, if not avoided, may result in minor or moderate injury.

NOTICE

Notice indicates a property damage message.

NOTE!
For general requirements, which must be adhered to.

B Safety Information

B.A Proper Use

The Ion irradiation facility *S* is designed for research and development applications.

Any application exceeding the bounds of these specifications is considered improper use, and can lead to serious personal injury or material damage. DREEBIT will not be held responsible for any damages resulting in such a case.

Further requirements of proper use are that you read and adhere to these operating instrcutions.

B.B General Safety Instructions

Voltage higher than 40V AC/120V DC is in all probably dangerous! Exact data depend on many factors like the path trough the body, the flow or the frequenzy. The rules set forth hereunder should always adhered before opening/working electrical machinery:

> switch off electricity

> ensure that electricity cannot be switched on again

> double check that no electrical current is flowing

> ground the circuit

> cover or otherwise isolate components that are still electrically active

Refer servicing only to qualified personnel. Further information are given in the related chapters.

Vacuum is the condition of a gas, that pressure is much less than atmospheric pressure (< 300mbar).

> Do not exposure any part of the body to Vacuum!

Ionizing Radiation is the description for parts or electromagnetic radiation, that are able to remove electrons from atoms or molecules. Ionizing radiation may cause serious injury!

> Ensure that the general rules for radiation protection are observed.

B.C Use of these Operating Instructions

This instruction manual contains the information required for the proper operation of the Ion irradiation facility *S*. The Operating Instructions are delivered with the Ion irradiation facility *S* and are an essential part of the product. They must be kept in an accessible, visible place next to the Ion irradiation facility *S*.

Product life phases

The Operating Instructions Ion irradiation facility *S* and the Maintenance Instructions describe all product life phases of the Ion irradiation facility *S*. They consist of the system conditions and applications that follow manufacturing: transport, installation, commissioning, operation, maintenance, service, storage and final disposal. Each related chapter can be found easily via the table of contents in the instruction manuals.

Supplier documentation

The delivery of the Ion irradiation facility *S* includes separate operating instructions for individual system components. They include important safety information and are essential parts of the system documentation. The safety instructions contained therein must be strictly adhered to. The information contained in the supplier documentation is required in particular for the maintenance and service of the respective components.

1

General Information

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Version: 1.1 05. 25. 2012

1 General Information

1.1 Transport

> Remove all water, power and data connections.

> The LeyboldTurboVac361 Ion irradiation facility *S* plant must be moved with a pallet truck or a forklift.
Do not lift the plant with any lifting tools!
Remember the center of mass while moving the facility

> If you move the LeyboldTurboVac361 Ion irradiation facility *S* over longer distances (e.g. removals) please contact DREEBIT for further information.

1.2 Product Description

1.2.1 assembly space

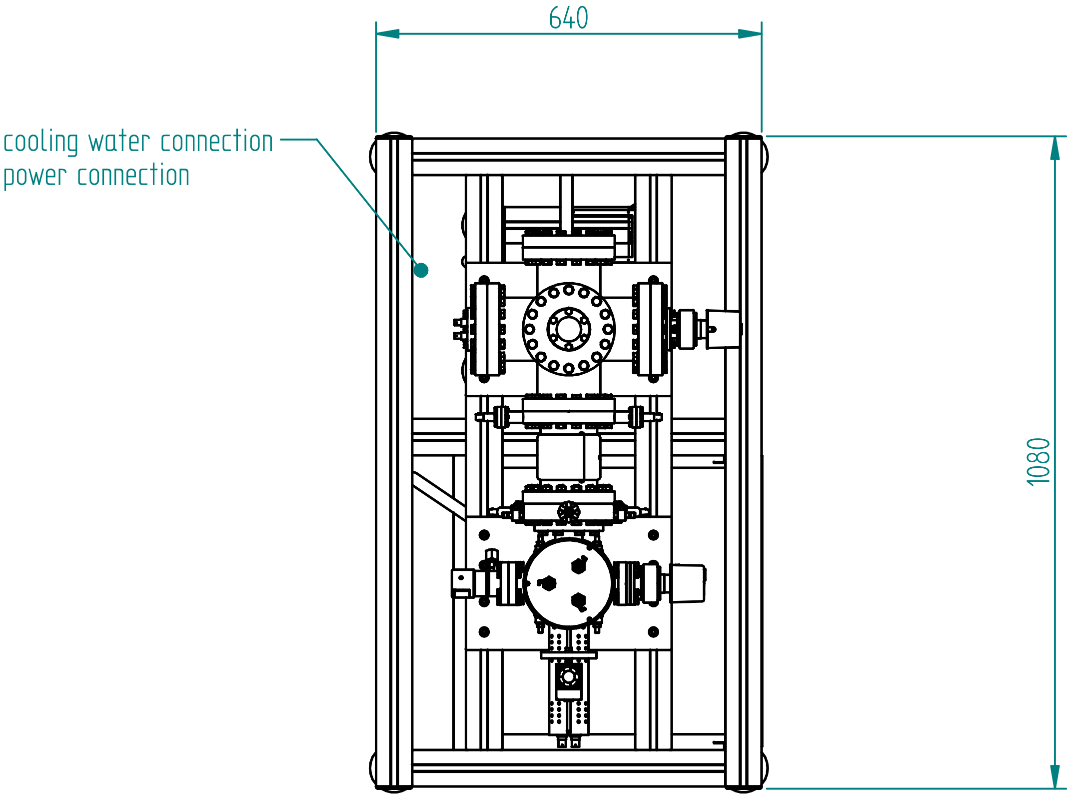

Figure 1: assembly space of the Ion irradiation facility *S*

1.3 Connections

	CAUTION
	The facility is setting up by the manufacturer. Please contact LeyboldTurboVac361 in case of any modifications. Otherwise any warranty claims, claims for defects or claims under guarantee shall be excluded.

> Connect the Mains with an 220V/ 16 A Schuko socket.

> Connect the cooling water with the local water supply.

> The installation of the components is described in the relevant parts of this instruction manual.

1.4 Device Front View of the Krakau EBIT Setup Hardware

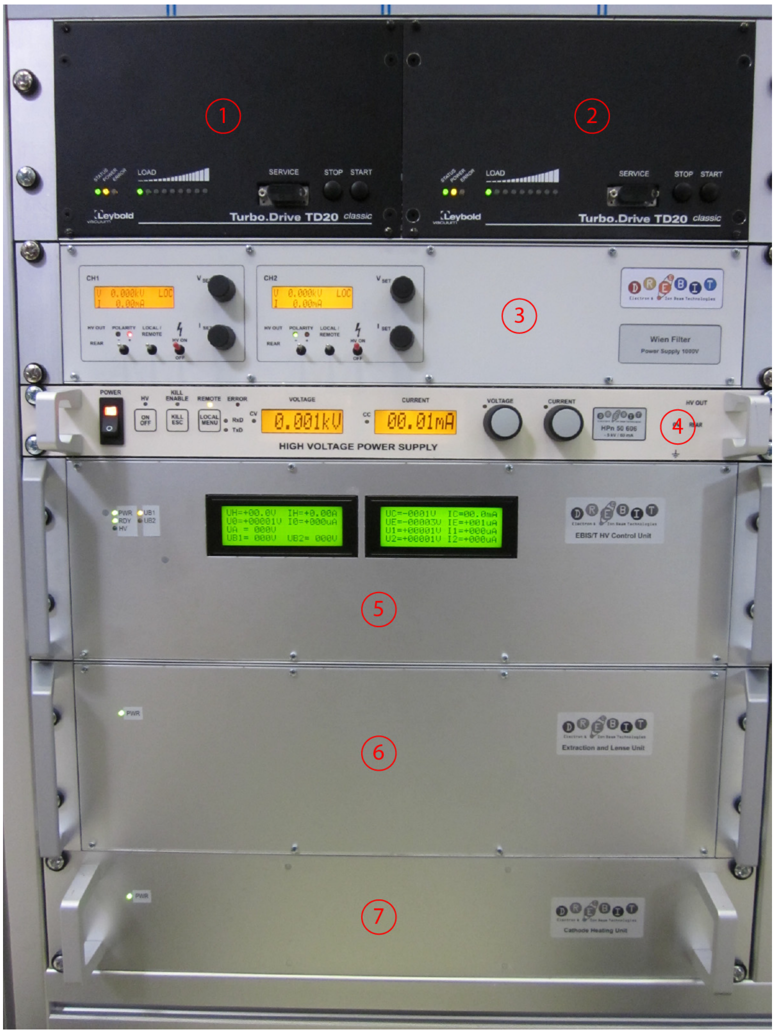

Figure 2: Front View of the Krakau EBIT facility

1	the turbo pump controller TD20 of the EBIT
2	turbo pump controller TD20 of the target chamber
3	the power supply of the two HV channels of the Wien Filter
4	the cathode potential
5	the EBIS/ EBIT HV control unit displaying all relevant EBIS/ EBIT operation parameters (drift tube potential, cathode potential, extraction potential, heating current and so on)
6	extraction and lens unit
7	cathode heating unit

1.5 Water Guard

The water guard (see figure 3) ensures the water flow trough the EBIT collector via water hoses (4 and 5) dumping the electron beam.
In order to adapt the local pressure conditions of the cooling water supply the Reed contact (3) of the water guard needs to be adjusted. Loose the screws (1 and 2) and move the Reed contact (3) back or forth until the water flow status of the software operation control panel is green. Then move it slightly further in the same direction in order to prevent shut down of the facility due to pressure fluctuations in the cooling water supply. After doing so tighten the screws (1 and 3) again.

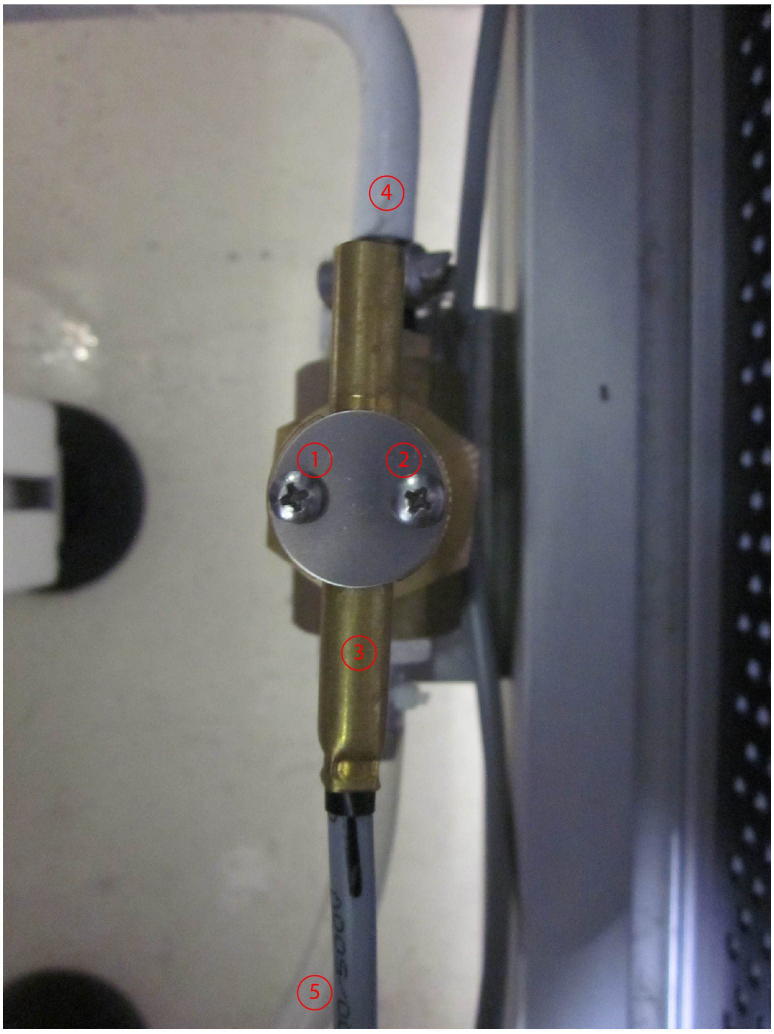

Figure 3: Water guard

1.6 Vacuum Equipment

The proper operation of the DREEBIT EBIT ion source requires very good vacuum conditions established by the turbo pumps LeyboldTurboVac361 installed below the ion source and the target chamber. The turbo pumps are connected to the roughing pump Pfeiffer HighCube80 which generates the necessary fore-vacuum

1.6.1 Commisioning

> For evacuating the facility start the roughing pump Pfeiffer HighCube80 Eco first by pressing the green status key.
> Then push the START key of the turbo pump controller TD20 of the ion source and of the target chamber.
  Check the pressure drop of the of the facility via the EBIT Control Center program on the control PC.
> The facility should go to normal operation (i.e. turbo pumps) after several minutes of pumping.

1.6.2 Venting

> For Venting the facility shut all HV-power supplies off.
> Press the STOP key on the turbo pump controller TD20 of the ion source and the target chamber.
> Then press the green status key of the roughing pump Pfeiffer HighCube80 Eco.
> Start venting by slowly opening the venting valve on the Pfeiffer HighCube80 Eco. Wait until the pressure display of the EBIT Control Center program signal environmental pressure.

1.7 Technical data

Dimensions	1080 x 1820 x 640 mm (WxHxD)	
Power consumption	220V 10A	
Cooling Water	pressure flow	~1-5 bar 1 l/min
control	PC control	

2

Wien Filter

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Version: 1.1 25. 05. 2012

2 Wien Filter

2.1 Introduction

Many applications in science as well as in industry presume charged particle beams of selected mass and charge. A compact and simple solution for this requirement is the use of a Wien Filter reducing the geometrical dimensions and costs of standard systems such as sector magnets or quadrupole filters.
The Wien Filter separates electrons of different velocities, ions of different velocities, ions of different masses, ions of different charges state, isotopes, multiple charged particles, charged molecules and charged clusters.

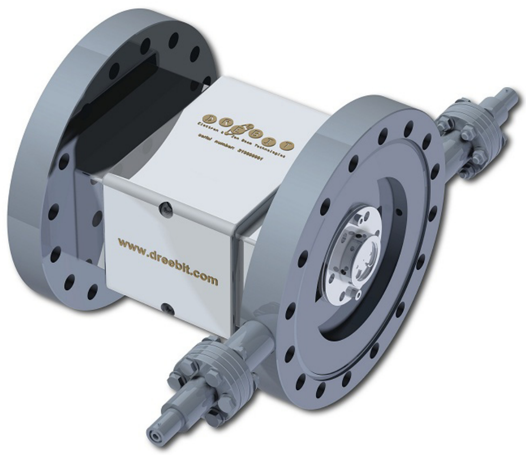

Figure 4: DREEBIT Wien Filter with DN100CF flanges

2.2 Specifications

The Wien Filter has an overall length of 150 mm and features two DN 100 CF flange ports for easy integration into beamline setups. The filter is equipped with a weak permanent magnetic yoke (0.14 Tesla) for low mass applications and a strong permanent magnetic yoke (0.52 Tesla) for broad mass and charge range applications. The electrodes of the Wien filter can be operated with up to 1 kV. Exchangeable apertures with

- 0.5 mm (resolution ≥ 80 at 5 kV beam potential and with strong magnet)
- 1.0 mm (resolution ≥ 40 at 5 kV beam potential and with strong magnet)
- 1.5 mm (resolution ≥ 20 at 5 kV beam potential and with strong magnet)

are included as well.

The smaller apertures provide a higher resolution, but at lower transmission. Hence the choice of the aperture is always a trade-off between resolution and transmission.

2.3 Scope of Delivery

- Wien Filter housing (DN100CF) with 2 SHV feedthroughs
- 2 magnetic yokes with installed permanent magnets
  140 mT (for low mass and charge range)
  520 mT (for broad mass and charge range)
- 6 apertures with 2 x 0.5 mm opening, with 2 x 1.0 mm opening and with 2 x 1.5 mm opening (1.0 mm aperture is installed by delivery)

2.4 Dimensions

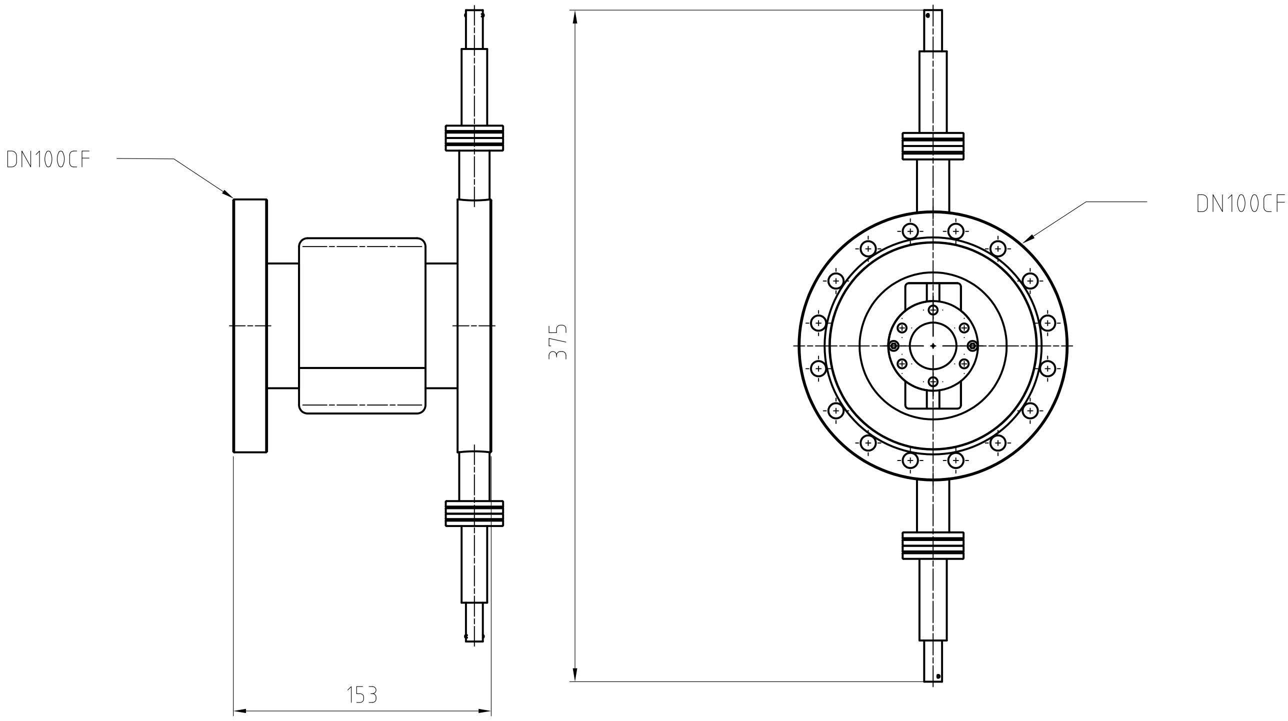

Figure 5: Wien Filter side and frontal view

2.5 Functional Principle

The Wien Filter is a very compact charged particle separator with crossed fields. Its functional principle is based on velocity separation. The charged particle species of interest with the velocity v_0 passes the orthogonal electric and magnetic fields of the Wien Filter in a straight line if the Wien condition $v_0 = E/B$ with $\vec{v} \perp \vec{E} \perp \vec{B}$ is satisfied. All other species are suppressed (see figure 6).

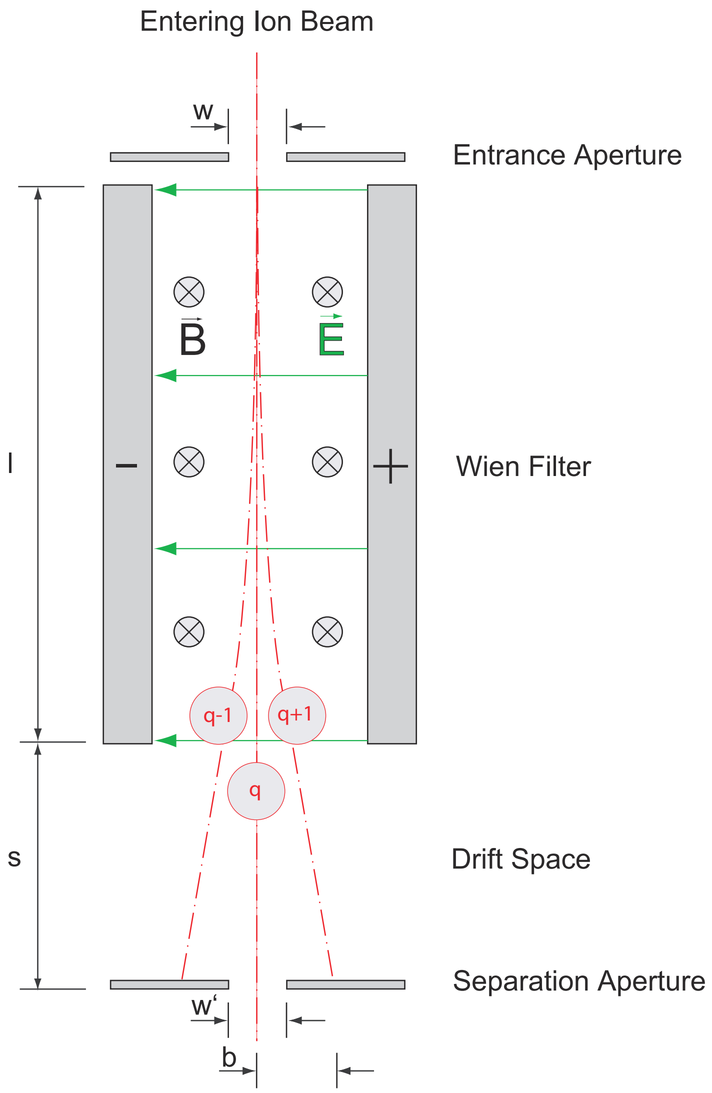

Figure 6: Wien Filter functional principle

2.5.1 Equations of Motion

Assuming the electric field $\vec{E} = E\vec{e_x}$ and the magnetic field $\vec{B} = B\vec{e_y}$, the equation of motion in component notation is

$$m\ddot{x} = \mathrm{qe}(E - B\dot{z}) \tag{1}$$

$$m\ddot{y} = 0 \tag{2}$$

$$m\ddot{z} = \mathrm{qeB}\dot{x}, \tag{3}$$

with the unit charge $e = 1.6 \cdot 10^{-19}$ C and the charge state q. The coordinates *x* and *z* describe the transversal (*x*) and longitudinal (*z*) position of the particle related to the initial ion beam line.

The explicit solution of $x(t)$, $\dot{x}(t)$ and $z(t)$, $\dot{z}(t)$ for the initial conditions $v_{x,0}=0$, $v_{y,0}=0$, and $v_{z,0}=v_0$ (the motion of the particles is perpendicular to the electric as well as to the magnetic field at $z=x=0$) is

$$x(t) = \frac{m}{qeB}\left(v_0 - \frac{E}{B}\right)\left(cos\left(\frac{qeB}{m}t\right) - 1\right), \tag{4}$$

$$\dot{x}(t) = \left(\frac{E}{B} - v_0\right)\sin\left(\frac{qeB}{m}t\right), \tag{5}$$

$$z(t) = \frac{m}{\mathrm{qeB}}\left(v_0 - \frac{E}{B}\right)\sin\left(\frac{qeB}{m}t\right) + \frac{E}{B}t, \tag{6}$$

$$\dot{z}(t) = \left(v_0 - \frac{E}{B}\right)\cos\left(\frac{qeB}{m}t\right) + \frac{E}{B}. \tag{7}$$

The special case $v_0=E/B$ is called the Wien condition and leads to a linear and steady motion of the charged particle along the z-axis with

$$z(t) = \frac{E}{B}t = v_0 t. \tag{8}$$

2.5.2 Resolution

Provided that the transversal deviation of ions traversing the Wien Filter of the length l is small compared to l ($v_0 \approx E/B$) first term of equation 6 can be omitted. Hence the time-dependence of $z(t)$ is described by equation 8. By eliminating the parameter *t* in equation 4 with equation 8 the trajectory $x(z)$ inside the filter is approximated by

$$x(z) = \frac{m}{qeB}\left(v_0 - \frac{E}{B}\right)\left(\cos\left(\left(\frac{qeB^2 z}{mE}\right) - 1\right)\right). \tag{9}$$

In order to improve the resolution of the filter a downstream drift space (approximately field-free) is added amplifying the transversal deviation of the particle. With equation 9 an approximate expression for the total transversal deviation of the Wien Filter including drift space is given:

$$x(l+s) = b = x(l) + s\frac{dx}{\mathrm{dz}}(l)$$

$$x(l+s) = \frac{m}{qeB}\left(v_0 - \frac{E}{B}\right)\left(\cos\left(\frac{qeB^2 l}{mE}\right) - 1\right) + s\left(1 - \frac{B}{E}v_0\right)\sin\frac{qeB^2 l}{mE}\Big) \tag{10}$$

The relation between the deviation and the parameters m and p of the particle as described in equation 10 is used for the determination of the resolution. Hence the minimum distinguishable distance between two neighboring charge states or masses

$$\frac{q}{\Delta q} = \frac{r_z}{2b}\left(\cos\frac{l}{r_z} - \frac{s}{r_z}\sin\frac{l}{r_z} - 1\right). \tag{11}$$

$$\frac{m}{\Delta m} = \frac{r_z}{2b}\left(1 + \frac{s}{r_z}\sin\frac{l}{r_z} - \cos\frac{l}{r_z}\right). \tag{12}$$

at the end of the drift space defines there solution of the filter provided that two neighboring charge states or masses are separated by at least the full width half maximum of the ion beam entering the Wien Filter. With the cyclotron radius r_z at a certain charge state Q

$$r_z = \frac{v_0(Q)m}{QeB} = \frac{\sqrt{2QeVm}}{QeB} \tag{13}$$

and the ion beam potential V .

2.5.3 Mass and Charge Range

The mass and charge range of the filter can be approximated by

$$m_{\mathrm{range}} = \mathbf{2}\ \mathrm{qeV}\left(\frac{B}{E}\right)^{\mathbf{2}} \tag{14}$$

and

$$q_{\mathrm{range}} = \frac{m}{\mathbf{2}\ \mathrm{eV}}\left(\frac{E}{B}\right)^{\mathbf{2}}. \tag{15}$$

> **NOTE!**
> **Neither mass/ charge state resolution nor transmission are constant over the mass, charge state and energy range.**

2.6 Installation

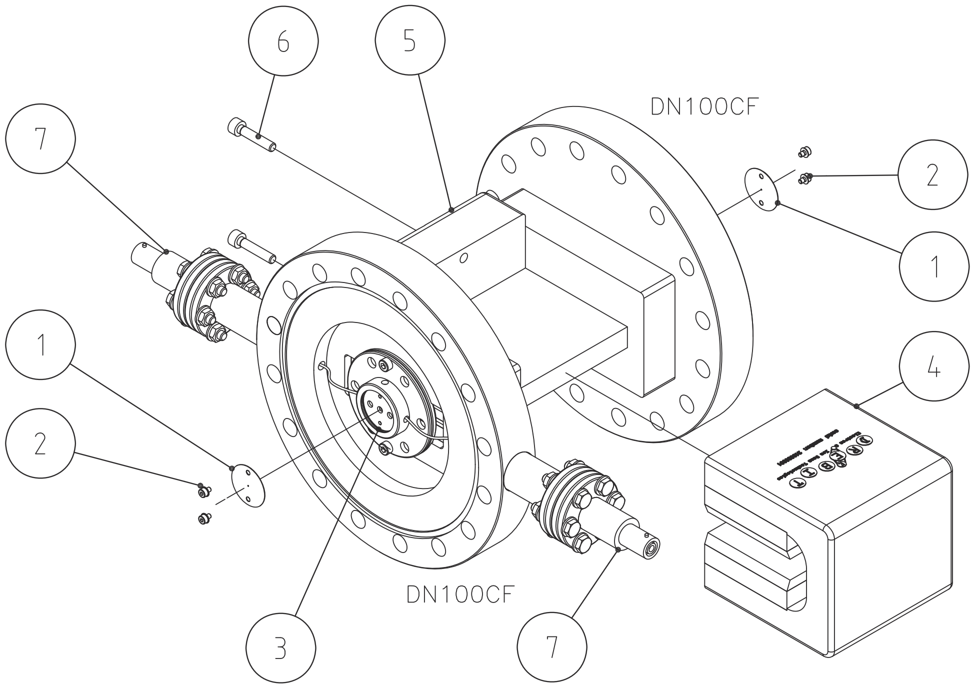

Figure 7: Exploded view of the Wien Filter assembly

The Wien Filter assembly (see figure 7) features two DN100CF flanges and can be easily connected to an existing beamline setup. The mounting direction of the system is arbitrary. The Wien Filter electrodes are connected via SHV feedthroughs (item 7 in figure 7) and the suitable HV cables with the HV power supply.

2.6.1 Installation and Exchange of the Apertures

In dependence on your needs of resolution and transmission you have the installation option of three different sizes of apertures (1.5 mm, 1.0 mm, 0.5 mm). For installation and exchange of the apertures at entrance and exit of the filter please proceed in the following way:

1. Remove the screws (item 2 in figure 7) from the aperture collet (item 3 in figure 7)
2. Gently remove the installed aperture plate from the aperture collet (item 1)
3. Place the new aperture plate in the aperture collet and fix it with the screws
4. Proceed with the 2nd aperture on the other side in the same way

2.6.2 Installation of the Housing

Mount the clean Wien Filter housing (item 5 in figure 7) including installed apertures onto the designated DN100CF flanges of your beamline or ion source setup. The filter flange with the two SHV feedthroughs can be oriented downstream as well as upstream of your beamline or ion source setup. The orientation of the Wien Filter housing in space is arbitrary.

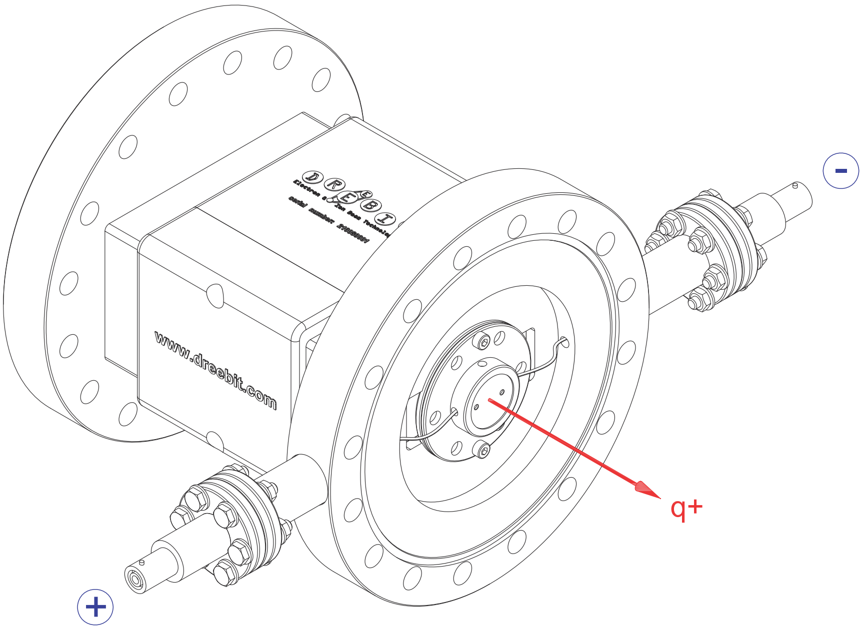

Figure 8: Configuration of orientation and polarity assignment of the Wien Filter assembly. The red arrow assigns the direction of motion of the positively charged particles

2.6.3 Installation of the Magnetic Yoke

Please install the magnetic yoke (item 4 in figure 7) with the orientation as shown in figure 7. The DREEBIT logo on the iron yoke as well as the DREEBIT internet address on the Wien Filter housing must be legible from one side. Use the two M4x20 Allen screws (item 6 in figure 7) to fix the magnetic yoke onto the filter housing.

2.6.4 Polarity of the Filter Electrodes

The polarity of the Wien Filter electrodes is dependent on the orientation of the filter as well as on the direction and on the charge of the traversing particles. A possible configuration with the polarity assignment of the filter electrodes is shown in figure 7. The direction of magnetization of the magnetic yoke is shown in figure 9. If one of the mentioned parameters changes (direction, charge, filter orientation) the polarity needs to be changed. The filter electrodes are connected to the high voltage power supply via the SHV feedthroughs (item 7 in figure 7).

> **NOTE!**
> **The voltage should always be supplied symmetrically to the electrodes (|+U|=|-U|) in order to reduce fringe field effects.**

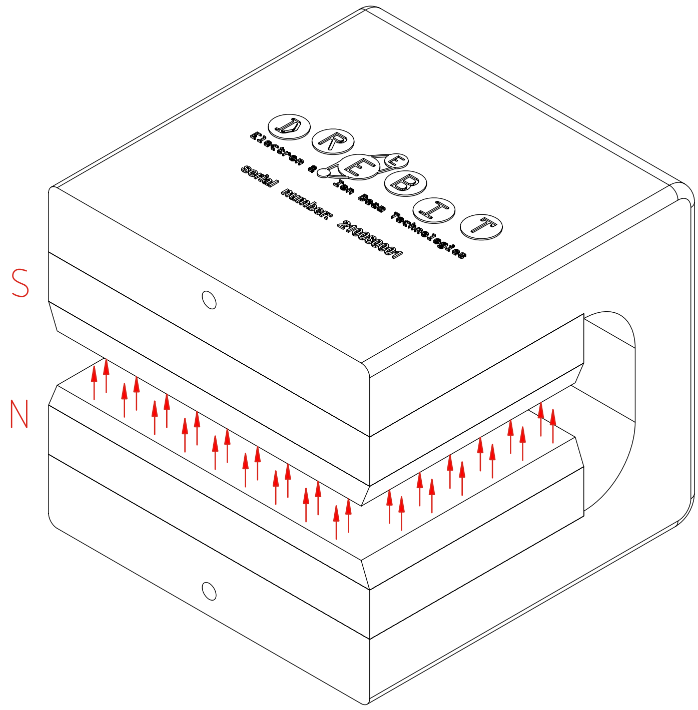

Figure 9: Direction of magnetization of the magnetic yoke

2.6.5 Bake Out

After evacuating the Wien Filter assembly you can start baking out with the following procedure

1. Remove the magnetic yoke.
2. Disconnect the high voltage cables from the SHV feedthroughs of the Wien filter.
3. Start baking out but do not exceed 100 °C!
4. After cooling down install the magnetic yoke and connect the high voltage cables to the SHV feedthroughs.

2.7 Operation of the Filter

1. First maximize the passing integral non-separated charged particle beam downstream of the Wien Filter with unmounted magnetic yoke and grounded filter electrodes (max. transmission).
2. Install the magnetic yoke and run an overview spectrum by ramping the voltage of the Wien Filter electrodes stepwise up or down. The step size should be between 0.1 V and 0.5 V. Smaller step size means longer measurement time but better resolution (dependent on the speed of the used power supply). Check the spectrum (beam intensity over Wien Filter voltage) and identify the species region of interest.
3. Set the voltage of the Wien Filter electrodes to the region of interest (e.g. a certain charge state of an element) and optimize the focusing at this working point.

For the highest charge states the optimization must be done several times starting from lower charge states to higher charge states.

2.8 Reference Data

The figure 10 shows a typical Wien Filter spectrum of the charge state distribution of a xenon ion beam extracted from a Dresden EBIS. The used Wien Filter aperture for this measurement was 1 mm. A so called overview spectrum can be obtained (see section operation of the filter) by ramping the voltage of the Wien Filter electrode stepwise up or down. For each voltage step the ion beam intensity measured downstream of the Wien Filter is logged. With this information the intensity of the charge and mass separated ion beam can be plotted over the Wien Filter voltage (see figure 10).

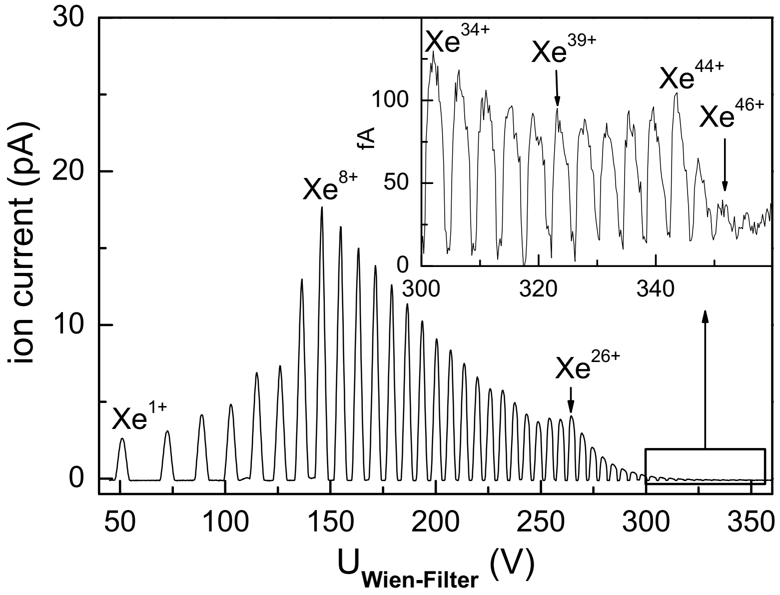

Figure 10: Charge state distribution of xenon extracted from a Dresden EBIS. This spectrum was measured with a 1 mm Wien Filter aperture (A spectrum of a Dresden EBIT is shifted to a lower charge state.)

3

Dresden EBIT

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Version: 1.1 05. 25. 2012

3 Dresden EBIT

3.1 Functional Principle

The Dresden EBIT (EBIT: Electron Beam Ion Trap) is a compact ion source working at room temperature and producing highly charged ions. The principle of operation is based on the electron impact ionization of i.g. primarily neutral atoms in a highly dense electron beam.

The electron beam emitted from the high current cathode is guided through three drift tube sections forming the ion trap. The first drift tube is the anode. After passing the drift tubes the electron beam finally ends in a water cooled collector.

The electron beam is compressed by an axially symmetric magnetic field up to the necessary electron beam density for producing highly charged ions.

The magnetic field is created and formed by two SmCo permanent magnet rings and various soft iron components.

The electron beam works as ionization medium but also, due to its negative space charge potential, as radial trapping potential for the ions.

The axial trapping of the ions is generated by additional potentials on the centre and the third drift tube section (see figure 11).

The extraction of the ions is realized by short-time lowering of the voltage offset of the third drift tube section and biasing the extraction electrode (L1) on a negative voltage of several kV.

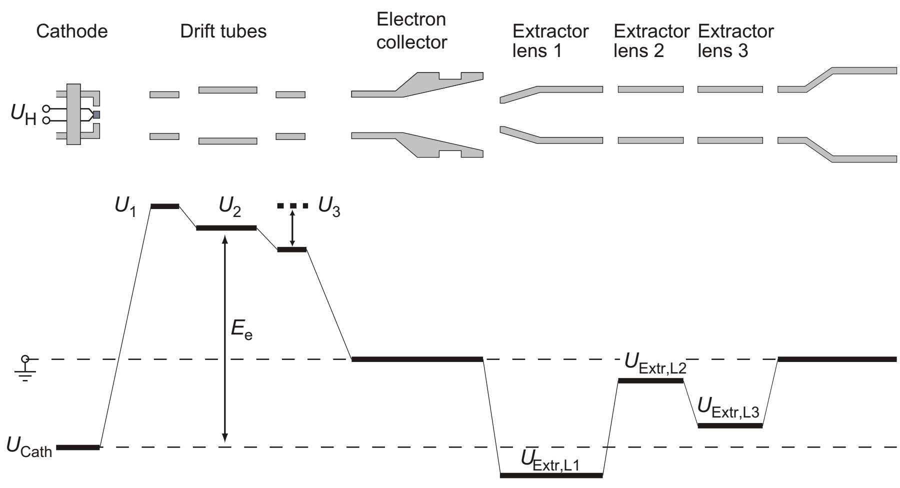

Figure 11: Scheme of the potentials in the Dresden EBIT

The kinetic electron energy, that is the ionization energy, is determined by the sum of both the cathode potential and the potential of the centre drift tube (see figure 11 on page 33) but is in addition reduced by the radial trap potential which results from the negative space charge potential of the electron beam

$$E_e = e[|U_{\mathrm{Cath}}| + |U_2| + V_e(r)]. \quad (1)$$

The ion confinement time can be used to adjust the ionization factor and therefore the mean charge state. The Dresden EBIT can be used as a source for highly charged ions or as a source of characteristic X-rays emitted by the highly charged ions. Furthermore VUV- and EUV-rays but also visible light can be produced. Depending on the conditions of the application the operating parameters of the source must be adapted. The necessary vacuum conditions of down to 10^{-10} mbar can be realized with standard UHV equipment and baking (without permanent magnet rings!). The working gas is admitted using a leakage gas valve.

3.2 Dimensions

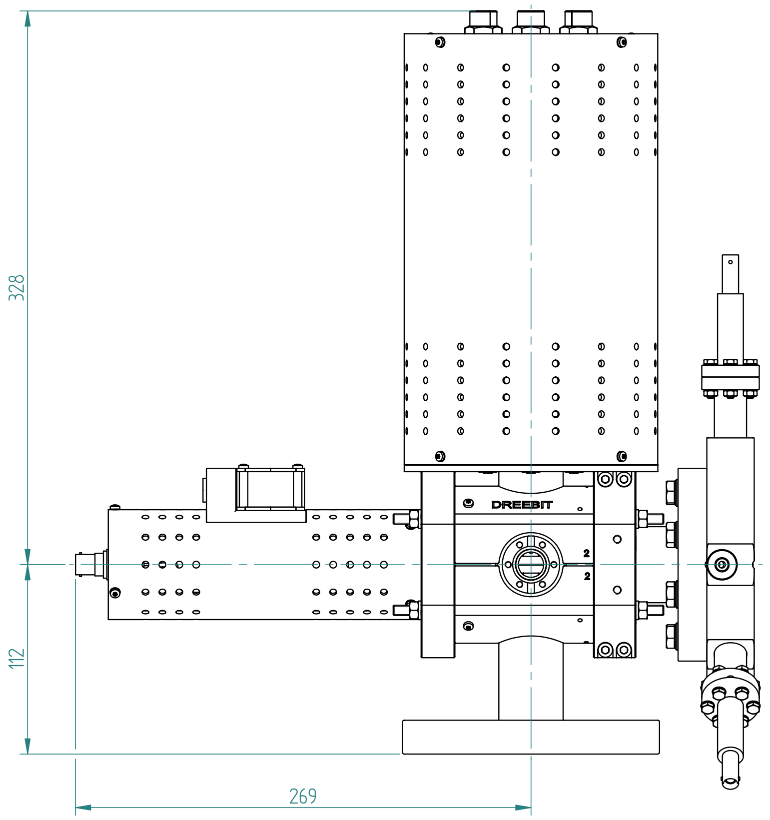

Figure 12: Dimensions of the EBIT (with protection caps)

Dimensions

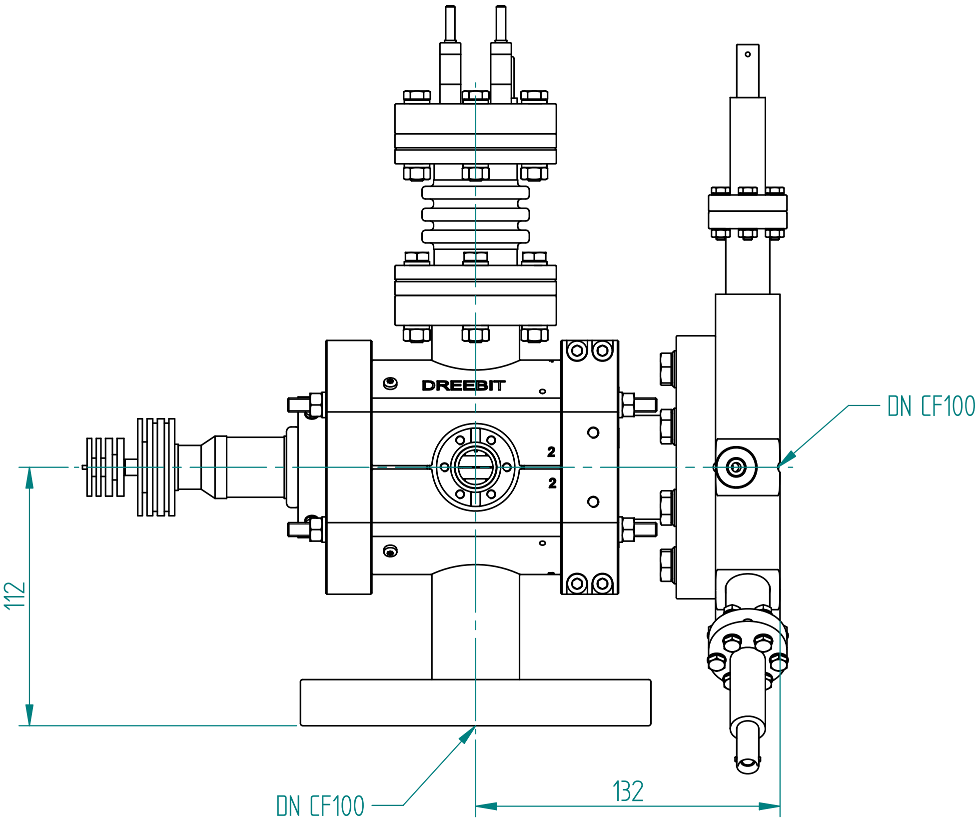

Figure 13: Dimensions of the EBIT (without protection caps)

3.3 Operation Instruction

The overview below summarizes the necessary steps to put the Dresden EBIT into operation. The sections after the overview should be read, too.

1. Assembling the EBIT body
2. Pumping and baking of the EBIT
3. Assembling the magnetic system
4. Connecting the coolant system and the safety control
5. Assembling the electrical connections
6. Installation of the high voltage shielding
7. Outgasing of the cathode
8. Switching on the high voltages
9. Switching on and controlling the cathode heating
10. Activating and adjusting the ion trap

3.4 Assembly of the Dresden EBIT3

3.4.1 Assembly of the Body

In principle the Dresden EBIT can be operated in any geometric position.

The EBIT will be delivered assembled. In the following section the assembling of the basic components (see figure 14) of the EBIT is described. This enables the operator to do simple maintenance and manipulation on the source on his own. The assembling of the magnetic system is described in section 3.5.

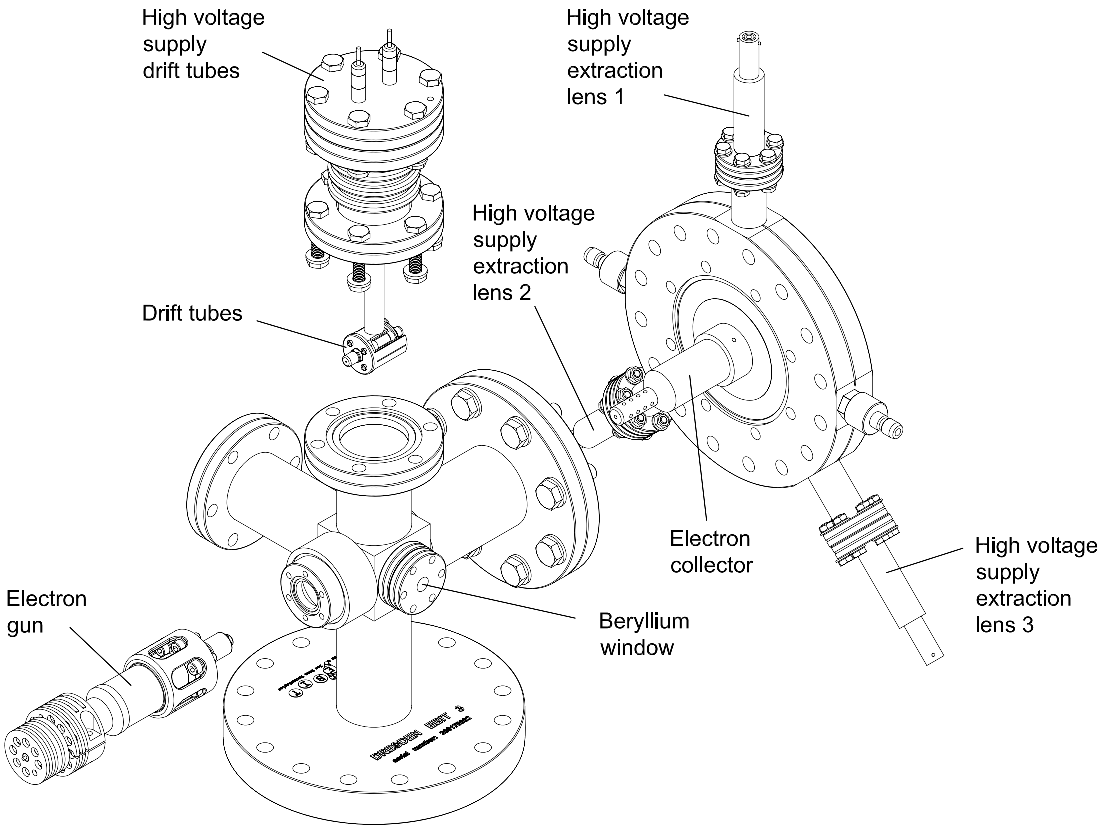

Figure 14: Components of the Dresden EBIT (without magnetic system)

Be cautious assembling the insulator and the beryllium window. The connection of the source to a beamline should be realized with a bellow to avoid mechanical stress.

Precondition for a simple and effective operation of the ion trap is an exact alignment of all components along the z-axis (beam axis).

3.4.2 Assembly of the Electron Gun

The pre-assembled electron gun must be installed with installed drift tube sections and disassembled or open extraction system. At least one more flange needs to be open to illuminate the interior of the source.

At first the electron gun is loosely screwed on the source body (not too tight!) using a CF16 copper seal. Due to the rotational symmetry the mounting orientation of the electron gun is not relevant. After that the electron gun needs to be positioned onto the z-axis by looking through the open extraction system into the source and correcting the position of the gun by tightening one of the screws of the CF16 flange.

Once the gun is fixed and aligned the screws of the CF16 flange should not be turned again! In the event of a cathode failure contact the manufacturer for replacement!

3.4.3 Installation of the Collector and the Extraction System

Right on the source body the collector is screwed. The extraction system consists of four electrodes. The longer one is the extraction electrode (L1) and the first to be installed. The second (L2) and third electrode (L3) are smaller then the first. The last electrode is screwed directly on the housing of the extraction system and therefore grounded by default. The electrodes are isolated to each other with the insulator plates. During assembling the centre position of all components needs to be controlled by looking through the open end.

The threads of the coolant system should be vertically straighten (when source operated horizontally). The tap connection is installed after assembling the magnetic system.

3.4.4 Installation of the Gas Admission System

The admission of the to be ionized medium is realized by an UHV full metal leak valve with CF40 flange. The gas capillar is screwed to the vacuum side of the valve. The leak valve can be connected either to the source body or to the diagnostics box. The gas capillar inside the source should end about 1 cm before the drift tubes (high voltage potential on the drift tubes!).

The load of the trap with metal ions by volatile metal-organic compounds can be realized by the gas admission. Information about this topic and about compounds that have been already used can be found at www.dreebit.com. An injection set for metal-organic compounds can be ordered as additional equipment.

⚠WARNING

Although halogen compounds (fluorine, chlorine, bromine and iodine compounds) provide various volatile substances they should be avoided to save the cathode due to chemical reaction with the halogens.

3.4.5 Connection to a Beamline

To avoid mechanical stress during installation of the magnetic system a bellow should be flanged on the extraction system of the EBIT if it is connected to a beamline.

3.5 Magnetic System

The components of the magnetic system are shown in figure 15. It consists of a permanent magnet ring (1), two permanent magnet half rings (2), a soft iron sleeve (3), and four soft iron quarter shells (4).

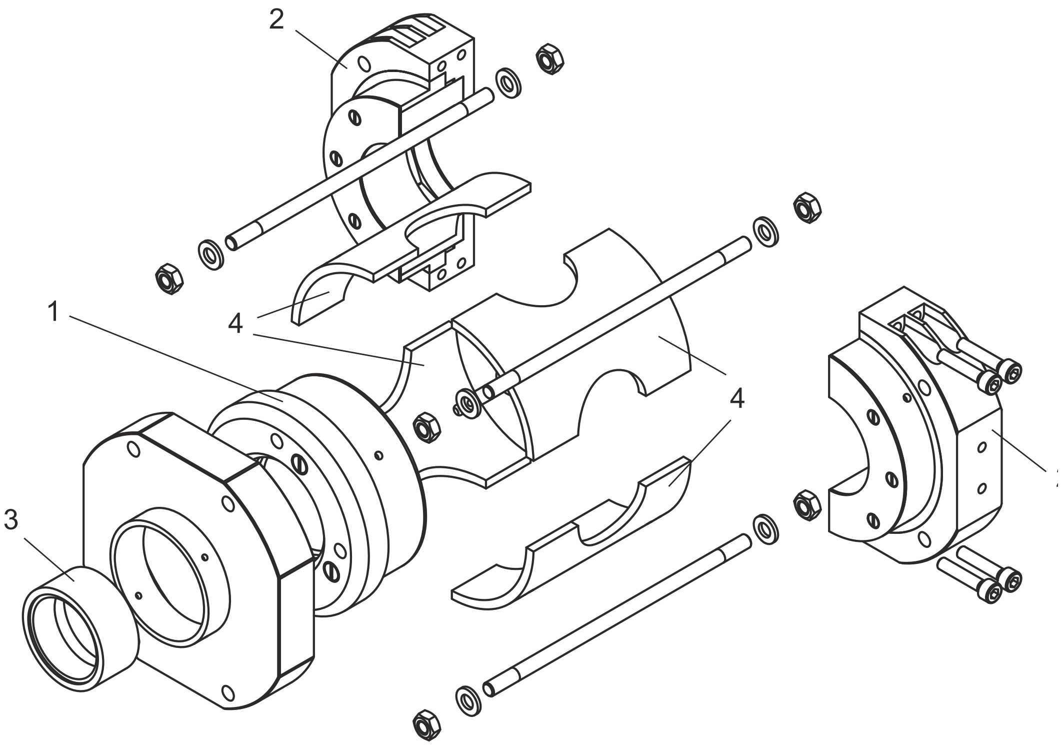

Figure 15: Components of the magnetic system of the Dresden EBIT

3.5.1 Installation of the Magnetic System

For installation first slid the soft iron sleeve (3) over the electron gun and screw until block.

First install the magnetic half ring with the inscription "collector". Therefore carefully approach the half magnet to the body where it is hold by the soft iron ring and turn the half magnet clockwise by half a turn as pictured in figure 17.

Then install the second half magnet in the same way (see figure 18 on page 43). Fix both half rings by the four screws so that both half magnets completely surround the soft iron ring.

Thereafter the four soft iron quarter shells (4) are installed around the source body using the shell installation ring (5) as pictured in figure 19.

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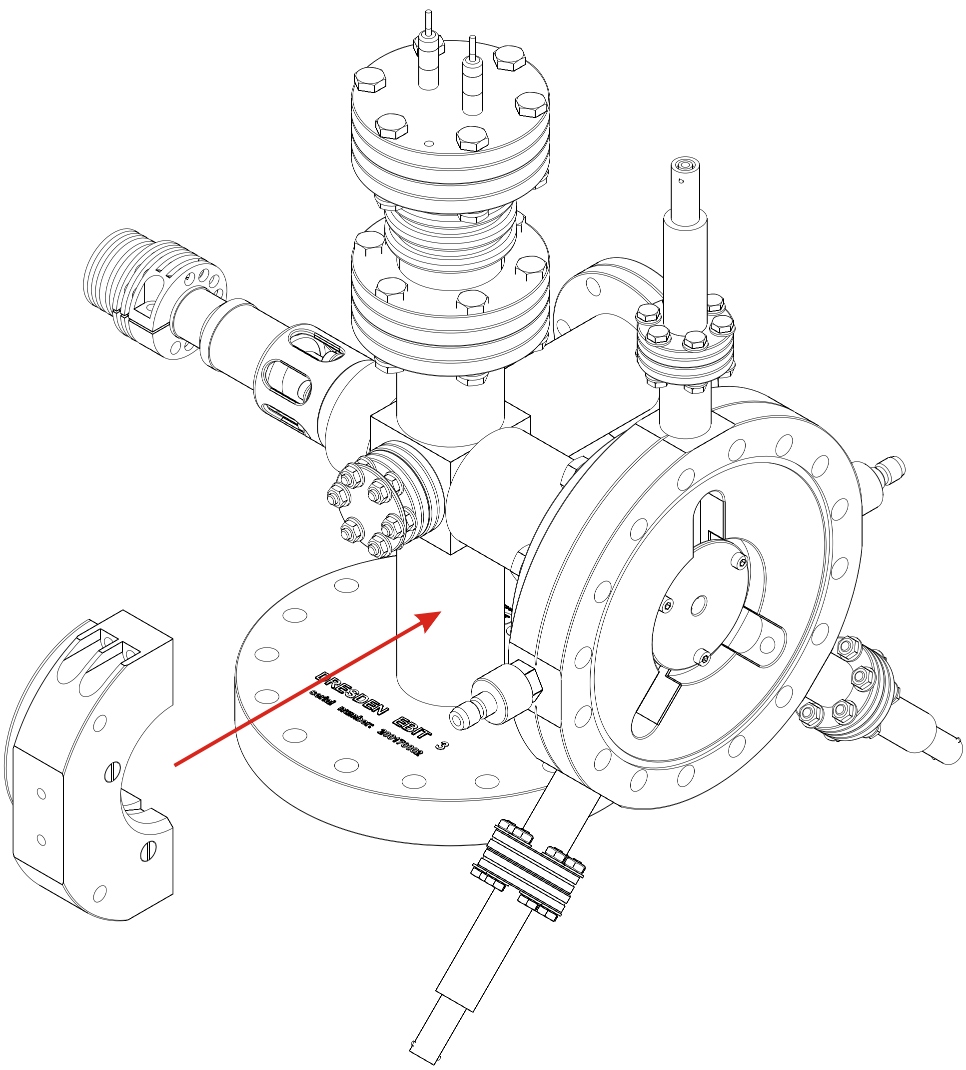

Figure 16: Installation of the first half magnet

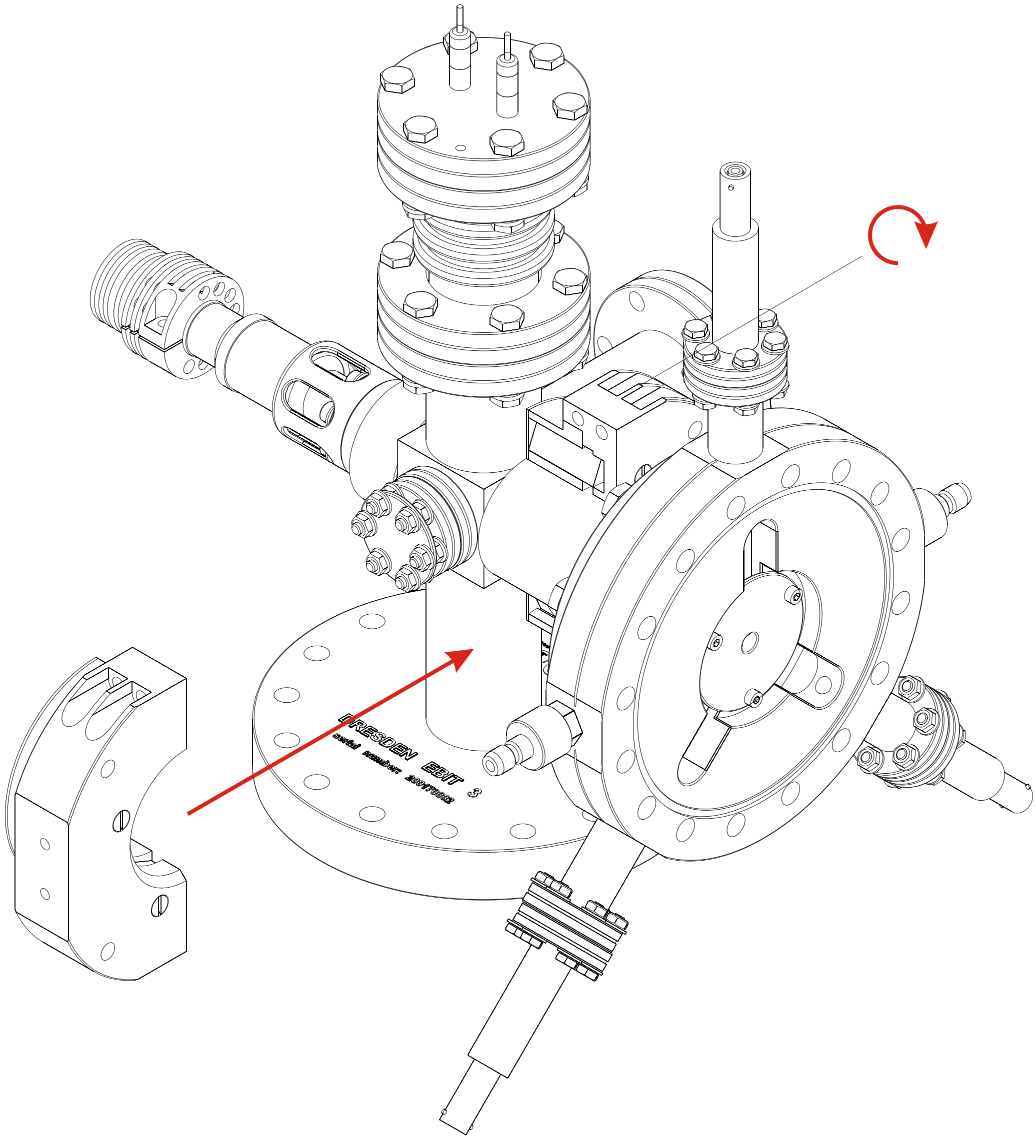

Figure 17: Installation of the second half magnet

Magnetic System

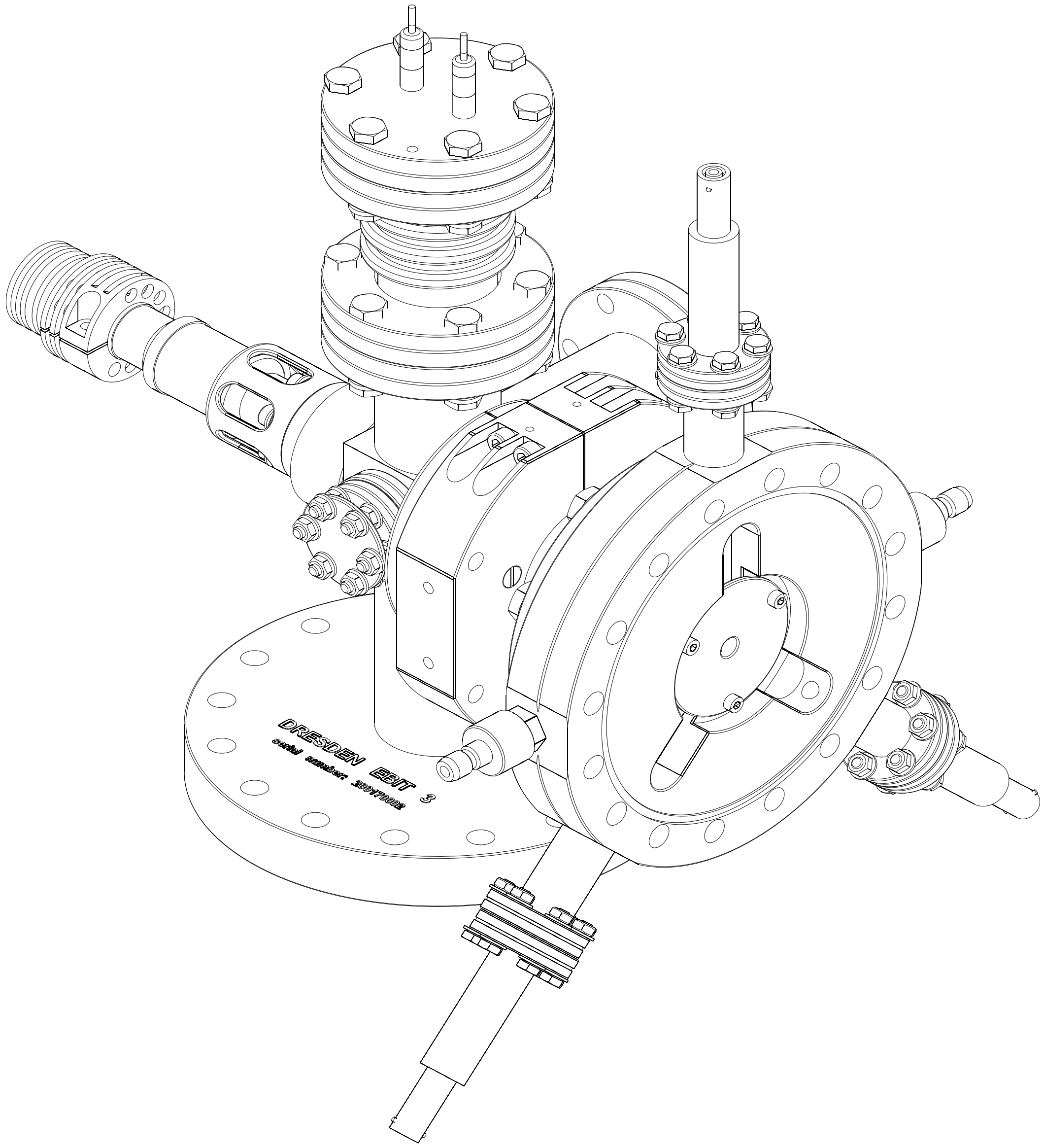

Figure 18: EBIT with both half magnets

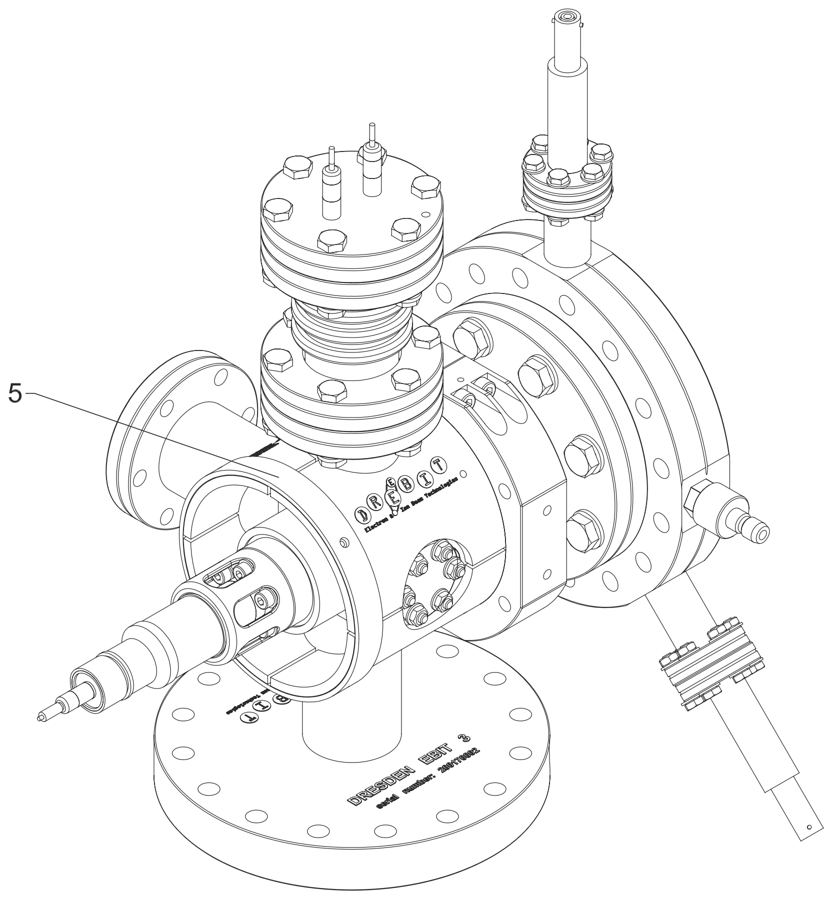

Figure 19: Installation of the quarter iron shells

Please make sure that the shells are fixed at the installation ring but that the screws (M3×6) do not extend into the interiour of the shells.

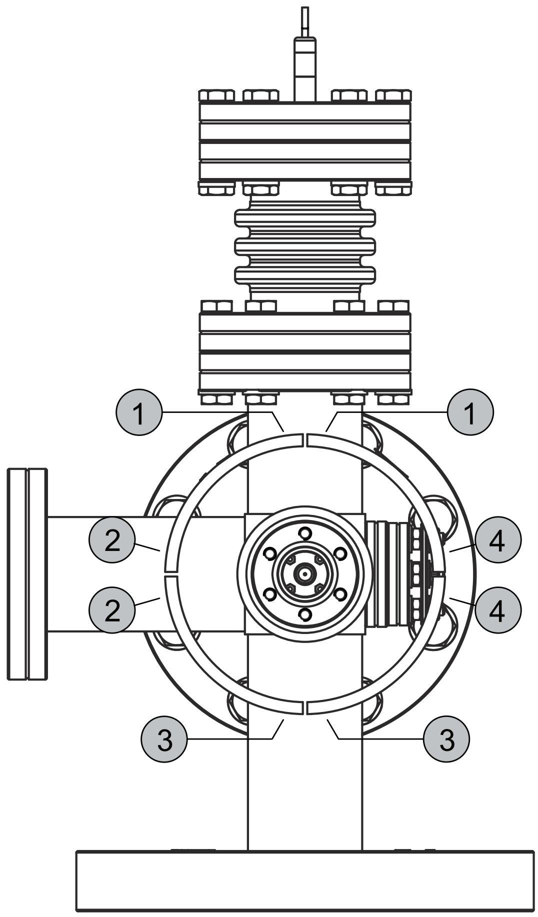

Figure 20: Installation position of the iron shells

The installation position of the shells is shown in figure 20. Equal numbers printed on the shells (1 to 4) need to be positioned side by side, pointing towards the extraction.

Then the magnet ring (1) can be slid on. therefore the magnet installation sleeve (6) is put on the screwed-on iron sleeves (see figure 21 on page 46), followed by the magnet ring carefully moved over the electron gun. A couple of millimeters before the iron quarter shells the magnetic field becomes so strong that it rapidly pulls the magnet towards the shells. Push it underneath the shells by turning it slowly. If necessary lift up the shells with a blunt tool. Then the magnet ring can be pushed against the source body (see figure 22 on page 46).

After the magnet ring is installed the magnets have to be fixed with the installation plate (8) which is pushed over the magnet ring. The magnets are then fixed by four threaded rods as pictured in figure 23.

3.5.2 Dismounting of the Magnets

First disconnect the high voltage covers (see figure 24 on page 49), the electrical connections and the coolant connection. Then start dismounting the magnets.

Dismounting has to be done in reversed order.

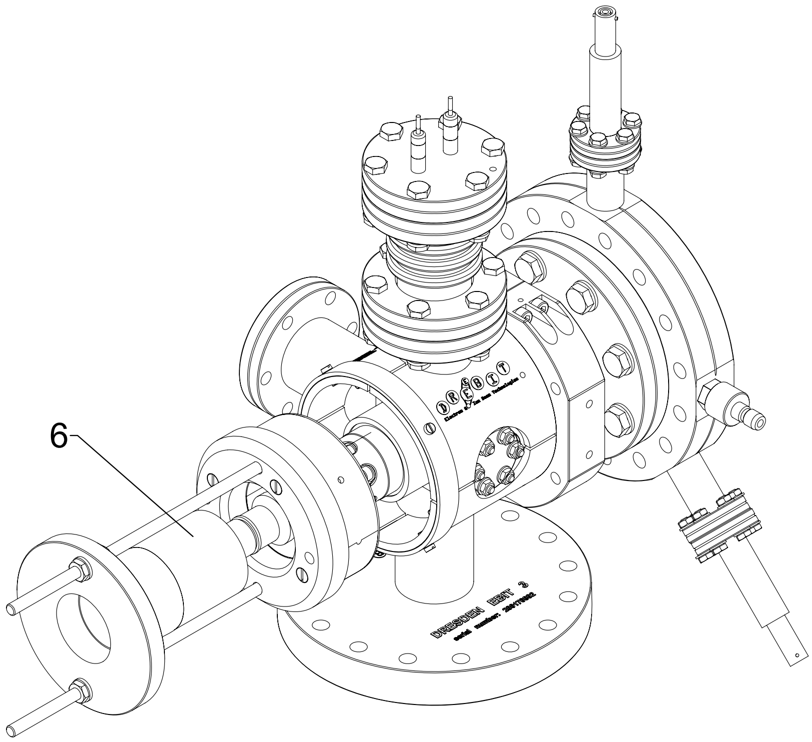

Figure 21: Installation of the second half magnet

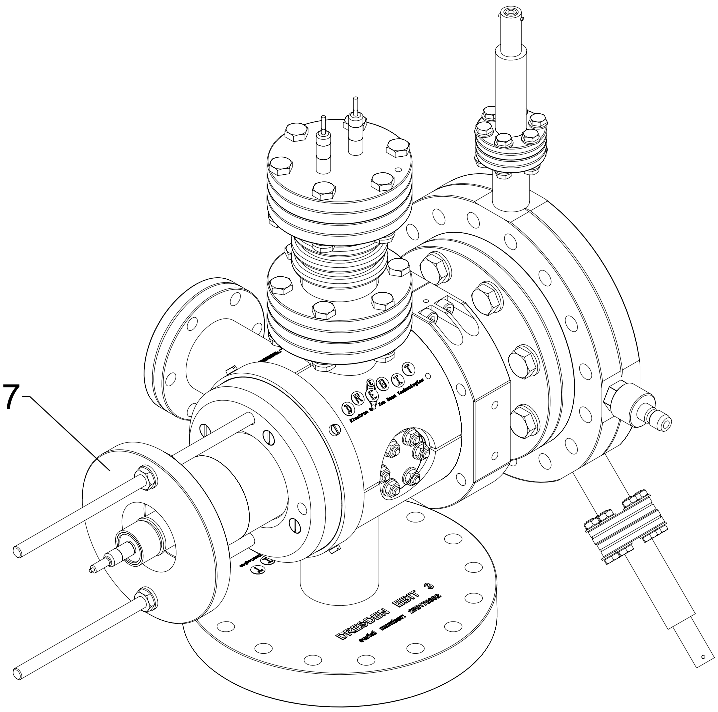

Figure 22: Installation of the second half magnet

First remove the threaded rods which fix the magnet rings. Next remove the installation plate from the magnet ring and slip the shell installation ring (5) over the iron quarter shells and fix them by screws.

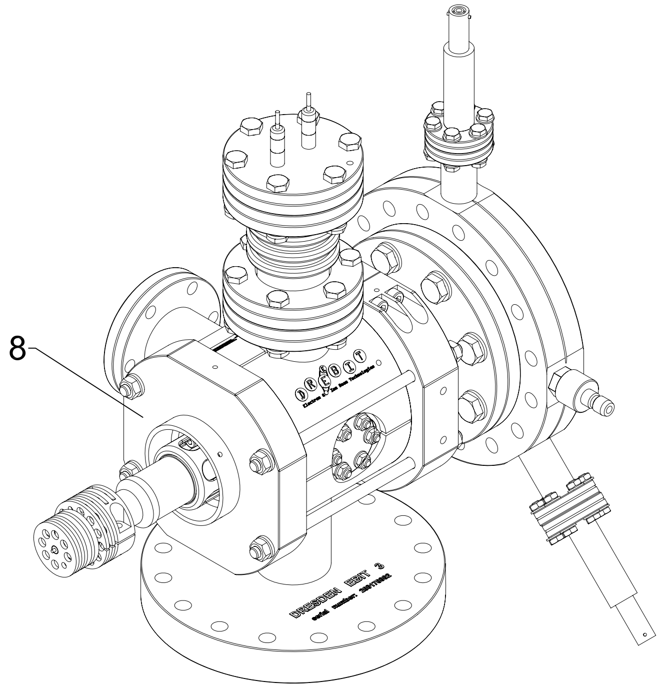

Figure 23: Dresden EBIT with completely installed magnetic system

Now pull the magnet ring from the source body by using the dismounting tools. For that purpose put the magnet installation sleeve (6) onto the inner iron ring. Then put the mounting disc (7) with the threaded rods onto the installation sleeve screwing the threaded rods into the magnet ring and fixing them by nuts (M6, wrench size 10). After that the nuts on the threaded rods need to be tightened until the mounting disc is fixed on the installation sleeve.

Now the nuts on the threaded rods are alternately tightened. Make sure that the inclination of the magnet does not become to big to protect the insulator. It is recommended to use non-magnetisable wrenches. In so doing the magnet ring is pulled over the source body out of the iron quarter shells (4) until it reaches over the iron sleeve. Then it can be removed by hand.

Thereafter dismount the iron quarter shells (4) from the two half magnets. Then remove the screws that hold the two half magnets. Remove the first half magnet, then turn the second half ring and remove it the same way. Finally remove the soft irons sleeve (3).

NOTICE
The magnets have to be stored separately, cool and not in the vicinity of magnetic materials!

3.6 Cooling Water Connection

After assembling the magnet system the coolant connection can be installed. For this purpose the lock nipples of the snap closing are screwed in the thread holes (G1/8-thread) of the CF100-extraction flange. The self-sealing-coupling with hose nozzle (for hoses with inner diameter 6 mm) can be slipped on the thread adapter. It is recommended to seal the thread by Teflon band.

The coolant supply should be plugged in from below to release air which might be still inside the water hose.

Make sure that a flow controller in the coolant circulation switches off the cathode heating power supply in case of a coolant flow interruption. If the coolant flow interruption is over the cathode heating power supply should remain switched-off to avoid an abrupt full heating of the cathode.

The recommended water flow should be higher than 1 liter per minute, which is sufficient for cooling the collector.

An appropriate safety switching is realized by the EBIT Control System.

3.7 Electrical Connection

The EBIT with completely installed high voltage protection is shown in figure 24. The protection consists of two aluminium sleeves, where the high voltage cables are plugged in.

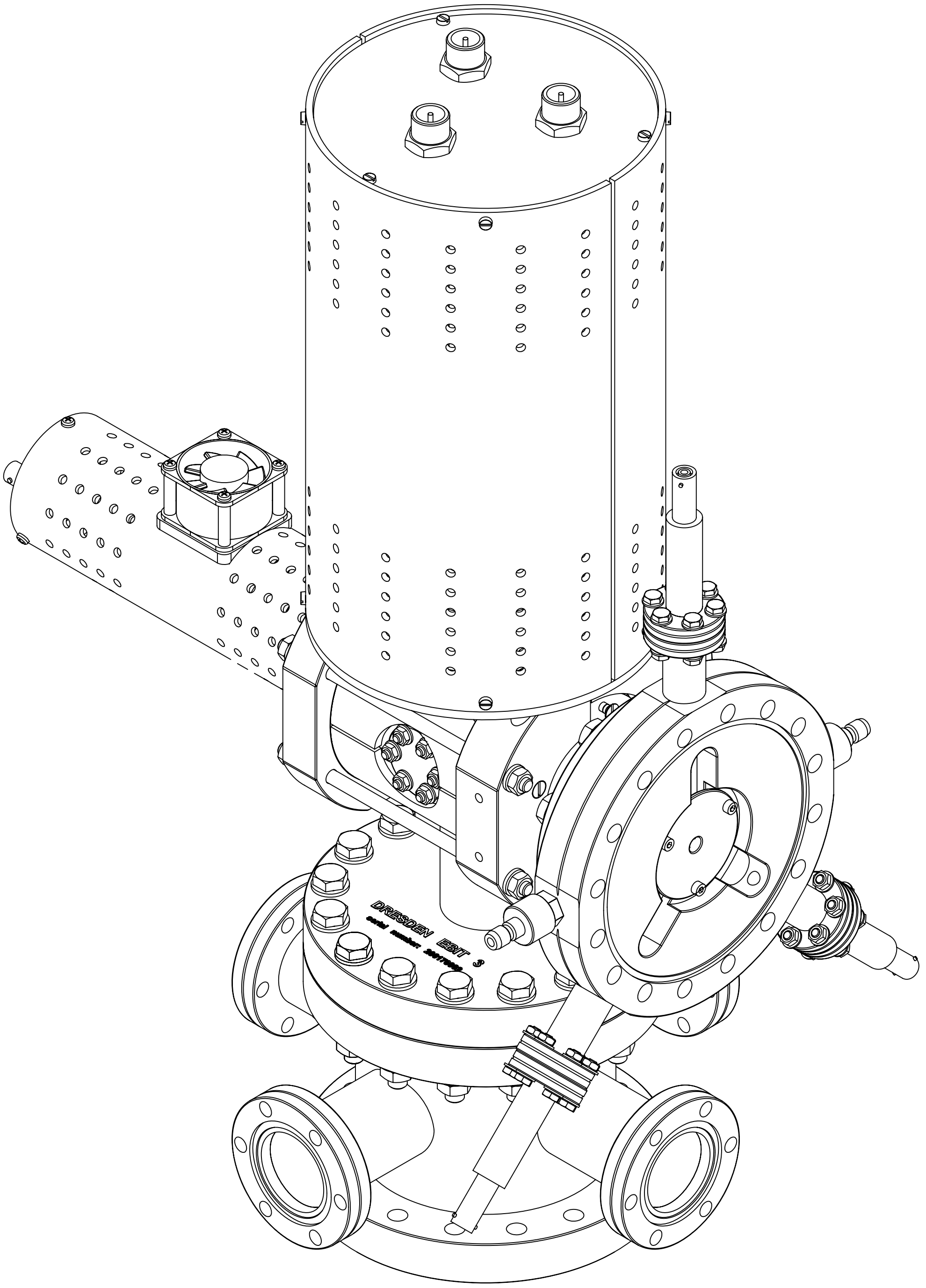

Figure 24: The Dresden EBIT with completely installed high voltage protection

3.7.1 Electrical Connection of the Drift Tubes

To install the high voltage protection of the electrical connection of the drift tubes (see figure 25) do the following: put the bottom of the protection sleeve (9) onto the CF40 flange below the insulator and fix it with the screws on to the magnet rings. Then screw the three supporting bars (10) in the bottom, put the protection sleeve cover (11) with the high voltage sockets on them and fix the cover with the M3-screws.

As a next step connect the high voltage sockets with the electrical feedthroughs of the drift tubes. For that purpose screw the plug connector in the upper CF40 flange and plug the 4 mm contact sleeve which is connected with the high voltage socket (high voltage U_0) in it.

Screw the connecting pins on the other both electrical feedthroughs. Then screw the plug connector in the connecting pins. Plug the contact sleeve for high voltage U_A on the feedthrough pointing towards cathode and plug the contact sleeve for high voltage U_B on the feedthrough pointing towards extraction.

If all three high voltage contacts are connected the protection sleeve (12) can be put on and fixed with M3 screws on the bottom (9) and the cover (11). Make sure that the high voltage cables do not contact each other and do not contact the protection sleeve!

Electrical Connection

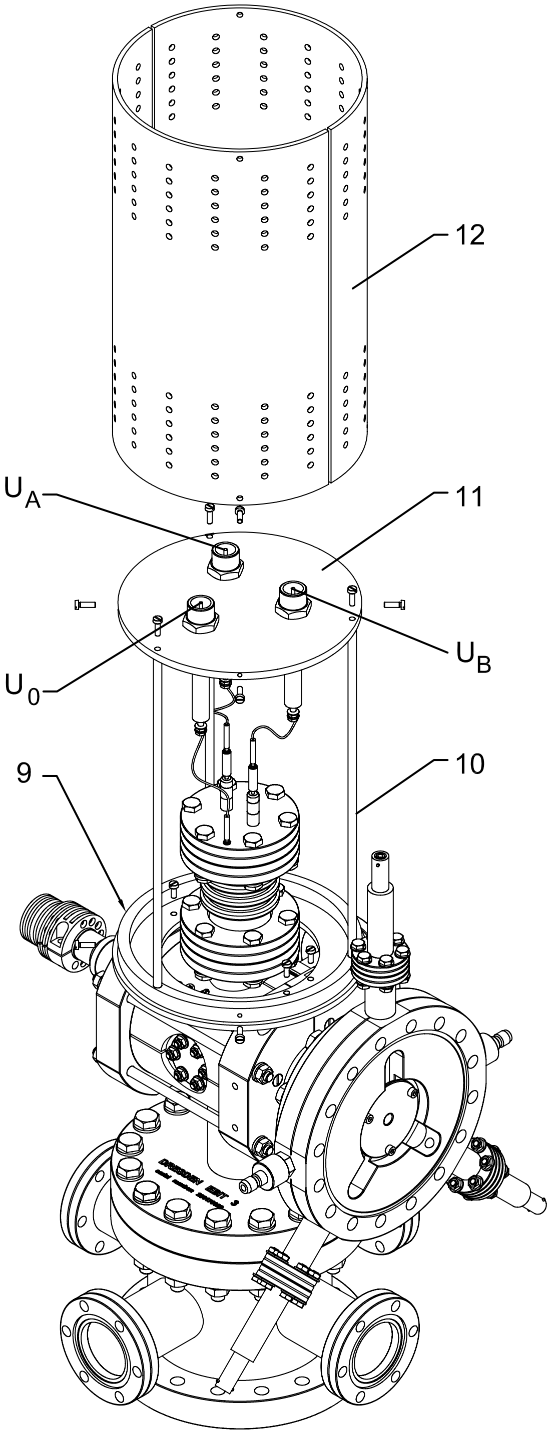

Figure 25: The installation of the high voltage protection of the electrical connection of the drift tubes

3.7.2 Electrical Connection of the Cathode

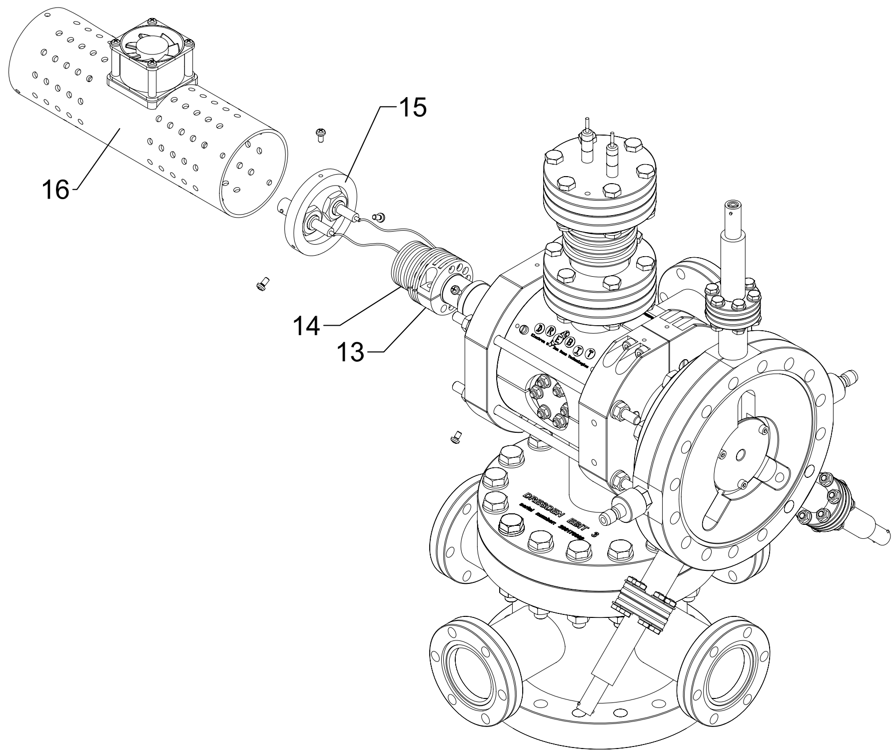

Figure 26: Installation of the high voltage protection of the electron gun

First put the copper radiators (13, 14) on the gun and fix them with M4 Allen screws. Then connect the sockets of the cover (15) with the copper radiators. For that purpose the tag of the first socket is pushed over a M4 Allen screw and it is fixed in the thread of the small radiator (13). The tag of the second socket is fixed in the same way on the big radiator(14).

Are both contacts connected the protection sleeve (16) can be put on and fixed on the installation plate (8) and on the cover (16) (see figure 26).

Again, make sure that the high voltage cables do not contact each other and do not contact the protection sleeve!

3.7.3 Electrical Connection of the Extraction System

For the connection of the extraction system all three cables from the extraction voltage supply has to be connected to the plug sockets at the CF100-extraction flange, signed with L1, L2 and L3.

3.8 Operation of the Dresden EBIT

3.8.1 Before Operation

The surface of the cathode must be cleaned by careful heating at initial operation and at operation after venting and baking.

For that purpose slowly increase the current of the cathode heating without high voltage. Thereby watch the pressure of the recipient. You should stop increasing the current at about $1{\cdot}10^{-8}$ mbar. After some minutes the pressure should noticeably drop. Then the current can slowly be increased until it reaches the maximum recommended heating current (see cathode specification data sheet). That should be the case after less than one hour. After that the source can be put into operation.

3.8.2 Operation of the Source

The operation of the EBIT meaning the adjustment of all high voltages and of the cathode heating can be done manually or via remote control using the analog and digital interfaces of the electrical power supplies.

Before operation check the electrical connections and make sure that, in case of a coolant failure, the cathode heating is switched off. Furthermore, all high voltages and the cathode heating must be switched off if the pressure exceeds a set limit to avoid the damage of the cathode and spark overs at the source. The pressure limit should be set at $1{\cdot}10^{-7}$ mbar or lower to prevent a life time reduction of the cathode.

⚠WARNING

The EBIT must not be operated without coolant!

First the cooling circuit of the electron collector must be in operation. A flow rate of about 1 l/min is sufficient to dissipate the thermal heat input of the electron beam. 1-2 l/min is recommended to compensate coolant pressure fluctuations. The lower set point of the pressure (cathode heating off!) should be not below 0.7 l/min.

After that the high voltages (cathode potential, extraction potential, drift tube potential) can be impressed by setting the voltage power supplies. The cathode voltage should be set to a value with an high electron emission current at low drift tube current. A good empirical value is −3 kV. The electron energy can then be set by U_2 .

Choose a drift tube potential U_2 with a low drift tube current if possible.

The extraction potential can be adapted to the extraction conditions but should be not higher than necessary to avoid spark overs within the extraction area of the source. It must be higher than the cathode potential, otherwise the electron beam passes the collector and hits non-cooled areas of the source and the beamline respectively.

	WARNING
	The potential difference between the drift tubes must not exceed 500V.

	WARNING
	The applied extraction potential must be higher than the cathode potential!

The cathode heating can be started and the heating current can be slowly increased after applying of all voltages (cathode potential, extraction potential, drift tube potentials). The minimal heating current for electron emission depends on the cathode (see cathode specification data sheet).

The resistance of the cathode filament depends on the heating current. This resistance is an indicator for the conditions of the cathode. A significant change is an evidence for the deterioration of the filament or the leads. The lifetime of the cathode at appropriate use of the EBIT is up to several thousand hours. The lifetime also depends on the operation parameters.

During heating of the cathode always watch the pressure of the recipient! The pressure usually increases at increasing cathode heating performance due to outgasing and subsequently decreases again. This behaviour particularly takes place at initial operation or at operation after venting and baking. After emission of the electron beam the axial trap potential can be adjusted by the voltages U_A and U_B .

3.8.3 Directions for the Choice of the Trap Mode

The assignment of the drift tube potentials is shown in figure 11 on page 33. The first drift tube section acting as anode is at U_0, die centre drift tube is at U_{A} and the extraction-side drift tube section is at U_{B}.

The ionization energy is the electron beam energy and can be calculated as follows

$$E_{\mathrm{e}} = e[-U_{\mathrm{Cath}} + |U_2| + V_{\mathrm{e}}(r)] \qquad \text{or} \qquad E_{\mathrm{e}} = e[|U_{\mathrm{Cath}}| + |U_2| + V_{\mathrm{e}}(r)]$$

The actual electron energy is reduced by the negative potential of the electron beam $V_{\mathrm{e}}(r)$ (see figure 27 on page 56). $U_{\mathrm{B}} = U_0$ and $|U_{\mathrm{A}}| - |U_{\mathrm{B}}| > 50V$ should be chosen for a closed ion trap configuration.

Operation of the Dresden EBIT

The ions can be extracted in leaky mode over a reduced potential $U_B > U_A$ or in pulsed mode opening the trap by reducing U_B after a certain ion trapping time. To reach a certain ion charge state the electron energy $U_B \geq U_A$ must at least be equal to the binding energy of the outer atomic shell of the ion. The ionization energy of all ion charge states of all elements through uranium can be found at http://www.dreebit.com/en/highly_charged_ions/data/ .

The ionization cross section of electron impact has its maximum at the 2.7-fold ionization energy. Hence it is recommended to use an electron beam energy 2 to 3 times greater than the required ionization energy.

The reachable ion charge state in the EBIT is determined by the ionization factor which is the product of electron current density j_e and ion confinement time τ_i :

$$j_e \cdot \tau_i$$

The electron current density j_e is determined by the magnetic field and can be tuned by the electron energy and the electron current.

The ionization factor is basically determined by the ion confinement time τ_i in the trap. As an example: to produce dominantly Xe^{44+} a confinement time of more than 1 s is necessary.

The trap capacity, that is the maximum number of positive charges in the trap, can be estimated from the electron energy, the electron current and the trap length of the Dresden EBIT (2 cm)

$$C_{Trap}[e] = 1 \cdot 10^{13} \cdot \frac{I_e[A]L[m]}{\sqrt{E_e[eV]}}$$

e-elementary charge.

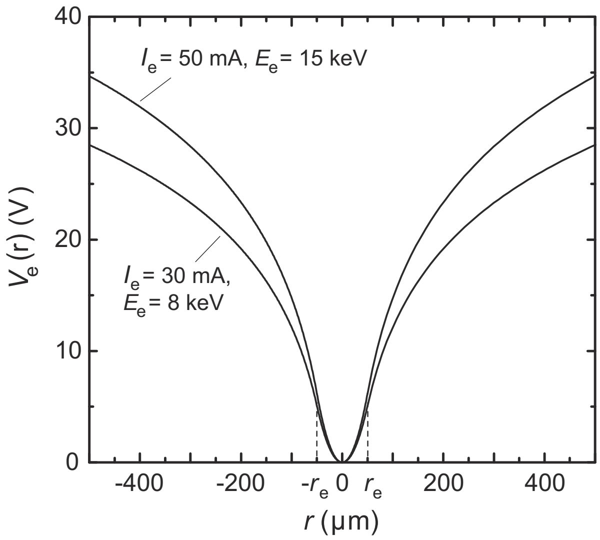

Figure 27: exemplary Radial trap potential of an electron beam with 30 mA electron current at 8 keV electron beam energy and with 50 mA at 15 keV, respectively

The radial trap potential (see figure 27) is determined by the negative space charge potential of the electrons. Hence it is proportional to the electron current and reciprocally proportional to the electron velocity.

The axial trap potential determined by U_A and U_B should be greater or at least equal to the radial trap potential to prevent ion loss axially. Hence U_A should be at least 30 V lower than U_B (see figure 27), recommended is 50 V through 100 V.

3.8.4 Recommended Settings

All settings necessary for operation of the source are listed below. The listed values are recommended for an efficient and safe operation of the ion source.

WARNING

The threshold values which are determined by the dimensions of the high voltage insulators must not be exceeded!

Table 1: Parameters of the Dresden EBIT

Parameter	Recommended settings	Maximum value
Cathode potential U_{Cath}	-3 kV	-5 kV
Cathode heating current I_H	depends on the cathode (see cathode specification)	depends on the cathode (see cathode specification)
Drift tube potential U_1	U_1 defines E_e together with U_{Cath} (preferably low drift tube current)	$12kV$
Trap potential $U_3 - U_2$	$-100V$	$-500V$
Trap potential $U_1 - U_3$ (trap closed)	$0V$	$-500V$
Trap potential $U_1 - U_3$ (trap open) Pulsed Mode: Leaky Mode:	$-100\ldots-150V$ $-80\ldots-100V$	$-500V$
Confinement time	$1ms \le t_{UB1} \le 10s$ (time of ionization)	
Time trap open	$1ms \le t_{UB2} \le 100ms$	
Extraction potential U_{Extr}	$-3,5\ldots-8kV$	$-8kV$
Extraction potential 2 U_{EL2}	$0\ldots-6kV$ $0\ldots+2kV$	$0\ldots-6kV$ $0\ldots+2kV$
Extraction potential 3 U_{EL2}	$0\ldots-9kV$ $0\ldots+2kV$	$0\ldots-9kV$ $0\ldots+2kV$

3.8.5 Assignement of device labeling

Table 2: Assignement of device labeling

Parameter	Desription	Label
Drift tube potential	U_1	U_0
Trap Potential	U_1-U_2	U_A
(closed)	U_1-U_3	U_{B1}
(open)	U_1-U_3	U_{B2}
Extraction Potential	U_{Extr}	U_{Ex} L1
Extraction Potential 2	U_{EL1}	U_{EL1} L2
Extraction Potential 3	U_{EL2}	U_{EL2} L3

3.9 Suggestions for Ion Extraction

The extraction electrode (L1) (on negative potential, which must be greater than the cathode potential!) deflects the ions like an Einzel lens. This results in an crossover of the ion trajectories behind the extraction electrode. The position of the crossover is shifted along the z-axis by changing the extraction potentials.

The starting conditions of the ions are determined by the drift tube potentials. The ions with a thermal energy of some 10 eV in the trap (equal to the trap potential height) experience first the potential difference between U_2 and U_3 (trap-open mode) and subsequently the potential difference between U_3 and the ground potential (electron collector). It is recommended to set U_3 20-50 V lower than U_2 in pulsed mode to empty the trap completely.

A change of the potential relations in the trap influences the extraction conditions and the ion beam must be readjusted in the beam line.

The extraction lense potentials $U_{\mathrm{Extr,\,L2}}$ and $U_{\mathrm{Extr,\,L3}}$ can be used to focus and defocus the ion beam. Deflectors can tilt or shift the ion beam, optionally.

3.10 Connection of the Electrical Powers Supplies

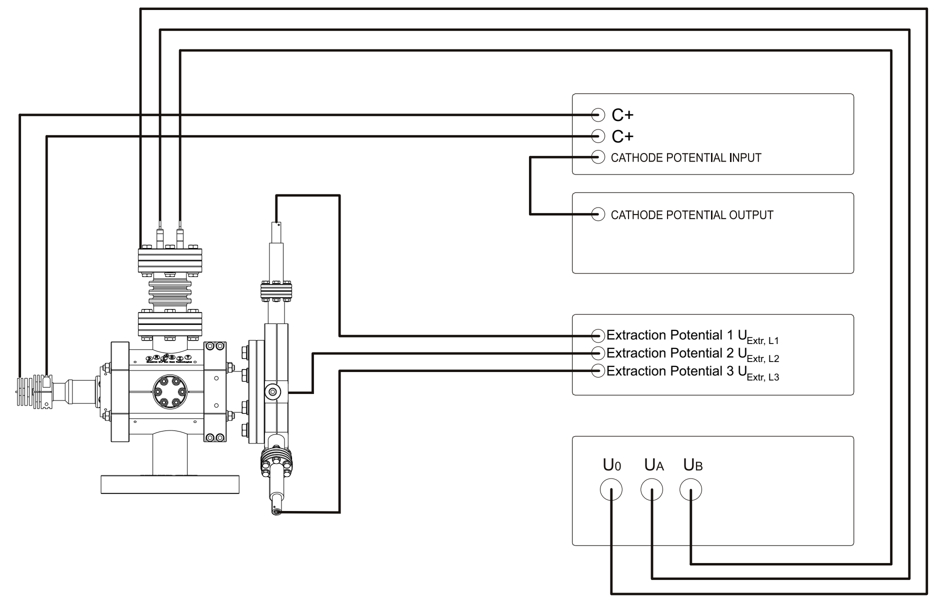

Figure 28: Connection scheme of electrical power supplies of the Dresden EBIT

4

Software control

DREEBIT GmbH
Zur Wetterwarte 50
01109, Dresden, Germany

Version: 1.1 05. 25. 2012

4 DREEBIT EBIT Control Center

The operation of the DREEBIT EBIT as well as the Wien filter is established via a software operation control panel installed on the operation control PC which is delivered with this setup.

After completion of installation including wiring boot the PC and start the DREEBIT_EBIT_Control_Center.exe. The software operation control panel provides all necessary information and control of the delivered system. In addition, all parameters except the pressure are displayed on the front displays of the delivered power supplies.

4.1 The EBIT Control Center

The software operation control panel of the program is subdivided in several sub-panels (see red labels in figure 29).

The sub-panels (1) through (12), except (7) are enabled/disabled via pushing the left-handed PWR button which feedback with green status if ready for input.

The second window in the sub-panels (1) through (12), except (7) shows the actual value of the set parameter.

The third window in the sub-panels (1) through (12), except (7) shows the actual current of the power supply unit.

Figure 29: The EBIT Control Center

(1) Drift Tube Potential U_0 0V...+12000V

Setting of the drift tube potential via typing in the number and confirming with ENTER. Once a value greater 1V is set the arrow keys can be used for increasing and decreasing the values.

The drift tube blind current I_0 is also displayed in order to ensure proper ion source operation conditions (the blind current should be always better than 2 per mill).

(2) Trap Depth U_A 0V...-500V

Setting of the center drift tube potential defining the trap depth via typing in the number and confirming with ENTER. Once a value greater 1V is set the arrow keys can be used for increasing and decreasing the values.

(3) Trap Wall U_{UB1} 0V...-500V

Setting of the extraction-sided drift tube potential defining the trap status (open in leaky mode and closed in pulsed mode) via typing in the number and confirming with ENTER. Once a value greater 1V is set the arrow keys can be used for increasing and decreasing the values.

(4) Trapp Wall U_{UB2} 0V...-500V

Setting of the extraction-sided drift tube potential defining the trap status (open in leaky mode and in pulsed mode) via typing in the number and confirming with ENTER. Once a value greater 1V is set the arrow keys can be used for increasing and decreasing the values.

Please keep in mind: U_{B2} must be always greater than U_{B1}. Hence also in leaky mode U_{B2} must have a value greater than U_{B1}.

(5) Cathode Potential U_{Cat} 0...-5000V

Setting of the cathode potential via typing in the number and confirming with ENTER. Once a value greater 1V is set the arrow keys can be used for increasing and decreasing the values.

(6) Wien Filter Potential U_{WF} 0...±500V

First of all make sure that the REM symbol is visible on the display of the Wien filter power supply. If not use the REMOTE/LOCAL switcher on the front panel of the device to switch from LOC (Local) to REM (Remote).

Setting of the Wien filter potential via typing in the number and confirming with ENTER. Once a value greater 1V is set the arrow keys can be used for increasing and decreasing the values.

(7) Vacuum Pressure

EBIT Pressure	p_{EBIT}	<1E-10 mbar-1000mbar 1E-7 mbar (pressure limit)
Target Chamber Pressure	p_{TC}	<1E-10 mbar-1000 mbar
Fore Vacuum Pressure	p_{Fore}	<1E-4 mbar-1000 mbar

All windows of the sub-panel display the actual pressure of the EBIT, the target chamber and the fore-vacuum tract of the facility.

(8) Extraction Lens Potential $U_{EXTRAKTION}$ 0...-8000V

Setting of the extraction lens potential via typing in the number and confirming with ENTER. Once a value greater 1V is set the arrow keys can be used for increasing and decreasing the values.

(9) Cathode Heating Current I_H 0.00...2.35A

Setting of the cathode heating current via typing in a number smaller than 0.1A and confirming with ENTER. Once a value greater than 0.00A is set the arrow keys can be used for increasing and decreasing the values. The maximum possible current step size is 0.01A in order to prevent cathode damages. The cathode heating current should always be changed in small and reasonable steps (0.1A, preferably 0.01A).

Keep in mind: The maximum heating current for the delivered cathode filament is 2.35A but can change for other cathode filaments.

(10) Extraction Lens Potential 1 U_{EL1} -6000V...0V...+2000V

Setting of the extraction lens potential 2 via typing in the number and confirming with ENTER. Once a value greater 1V is set the arrow keys can be used for increasing and decreasing the values.

In order to change the lens polarity, the PWR button of the extraction lens potential 2 needs to be off.

In dependence on the ion source operation parameter the polarity needs to be set. Sometimes the deceleration-mode (positive polarity) for (positive) ions works more efficient than the acceleration-mode (negative polarity) and vice versa.

(11)	Extraction Lens Potential 2	U_{EL2}	-6000V...0V...+2000V

Setting of the extraction lens potential 3 via typing in the number and confirming with ENTER. Once a value greater 1V is set the arrow keys can be used for increasing and decreasing the values.

In order to change the lens polarity, the PWR button of the extraction lens potential 2 needs to be off.

In dependence on the ion source operation parameter the polarity needs to be set. Sometimes the deceleration-mode (positive polarity) for (positive) ions works more efficient than the acceleration-mode (negative polarity) and vice versa.

(12)	Pulsed Mode Clock		
	Ionization Time	t_{ION}	1ms...10000ms
	Extraction Time	t_{EXT}	1ms...100ms
	Trigger		internal/external

Operating the ion source in pulsed mode requires the setting of ionization time and extraction time.

For external triggering (via BNC connector, level low: 0V – 1V, level high: 3.5V-5V) move the trigger slider to external.

For internal triggering move the trigger slider to internal.

Set the ionization time and extraction time via typing in the number and confirming with ENTER. Once a value greater 1ms is set the arrow keys can be used for increasing and decreasing the values.

(13)	EXIT Button	EXIT	Programm off

The EXIT button switches the program off.

(14)	Connection Status	On/Off Green/Red	connected/ not connected

Connection Status Button displays established connection to the setup hardware.

(15)	Status Feedback	On/Off	
	Water		flow established/ not established

The water flow status button must be on in order to enable operation of the ion source.

	EMS (Emergency stop Button)	unpressed/ pressed

The EMS status button displays unpressed (normal operation) and pressed (emergency stop button active, all power supplies shut down) status.

	Line (Power Line)	Power Supply on/ off

The line status button displays the online or offline - status of the power supplies.

(16)	Line Connection Button	On/Off

The Line Connection Button establishes the connection between PC control and setup hardware (power supplies of EBIT and Wien filter) which is displayed by the Connection Status Button. Pushing the button usually requires several tens of seconds up to some minutes until connection is established.

The operating principle of the Dresden EBIT3 is protected by following patents:
EU Patent No.: 1222677
US Patetn Application: US 6,717,155 B1

General Inquires
Service Contracts

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