Instruction Manual

CETCOR

Spherical Aberration Corrector for Transmission Electron Microscopes

TITAN 80-300
Release 1.0

Version 2.1.5, English

by Peter Hartel

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CEOS
Corrected Electron Optical Systems GmbH

Important

- Please read this manual carefully and store it in a safe place nearby the instrument.
- Read the safety instructions and precautions carefully before using the instrument.

Notice

- The instrument must not be modified without prior written permission. If any such modification is made, all the stipulated warranties and services contracted by CEOS GmbH, by the microscope provider or its affiliated company will be void.
- In no event will CEOS GmbH be liable for direct, indirect, incidental or consequential damages resulting from the use of software described in this manual.
- In the event of changes to the typical process chemistry or the equipment the microscope provider and/or user should inform the manufacturer because it could alter the anticipated environmental impact. In this case, appropriate sections of the SEMI S2 standard might be reevaluated.
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- When this manual or the software described in this manual is furnished under a license agreement, it may only be used or copied in accordance with the terms of such license agreement.
- Information contained in this document is subject to be changed without notice for improvement.

Manufacturer

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Important Note

For servicing or inquiries, please contact the service office of the microscope provider, *not* the manufacturer.

Foreword

Application

The CETCOR system is designed and constructed for the correction of the spherical aberration in a conventional Transmission Electron Microscope (TEM). It improves the resolution limit and reduces delocalization effects in TEM images. The CETCOR consists of a column extension for an electron microscope (in the following often called 'corrector' or 'C_S-corrector') and a Power Supply Cabinet (PSC), containing also a Personal Computer (corrector PC) for control purposes.

Precaution

Regarding the use of an electron microscope equipped with a CETCOR system, same safety regulations hold true as for the microscope without a CETCOR system.

Usually (if not specified differently from the microscope provider) it is not required to make registry notification to the authorities concerned in accordance with the "Radiation Hazard Preventive Laws" or the "Ionizing Radiation Hazard Preventive Regulations" currently in effect since X-rays are not taken out of the electron microscope in common application. Regarding the use of the microscope overall system it is due to the microscope provider to follow all applicable requirements of sections 24.1 - 24.5.3 and appendix 4 of SEMI S2-0703. It is due to the *user* of the microscope to follow local regulations regarding additional X-ray labeling requirements of the country where the overall system will be operated.

The CETCOR system is designed to conform to section 24.2.1 and appendix 4 of SEMI S2-0703, stating that the effective dose equivalent of leakage X-ray radiation should be less than 2μSv/h during normal operation. This has been officially tested at a FEI TITAN 80-300 electron microscope applying the German X-ray regulations (RöV). No warranty is taken if parts of the electron microscope are different from this microscope.

Within a CETCOR system neither radioactive sources nor gamma rays are used. Therefore access to radioactive contamination or internal exposure to radioactive materials is not possible, neither when installed in the microscope column nor when unmounted.

However, electron microscopes, along with home TV sets, fall into a category of potential radiation sources that could produce undesired byproduct X-rays. It is therefore required to ensure safety with sufficient care in operation of an electron microscope equipped with a CETCOR system.

Risk assessment

The manufacturer did not perform a hazard analysis of the CETCOR system according to SEMI S10. This is due to the microscope provider after incorporation of the equipment into the overall electron microscope system.

However, the equipment was evaluated according to the standard IEC 61010-1. Since hazards associated with the equipment are primary of electrical nature, the results of this evaluation were considered sufficient as fire protection documentation.

Warranty

All warranty concerns of the electron microscope equipped with a CETCOR system are due to the microscope provider. Please read the warranty statement of your microscope provider for details.

Installation, relocation and technical service

Installation, relocation and technical service shall be carried out by or under supervision of qualified service personnel of the manufacturer, of the microscope provider or of its authorized service agent. Installations are not permitted to be done by the user.

Conditions for relocation service and after-sale technical service are in the responsibility of the microscope provider.

Precautions on disposal of instrument parts

In the present design, this instrument does not use materials that would directly cause environmental disruption. However, note that the environmental protection laws and regulations may be revised or amended. Therefore, contact the microscope provider when planning to dispose the instrument or parts of it.

Training for customers

For ensuring safety and for getting best results in operation of the instrument, technical seminars and training courses should be attended by the users. Training of the customers is in the responsibility of the microscope provider. For further information, contact your microscope provider.

⚠ Safety precautions

⚠ General safety guideline

For the proper use of the instrument, be sure to read the following safety precautions prior to starting operation or maintenance. We request you to use the instrument in a proper manner and in the scope of the purposes and usage described in this operation manual. Never make modifications such as removing protective parts, exchanging component parts and unlocking safety measures. The instrument should be installed by CEOS GmbH engineers or especially trained service engineers of the microscope provider.

As the corrector is part of the microscope, read the manual of the microscope provider before using the equipment. The safety precautions of the microscope provider have to be followed. For precautions on transport, power connection points, emergency shutdown and installation conditions refer to the manual of the microscope provider.

The hazards inherent in each task are indicated by a safety alert symbol ⚠ followed by the signal words ’DANGER’, ’WARNING’, or ’CAUTION’. The alert symbol and the signal words appear on the labels on the instrument as well:

⚠ **DANGER:** Indicates an imminently hazardous situation which, if not avoided, will result in death or serious injury.
This warning does not apply to this equipment.

⚠ **WARNING:** Indicates a potentially hazardous situation which, if not avoided, could result in death or serious injury.

⚠ **CAUTION:** Indicates a potentially hazardous situation which, if not avoided, may result in minor or moderate injury. It may be used to alert against unsafe practices.
In this manual ’CAUTION’ without safety alert symbol is used to indicate a potentially hazardous situation which, if not avoided, could result in property damage.

⚠ WARNINGS

Electric shock hazards: Line voltage can be present within the equipment even if the main switch is switched off. You may receive an electric shock in contact with the inside of the power supply cabinet, which can result in a fatal or serious injury. The equipment may be powered by two sources.

Lock out power at the equipment of the microscope provider before servicing. Do not remove any cover from the corrector hardware or the power supply cabinet, while power is turned on.

⚠ CAUTIONS

Electric shock hazards: Improper grounding may cause electrical shock.

Do not remove the grounding wires from the equipment.

Electric shock hazards: IEC power outlets at the back side of the power supply cabinet are powered with the input main voltage.

These plugs are for servicing equipment only. Check main input voltage before connecting servicing equipment and make sure that the equipment is designed for this voltage.

Ionizing radiation: Attention to X-rays. This equipment mounted in the electron microscope can produce radiation when the microscope is energized. The electron beam accelerated to 200 kV in the microscope can produce high-energy X-rays. If the cautionary instructions below are not observed, X-rays may leak outside.

Exposure to high-energy X-rays could damage the skin, eye or generative organs.

Do not remove any protective covers or parts from the instrument during operation. Observe the general regulations stated in the section 'Precautions' of the foreword of this manual. Read the manual of the microscope provider for further precautions.

CAUTIONS

Inductive circuits: Disconnection of the corrector wiring under load may cause equipment damage.

The connectors and/or lens circuits can be seriously damaged.

Power down the corrector correctly and switch off the power supply cabinet before servicing.

Cooling water circuits: Disconnection under load may cause equipment damage.

If the power is not switched off and the lens interlock is not functional, the lens circuits can be seriously damaged.[1]
If the water is not blown off correctly or the inlet and outlet are not closed, water can enter the microscope column and cause serious corrosion and electric short circuits. It is due to the microscope provider to minimize the above mentioned hazards caused by a failure of the liquid fittings of the CETCOR system.

Power down the corrector correctly and switch off the power supply cabinet. Close the water inlet of the corrector, blow off the water from the lens system and close the water outlet following the instructions in the maintenance section before servicing.

IMPORTANT

- If any abnormality occurs with the corrector, immediately shut down the power supply of the corrector at the main switch, close the in- and outlet of the cooling water for the corrector and contact your service office of the microscope provider.

- Be aware that the IEC power outlets at the back panel of the power supply are for service purposes only. They are powered with the main input voltage. They are switched off by the main switch.

[1]The coils of the lenses can overheat if driven without cooling water. This may result in an internal short circuit of the windings or in a short circuit to ground. As the lens current driving circuits are designed as IEC 61010-1 'SELV Limited Energy Circuits', no additional hazards for the user will arise from this situation.

- Never open the screw driven valve at the waterflow control unit for the blow off of the cooling water during normal operation. This valve is allowed to be used only for deenergizing of the equipment as described in Section 6.4.2.

OTHER PRECAUTIONS

Data Backup: The data stored on the hard disk of the corrector PC may be damaged or destroyed by some failure or malfunction. Therefore it is advisable to periodically backup the data.
Read as well the ’Backup and Restore’ manual for this purpose.

Other application software: Changes of the pre-installed software, the operating system environment or the installation of other software may result in a dysfunction of the equipment. Abnormal operation of the corrector due to software changes is out of the scope of warranty.

NOTICE

In case of a damage, failure or malfunction of the corrector PC, the remaining parts of the power supply cabinet work stand-alone. If no other component than the corrector PC is affected by this damage, failure or malfunction, no hazards different from those mentioned above will emerge.

The hardware interlock which prevents the lens circuits from serious damage is still active. The power supply itself always remains in the last state set by the corrector PC. It may happen that during the breakdown of the corrector PC erroneous data are sent across the serial RS232 connection to the microcontroller. Although this may change the excitation of some elements, it will not cause any hazard.

See comments in Section 6.4.1 for a shutdown of the power supply cabinet without using the computer.

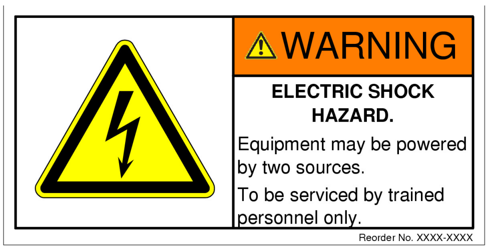
WARNING AND CAUTION LABELS ON THE INSTRUMENT

The labels comply with ANSI Z535.4 and ISO 3864. The following ’WARNING’ and ’CAUTION’ labels are placed on the equipment:

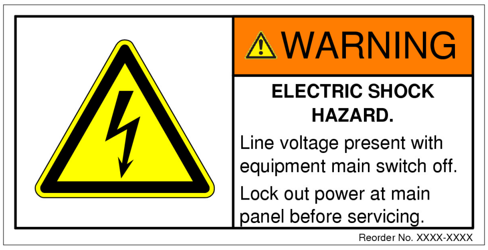
Power supply cabinet

On the back side (solid line) and inside (dashed lines) of the power supply cabinet the following labels are attached:

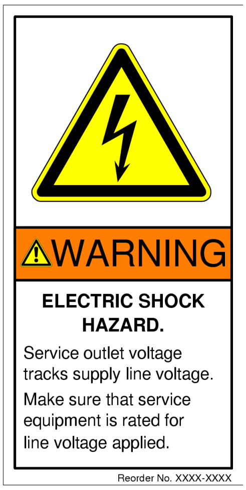
1. ⚠ WARNING



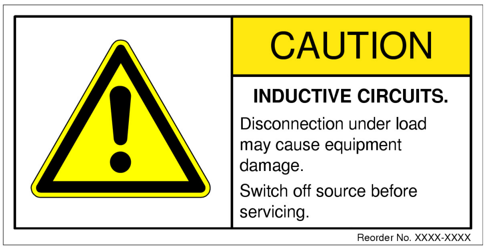
2. WARNING



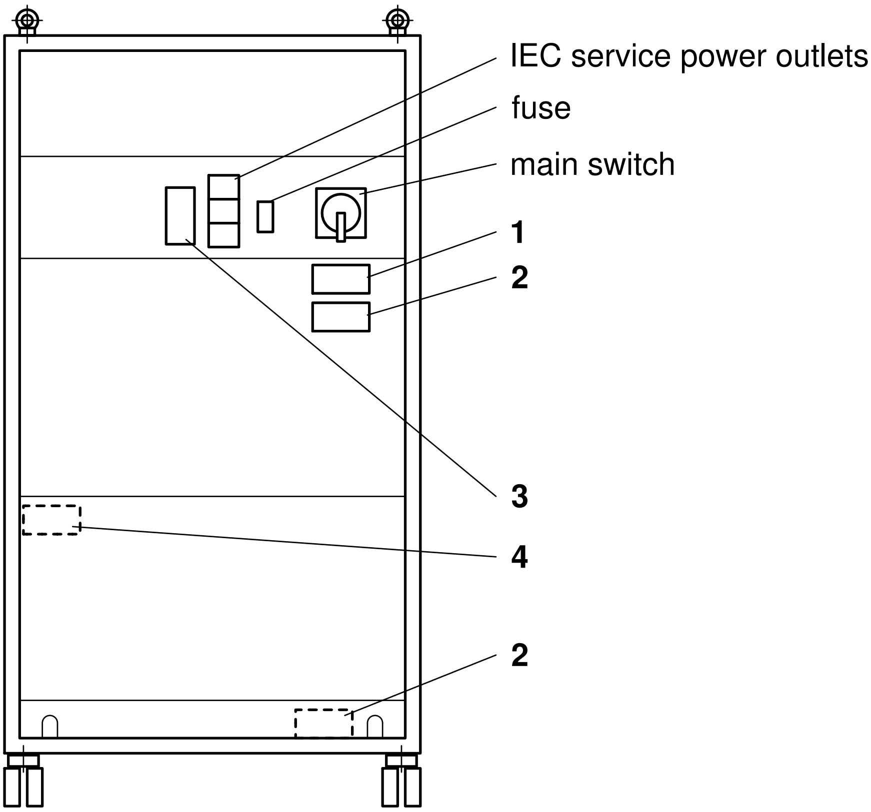
3. WARNING



4. CAUTION



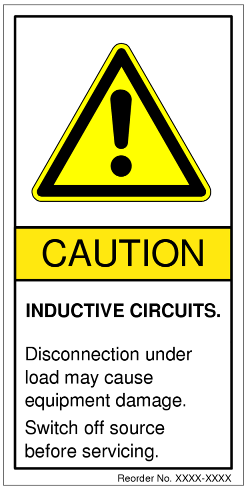
The position of the labels can be seen from the sketch of the back view of the power supply cabinet:



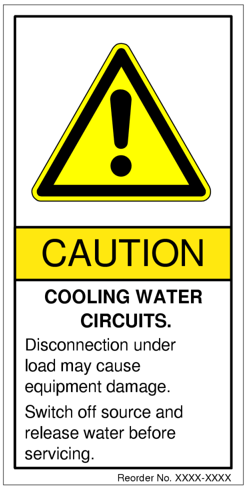
C_S-corrector

At the column extension of the microscope the following labels are located:

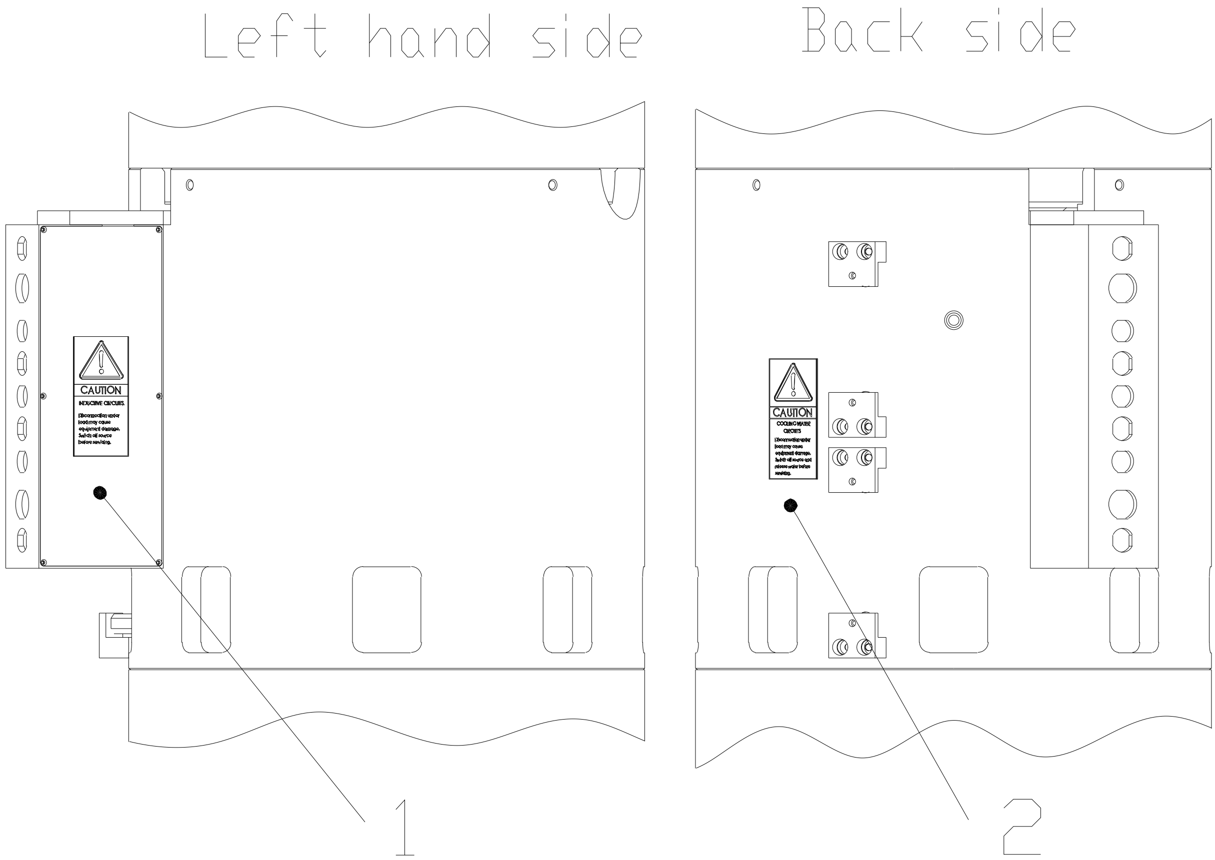
1. CAUTION



2. CAUTION



The labels can be found at the corrector mounted in the microscope column at the following locations. These labels may be not visible as they are hidden behind covers of the microscope:



HARDWARE INTERLOCKS

The CETCOR system contains one hardware interlock - the *Lens Interlock* (LI). It prevents the lens circuits from serious damage. As the lens current driving circuits are designed as IEC 61010-1 'SELV Limited Energy Circuits', no additional hazards for the user will arise from this situation.

At the waterflow control unit, there are three flow meters. If the water flow of at least one flow meter drops below the minimum permissible flow rate, all lens circuits are switched off by relays. The lenses remain switched off as long as the water flow has been readjusted.

The status of the lens interlock is indicated by a LED in the front panel of the power supply cabinet. If the LED is on, the water flow is normal, if the LED is off, the water flow is too low and the lenses are switched off.

EMERGENCY-OFF FUNCTIONALITY, OVERCURRENT PROTECTION, AND CURRENT INTERRUPTING CAPACITY

As the CETCOR system is a subunit of the electron microscope and not intended to be used as stand-alone equipment, it has no emergency-off (EMO) circuit. It is due to the microscope provider to include the CETCOR system into the general emergency-off (EMO) functionality of the overall microscope system and to fulfill the requirements of the entire section 12 of SEMI S2-0703.

The CETCOR system has to be powered by the microscope main supply unit. Therefore it is due to the microscope provider to provide the necessary main overcurrent protection devices and main disconnect devices rated for at least 10000 rms symmetrical amperes interrupting capacity and to observe the requirements of SEMI S2-0703, sections 13.4.1 and 13.4.11. If the main disconnect of the overall microscope system is placed to the off position it should interrupt all power to the CETCOR system. The main disconnect of the overall microscope system should fulfill the requirements for affixing energy isolating ('lockout/tagout') devices.

No warranty is taken by CEOS GmbH if this functionality is not provided by the microscope provider. It is not allowed to use the CETCOR system without these measures.

ENERGY ISOLATION

It is due to the microscope provider and/or user to ensure that the energy isolating devices of the overall microscope system are located in a place where the person actuating or inspecting the devices is not exposed to serious risks or contact to hazardous equipment.

Electrical energy: It is due to the microscope provider to verify that the main disconnect of the overall microscope system should be in a location that is readily accessible and lockable only in the deenergized position.

Non-electrical energy: It is due to the microscope provider to verify that the energy isolating devices of the vacuum and cooling water supplies should be in a location that is readily accessible and lockable in a position in which the hazardous energy is isolated.

The deenergizing procedure of the equipment without shutdown of the microscope is described in Section 6.4.1.

NON-IONIZING RADIATION

It is due to the microscope provider and/or user to meet the requirements of SEMI S2-0703, sections 25.1 - 25.6.2 upon incorporation of the CETCOR system into the overall microscope system.

SOUND PRESSURE LEVEL

The manufacturer has performed a sound pressure level test on the CETCOR system power supply cabinet in accordance to ISO 11200, additionally applying the test criteria of SEMI S2-0703, sections 27.3.1.1 and 27.3.1.2. The sound pressure level did not exceed 55 dBA.

FIRE PROTECTION

The equipment uses primarily non-combustible materials or consists of types that possess a low flammability index. There are no process chemicals utilized in the system.

The hazards associated with the equipment are primary of electrical nature. Minor smoke damage may be possible outside of the equipment due to smoldering of electrical components.

Contents

Introduction

Part I - the *user manual* - contains all information for the operation of the CETCOR system (see Sections 1 and 2). Some hints for trouble shooting are given in Section 2.5. More information is given in Section 6. The functionality and the usage of the graphical user interface (GUI) are described in Section 3. We suggest to read the first two sections in parallel with the section upon the user version of the GUI. The electron optics of the CETCOR system is briefly described in Section 5.

Important information on how to install the instrument by the service personnel is given in Part II - the *installation manual*.

Part I
User Manual

1 Getting started

1.1 Brief checks

Before you start working at the microscope we recommend some fast checks:

- Make sure that water is flowing through the corrector at a sufficient rate.
  If the water flow has stopped or is too low, the lens interlock LED in the front panel of the power supply cabinet is dark. The lenses are switched off. To work with the corrector, the water flow has to be readjusted. More information can be found in Section 6.
- Verify that the main switch of power supply, the base supply and the corrector PC are switched on.
  If the image acquisition PC *and* the corrector PC are switched off, boot the image acquisition PC before the corrector PC.
- Check whether a display of the corrector PC has already been exported to the monitor of the image acquisition PC by means of the VNC-viewer. In case not, follow the login procedure:

1.2 Login procedure on the corrector PC

Start the VNC-viewer (with the pre-configured IP address '192.168.254.2:50' if LAN1 is used or '198.211.143.10:50' if LAN2 is used) at the image acquisition PC to export the display of the corrector PC to the monitor of the image acquisition PC (especially after a reboot, you should retry several times if the first attempts fail).[2] Log on as 'cscorr' with the appropriate password. On newer systems, in addition an account 'user' is available. Please ask the supervisor of the microscope for your account.

Click on the TEM-GUI symbol to start the graphical user interface for CETCOR. Check that the 'Supply' Button is green. Otherwise there is no connection between the computer and the

[2] Make sure that the software and the network connection has been installed properly. See 'Install.pdf' on 'CETCOR/CESCOR Win2000/XP driver suite' CD-ROM. Different sizes of the exported display of the corrector PC can be selected by port numbers different from ':50'.

power supply cabinet.[3] Choose in the File-menu 'Open...' and load a dataset for the corrector. The 'HAL' button should be green (this is necessary to send commands to the microscope and to receive events like magnification changes from the microscope). The actual magnification should be shown in the 'Config' dialog.[4] If it is not shown, change the magnification at the microscope and check the reading in the 'Config' dialog again. If there is still no label shown, make sure that the connection to the microscope has been activated at the microscope and/or image acquisition computer.[5]

From now on, the CETCOR system adapts to the state of the microscope automatically.

2 Operation of CETCOR

2.1 Differences to conventional TEM

The operation of a TEM equipped with CETCOR differs in certain aspects from a conventional TEM. Please follow the instructions to get best results. The most important differences are the following:

1. The auto-tuning software requires a specimen with a sufficiently large amorphous area. A standard test specimen with amorphous carbon (e.g. amorphous parts of a cross grating replica), tungsten or germanium has proven to be very useful and easy to handle.

2. The objective lens and the corrector form a close unit. For optimum operation of the corrector, the current of the objective lens has to be kept close to a fixed value. The current of the objective lens should be set to its standard focus[6] for high resolution work defined by the microscope manufacturer. Therefore focusing has to be performed primarily with the z-height of the specimen.

   For certain operation modes of the microscope the objective lens will be switched off. If you use one of these modes it is necessary to realign the corrector as there will be introduced aberrations due to remanence effects (mainly coma and 2fold astigmatism).

3. With a conventional TEM, you usually work at slight underfocus (Scherzer focus). The contrast in the image is then mainly phase contrast. This is different in a corrected microscope. The optimum condition is Gaussian focus if the spherical aberration 'C3' is corrected completely. The contrast mechanism then is amplitude contrast.
   It is also possible to adjust small positive or negative values of C3 with an appropriate chosen Scherzer defocus. Then one can combine phase contrast imaging and vanishing delocalization.

4. Coma free alignment is *not* done with the tilt of the incident beam but inside the corrector. So the beam tilt should be adjusted to the rotation center of the objective lens.

[3] If the button is red, press the button. If it does not change to green see Section 6.
[4] To open the 'Config' dialog, click in the 'Dialog' menu on 'Config'.
[5] See microscope instruction manual and Section 6 for details.
[6] This is done by pressing the 'eucentric focus' button on the microscope panels.

2.2 Daily procedure

For the daily *startup procedure in the morning* one needs an appropriate test specimen (see Section 2.1). The objective lens current should be set to its standard focus value. Rough focusing will be done using the z-height of the specimen. For details how to use the graphical user interface (GUI) of the corrector, read Section 3.

The alignment procedure consists of 2 steps:

1. Pre-alignment by direct observation of the specimen.
2. Auto-alignment using diffractograms of amorphous material.

In the morning, you should follow the complete procedure. After an exchange of the specimen we recommend at least to check point No. 1. If possible with your specimen, take a tableau to verify that the aberrations are sufficiently low.

2.2.1 Pre-alignment

Select an appropriate area of the specimen. Choose a proper magnification (e.g. 300kx).

- Adjust the rotation center of the imaging side using the beam tilt. A detail of the specimen in the center of the screen should not move any more. Center the illumination with beam shift.
- Ensure that the image of the specimen is underfocused.
- Check the pivot points of the illumination tilt.
- Allow the corrector software to control the CCD-camera:
  Make sure that the CCDImageServer is running on the microscope PC. This can be seen from a green 'Image'-button at the CETCOR-GUI.

Before starting the auto-alignment, make sure that the microscope screen is liftet and the CCD camera is working.

2.2.2 Auto-alignment using diffractograms of amorphous material

Now you can analyze and improve the state of the corrector with auto-alignment procedures. For best results please read Section 2.4 about measuring accuracy carefully.

1. CORRECTION OF FIRST ORDER ABERRATIONS:
   Start the 'Continuous mode' at the GUI. Verify that the defocus 'C1' and 2fold astigmatism 'A1' are determined properly from the displayed diffractogram. The measured values are displayed in the canvas below the diffractogram. It is preferable to adjust the defocus between a quarter and a half of the maximum detectable range.[7] Correct for the 2fold astigmatism using the 'A1' button or the 'A1 coarse' button of the GUI's auto-correction tools one or more times. The 'A1 coarse' button is recommended for

[7] The maximum range is displayed in the GUI main window as 'Max: ...'. The value depends on magnification and the BIN/CUT switch in the 'Config' dialog.

a 2fold astigmatism of more than 100 *nm*.[8] If the astigmatism doubles, check if the correction-switch has been set to ’-100 %’ or you are in overfocus by accident. If there is no improvement by pressing one of the two auto-correction buttons, check whether you are out of the measurable range of defocus and astigmatism (which is displayed in the main window of the GUI as ’Max: ...’). See Section 2.4 in case of problems.

2. CORRECTION OF SECOND ORDER ABERRATIONS:[9]
   Before you take a tableau, adjust the first order aberrations as described above. For further details on tableaus refer to Section 3.1.2. Start the acquisition of a (standard) tableau at the GUI. The outer tilt angle can be chosen in the ’Config’ dialog (a good choice for second order aberrations is 18 *mrad*). The aberration coefficients are computed from the tableau and are displayed in the terminal window.[10] Decide if the tableau is a good measurement of the aberration coefficients (for criteria see Section 2.4). In case you trust the measurement, press the ’Accept’ button (the icon contains ’!’ and ’ok.’). Then you can use all correction tools.[11] For compensation of aberrations up to 2nd order (’A1’, ’A2’, and ’B2’), press the ’1st - 2nd’ button of the GUI’s auto-correction tools. To check whether the correction step was successful, acquire a new tableau.
   Usually 1 to 3 cycles are necessary to reach a ’fully corrected state’. As a rule of thumb for the second order aberration coefficients, values below 100 *nm* for ’A2’ and below 50 *nm* for ’B2’ are fine. However see also Section 2.3 for limits of aberration coefficients as they depend on the intended resolution.

3. CONTROL OF THIRD ORDER ABERRATIONS:
   The third order aberrations (4fold astigmatism ’A3’, star aberration ’S3’ and spherical aberration ’C3’) usually remain stable over weeks. However, you should check their magnitude daily. As a rule of thumb, values below 5 μm for ’A3’ and ’C3’ and below 3 μm for ’S3’ are fine (for limits see also Section 2.3).
   Correction of spherical aberration ’C3’: The spherical aberration ’C3’ can be changed without accepting a tableau by pressing the ’C3’ button. Then ’C3’ is changed by the amount which is displayed left from the button. The step size can be changed using the ’up’ and ’down’ buttons right hand side from the value. A change of ’C3’ has to be confirmed in a pop-up window. We recommend to check the result by taking a tableau and to compensate for the 1st and 2nd order aberrations if necessary. Due to magnetic drift it can take some minutes for a stable state of the corrector.
   Before adjusting the third order aberrations ’A3’ and ’S3’ make sure that the measuring accuracy is as good as possible (see Section 2.4). The second order aberrations should be fully corrected. Take some tableaus to confirm a stable measurement by comparing subsequent measured aberration coefficients. The outer tilt angle in the ’Config’ dialog should be chosen between 18 *mrad* and 27 *mrad*. To be on the safe side, save your working file before pressing any 3rd-order button. Then you can return to the previous

[8] In case you introduced the astigmatism manually by using the ’Stig A1’, use the ’A1’ button even for large values of ’A1’.

[9] The second order aberrations (coma ’B2’ and 3fold astigmatism ’A2’) usually remain well below 2 μm for day to day work.

[10] In the terminal window, the last lines of the log file ’/home/cscorr/em_data/c3temgui.log’ or ’/home/user/em_data/c3temgui.log’ are displayed.

[11] In the terminal window an interval of confidence for the fitted aberration coefficients (95 %-value) is given. If a measured aberration coefficient is smaller than its interval of confidence, you cannot compensate for this aberration unless you increase measuring accuracy (see Section 2.4).

state by loading the saved file. If the third order aberrations ’A3’ and ’S3’ are too large, use the following procedure:[12]

(a) **Correction of 4fold astigmatism ’A3’:** Accept a tableau if you trust the measured value of ’A3’ and ’S3’. If the third order aberrations are above 5 μm, set the correction switch from 100 % to 50 % (Remember to switch it back after the next step!). Press the ’A3’ button. Start the ’Continuous mode’ and compensate for the 2fold astigmatism with ’A1 coarse’ (see No. 1 above, correction switch set to 100 %).

(b) Compensate for second order aberrations (see No. 2 above). Take a tableau. If ’A3’ is still too large, repeat step (a). The correction of the 4fold astigmatism ’A3’ can introduce star aberration ’S3’.

(c) **Correction of star aberration ’S3’:** Accept a tableau if you trust the measured value of ’A3’ and ’S3’. If the third order aberrations are above 5 μm, set the correction switch from 100 % to 50 % (Remember to switch it back after the next step!). Press the ’S3’ button. Start the ’Continuous mode’ and compensate for the 2fold astigmatism with ’A1 coarse’ (see No. 1 above, correction switch set to 100 %).

(d) Compensate for second order aberrations (see No. 2 above). Take a tableau. If ’S3’ is still too large, repeat step (c).

(e) Repeat (a) to (d) until all aberrations up to third order are sufficiently small. Usually you need 1 or 2 cycles.
If you are very confident in the measuring accuracy and both aberrations ’A3’ and ’S3’ are below 5 μm, instead of the steps (a) to (d) you can perform steps (a) and (b) only but pressing the ’A3+S3’ button (with the correction switch set to 50 %) instead of the ’A3’ button.[13]

4. START IMAGING:
Now the corrector should be well aligned. To finish the auto-alignment procedure, you can start the ’Continuous mode’ again and use the ’Focus’ button. This sets the current of the objective lens close to Gaussian focus and compensates for the 2fold astigmatism.

If you want to exchange the specimen, remember to focus mainly by z-height.

2.2.3 Comments on stability of aberration coefficients

The third order aberrations (4fold astigmatism ’A3’, star aberration ’S3’ and spherical aberration ’C3’) usually remain stable over weeks. If a measurement shows too high values make sure first that the measuring accuracy is good enough before using the auto-correction tools. The second order aberrations should be checked at least twice a day (in the morning and after lunch).

As the first order aberrations (2fold astigmatism and focus) depend on the specimen, they have to be adjusted more often. If the specimen has amorphous areas, you can use the corrector for automated pre-adjustment. Follow step No. 1 in Section 2.2.2. The fine-adjustment of 2fold astigmatism can be done as usual by observing the image or the FFT of the image.

[12] Since the correction of the third order aberrations also has undesired side effects on lower order aberrations, the procedure is iterative.

[13] In some software versions this button is called ’3rd order’.

2.3 Limits for aberration coefficients

A detailed discussion of 'Residual wave aberrations' has been published earlier.[14] It contains the definition of the aberration coefficients used by the software. A reprint of this paper can be found in the Instruction Manual. There the maximum tolerable magnitudes of the aberration coefficients are given. As criterion a maximum parasitic phase shift of $\pi/4$ within a given aperture has been used.

The calculations do not take into account that in the corrector one usually counterbalances aberrations of same multiplicity but different order automatically.[15] E.g. the 2fold astigmatism 'A1' (first order, multiplicity 2) partly counterbalances the star aberration 'S3' (third order).

The CETCOR is adjusted in a way that the third-order off-axial coma B3 is minimized. This allows the largest field of view. From that alignment results a small spherical aberration of fifth order 'C5' in the range of a few millimeters. The first intrinsic aberration of the system is the 6fold astigmatism 'A5' (fifth order). Its size of less than four millimeters depends on the focal length and the spherical aberration of third order of the pole piece and the strength of the hexapoles.

2.4 How to optimize measuring accuracy

Take care that all connections of the GUI to the outside, to the microscope via hal, to the image server and to the power supply are working. If not, see Sections 1 and 2.5.

In the following some hints are given how to get the best measuring accuracy. It depends on many factors. One of the most important is the specimen itself.

2.4.1 Specimen

For high quality diffractograms one needs a specimen with thin amorphous regions. As a test specimen a standard cross grating replica and tungsten or germanium films have proven to be useful. You should take care that no strong lattice fringes are visible in the diffractogram. If the specimen is too thick, this becomes visible as a diffractogram with rings where the white areas are much broader than the black areas. At the same time the noise level increases.

It is important to change the area after a while as contamination can degrade the contrast or the thin area of the specimen can break.

2.4.2 Defocus and astigmatism: quality of diffractograms

From a single diffractogram you cannot decide whether your image is over- or underfocused. The GUI assumes that the image is underfocused, so the user has to adjust the underfocus.

If the measurement of defocus and astigmatism does not work, check the following points:

- You could be out of the measurable range. The maximum detectable defocus and astigmatism is displayed in the main window of the GUI (see Figure 1). The maximum range is limited to 12 visible fringes (if no astigmatism is present). If you believe that you are out of this range, go closer to focus by the z-height or by changing the current of the objective lens. Alternatively, you can go to lower magnification or activate the 'Cut' switch.

[14] S. Uhlemann and M. Haider, Ultramicroscopy 72 (1998) 109-119.

[15] Except for the predominant example: The Scherzer focus. There the effect of the round aberrations defocus 'C1' (first order) and spherical aberration 'C3' (third order) partially cancel each other.

Usually you get the best results if the displayed maximum measurable range is about 1 μm and the underfocus is adjusted between a third and the half of that value.

- Check the contrast in the outer regions of the diffractogram: You need good contrast at least up to half of the maximum frequency in the diffractogram. If this is not fulfilled you can reduce magnification or switch on the 'Cut' switch in the 'Config' dialog. Sometimes changing to new part of the specimen helps.

- The noise level of the diffractogram depends on the absolut intensity of the image. Use the total dynamic range of the CCD camera to get best results. You can change the illumination time in the GUI (right hand side of 'Image' button).

- The contrast of the diffractogram can be degraded if the dark and/or gain reference is not up to date anymore. In most of these cases you can observe bright horizontal and vertical lines crossing at the center of the diffractogram. Verify that the specimen is illuminated homogeneously without differences in the mean intensity from one side to the other side of an image.

- The quality of a diffractogram is influenced by the adjustment of the beam tilt by means of the rotation center of the objective lens. So check this point as well.

2.4.3 Higher order aberrations: Zemlin tableaus

The user has to judge the quality of a tableau which needs some experience. In the following some important hints will be given. Usually you will get good results with the standard tableau and an outer tilt angle of 18 *mrad* to 24 *mrad* (see 'Config' dialog) at a magnification of about 300kx. For more information about the tableaus, see Section 3.1.2.

As the Zemlin tableau is based on precise measurement of defocus and 2fold astigmatism using diffractograms, make sure that you have already optimized the image analysis itself following the hints of the previous two sections. The following remarks concentrate on tableau acquisition and interpretation:

1. Make sure that you have at all tilt positions nice diffractograms. In case the displayed diffractograms are nearly black, stop the acquisition and check whether the screen is open, the illumination is centered and an amorphous part of the specimen is in the middle of the screen. The mean intensity (displayed on the canvas) should be between one eighth to one half of the dynamic range of the camera. If only some of the diffractograms are black, adjust the pivot points for the illumination tilt.

2. For a correct measurement of the aberration coefficients, it is essential that at no tilt position the induced defocus and 2fold astigmatism is out of the measurable range or is taken at overfocus.[16] This happens e.g. if the axial coma is large (the focus changes from one side of the tableau to the opposite side). To get a correct aberration measurement try first to adjust an underfocus of about half of the measurable range for the central image in the 'Continuous' mode. If this is already done or does not help, reduce either the outer tilt angle or the magnification. Correct for the second order aberrations and increase the outer tilt angle and/or magnification to the usual values.

[16] A hint for that are diffractograms showing hyperbola with nearly perpendicular crossing asympotic lines, which means Gaussian focus.

Example: If the second order aberrations are quite large (clearly above 1 μm), the quality of the tableau is decreased. In this case, try something like 9 *mrad* for the outer tilt. In addition you can set the 'Correction' switch to 50 % or 20 % at the first correction step(s). If the second order aberrations are small again, you can go back to 18 *mrad*.

3. Finding the best magnification and outer tilt angle is an optimization process:

   (a) The larger the magnification, the higher is in principle the measuring accuracy as the sampling becomes finer. However, with increasing magnification, the quality of the diffractogram decreases as the damping envelope of the contrast tranfer function reduces the contrast in the outer regions of the diffractogram.

   (b) The larger the outer tilt angle, the better is in principle the measuring accuracy as the induced defocus and 2fold astigmatism by higher order aberrations is increased. However, at large tilt angles the higher order aberrations, the chromatic aberration and current fluctuations of round lenses affect the images: In the direction of the induced tilt, the transfer of spatial frequencies is reduced.

4. If you try to compensate for aberrations, take care that your measuring accuracy is sufficient. Look at the 95 %-value of confidence which is displayed in the terminal window behind each aberration coefficient. The aberration coefficients which you want to reduce should be larger than this value. Try to improve measuring accuracy (as described above) before using the correction tools. This is especially important for the correction of the third order aberrations (4fold astigmatism 'A3' and star aberration 'S3').

2.5 Trouble Shooting

2.5.1 Communication checks

In this section very brief checks are described. If some test fails, for further fault diagnostics refer to the more detailed Section 6.1.

- The 'Supply' button must be green in order to enable changes at the CETCOR power supply.

- The 'HAL' button must be green e.g. to enable tilting of the beam for tableau acquisition, auto-alignment of axial coma and for transfering the state of the microscope to the CETCOR for automatic adaptation. If the 'HAL' button is not green, press the button to toggle it to green.

- The 'Image' button should be green. If not, press the 'Image' button and/or select in the 'Debug' menu the 'auto connect' switch. If the button does not change its color to green, in case of a Gatan CCD camera, check if Digital Micrograph is running in the background and the CCDImageServer service has been started.

If all three buttons are green, all connections to the outside have been established. They are not checked at regular intervals, but in case a command fails you will be notified. In case of a broken connection, the relevant button toggles its color to red. The current software does not check if the connections between microscope software, MicroscopeHandler and hal are working. However, if you change the state of the microscope (e.g. magnification) and the display in the ’Config’ dialog of the CETCOR GUI follows the state of the microscope, this connection is fully functional.

If the above mentioned conditions are fulfilled, you should be able to acquire continuous series and Zemlin tableaus.

2.5.2 Hints for finding the beam

Checks at the microscope:

- Is the gun valve open, is the microscope in the right mode and are just the necessary and suitable apertures inserted?
- Move the specimen: maybe the beam hits the grid of your specimen.
- Check also at low magnification in TEM (but *not* TEM LOW MAG) if there is no beam.

Checks at the camera system:

- Verify that the illumination is centered on screen. Then lift the screen.
- Is the camera inserted and cooled?
- Try to take an image with the software of the CCD camera provider. In case this is possible, verify that the ’Image’ button at the CETCOR software is green. If not, refer to Sections 2.5.1 and 6.1 for suitable measures. If the ’Image’ button is green, you should be able to take a ’Continous’ series using the CETCOR GUI.

Checks at the corrector:

- Make sure that the power supply cabinet of the corrector and the corrector PC are switched on. If the CETCOR system is switched off, follow the restart procedure given in Section 6.3.
- Check whether the lens interlock LED is on (left hand side in the front panel the power distribution unit of the power supply cabinet). Readjust the water flow if necessary. In case the LED does not switch on if the water flow is adjusted, see Section 6 for further instructions.
- Check whether the display of the corrector PC is exported to the image acquisition PC. The GUI for the CETCOR should run and a ’resource’ file should be loaded from which you know that it had worked in the past. Verify that the ’HAL’ and ’Supply’ buttons are green and that the displayed magnification label in the ’Config’ dialog coincides with the state of the microscope. If you take images using the CETCOR software, the ’Image’ button has to be green as well. For more details see Section 6.

If the corrector is working properly, remove all apertures and try to find the beam again. Refer also to the manual of the microscope manufacturer.

3 Graphical user interface

The graphical user interface (GUI) runs on the corrector PC. In Section 1 it is described how to start the program.

3.1 Main window

The program has a main window (see Figures 1 and 2) and some dialog windows, which can be activated in the ’Dialog’ menu (see Section 3.1.2). The large area of the main window (see No. 15 in Figure 1) is the canvas on which images, diffractograms and the tableaus are displayed. Just below the menu bar there are some buttons. Their functionality is described in the following section. The area between the first line of buttons and the canvas is multiply used, see buttons No. 1 and 2 below.

3.1.1 Buttons

The first two buttons change the appearance of the main window between the first line of buttons and the canvas.

1. Toggles display to manual alignment tools as shown in Figure 2.
2. Toggles display to auto-alignment tools (Figure 1).
3. Saves all data belonging to the current state of the corrector (’resources’) to the file which is displayed at the bottom of the main window (No. 16).
4. ’Accept’ button: This button activates all auto-alignment tools. It should be pressed if all of the following conditions hold true:
   (a) a tableau has been taken,
   (b) the user decided that the measurement of the aberration coefficients was sensible and
   (c) the user wants to compensate for aberrations in the following.
5. ’Continuous mode’ button: The continuous acquisition of images is started (or stopped). The diffractograms will be shown on the canvas. Below the measured defocus ’C1’ and 2fold astigmatism ’A1’ are displayed. They are written to the log file and reported in the terminal window. If the continuous mode is running, the three buttons ’A1’, ’A1 coarse’ and ’Focus’ of the correction tools are active. Usually the ’Image’ button (No. 11) should be green.[17]
6. ’Tableau’ button: Starts (or stops) the acquisition of a tableau which consists of 7, 18 or 22 diffractograms with different tilted incident beam. From each diffractogram, defocus and 2fold astigmatism are calculated (for further details see tableau menu in Section 3.1.2). The higher order aberration coefficients are determined from this set of values by a least square fit and reported in the terminal window and in the log file. The number

[17] If the button is red, there is no direct connection to the ’CCD Image Server’. Then the buttons No. 5 to 7 expect as input special files on hard disc (see ’Install.pdf’ on ’CETCOR/CESCOR Win2000/XP driver suite’ CD-ROM).

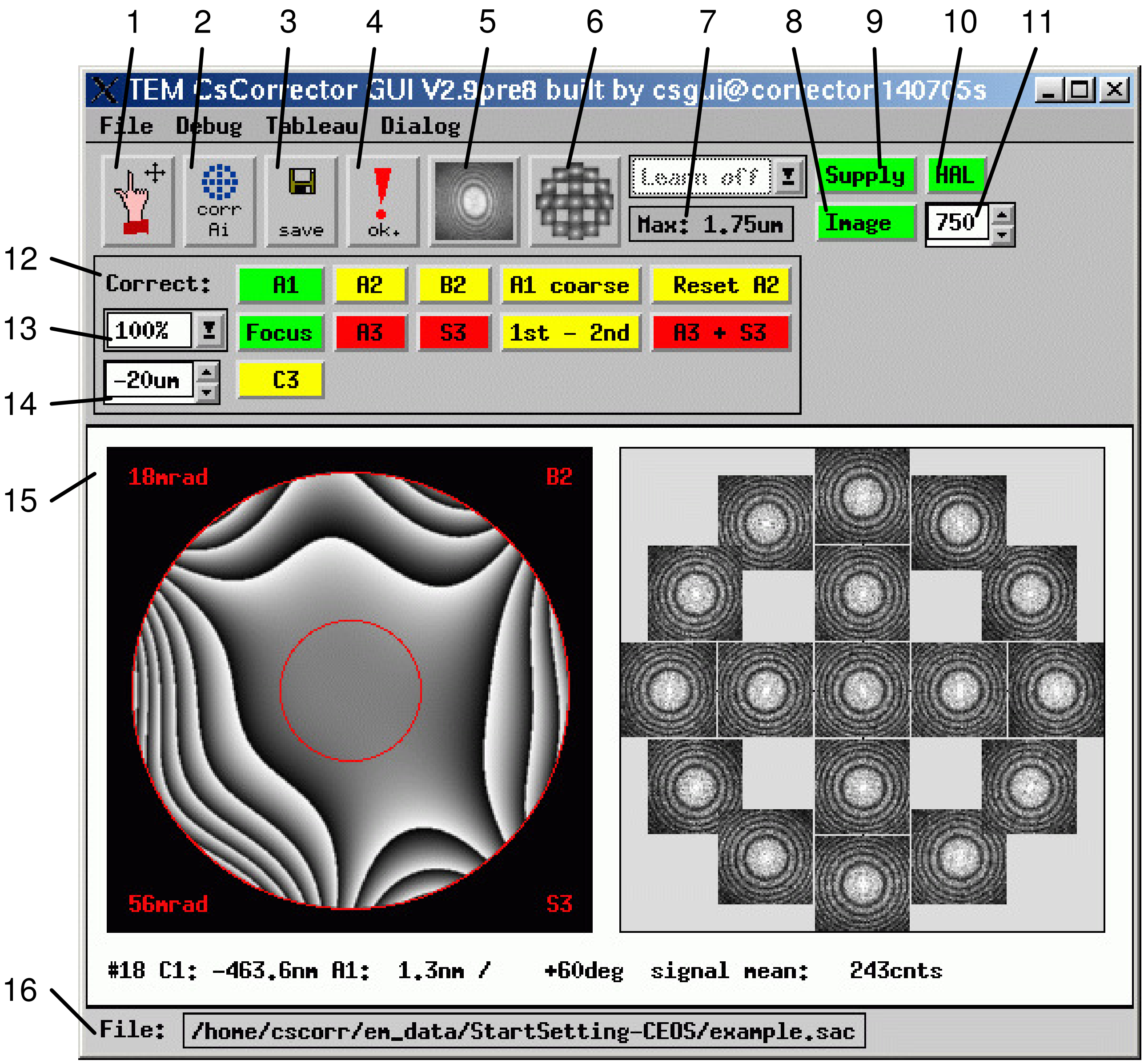


Figure 1: Main window. The auto-alignment tools are displayed. The button No. 1 toggles to the manual alignment tools (see Figure 2), button No. 2 toggles to the auto-alignment tools.

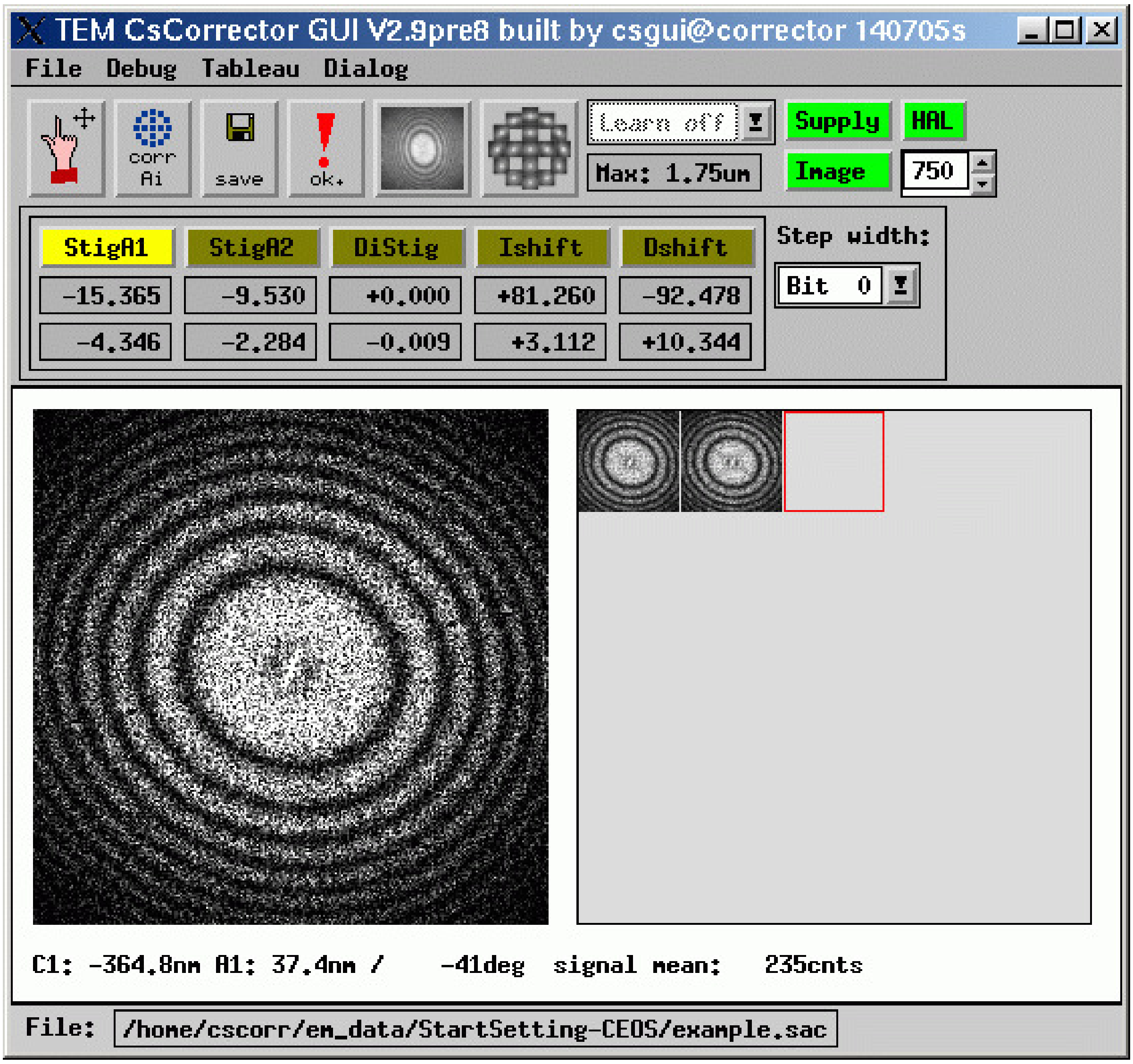


Figure 2: Main window. The manual alignment tools are displayed. The highlighted (yellow) alignment tool can be changed by the cursor keys (left/right: upper channel, up/down: lower channel). The step width can be changed. The unit for the step width is the bit number of the DAC which will be changed. The step width can also be increased or decreased by 'page up' or 'page down' on the keyboard. The cursor control keys are activated as long as the GUI window is the active application. They work even if the auto-alignment tools are displayed.

of images contained in a tableau is selected in the 'Tableau' menu. The parameters for a tableau acquisition can be changed in the 'Config' dialog. If the switch 'Acquire' is deactivated in this dialog, the previously accepted tableau is reevaluated. Thereby changed entries in the 'Config' dialog are taken into account.

7. Displays the 'maximum detectable defocus' and 2fold astigmatism from a single diffractogram. The value depends on the Nyquist frequency and the switch 'Cut' in the 'Config' dialog. If checked, the central quarter of the diffractogram is shown and evaluated. This enlarges the maximum detectable range by a factor of four.

8. 'Image' button: If it is green, there is a direct connection to the camera software. The corrector software then can acquire digital images.
   To disconnect permanently, first deselect the 'auto connect' switch in the 'Debug' menu and then press the 'Image' button.
   If the button is red, there is no connection to the camera software. In case of a Gatan CCD camera make sure that Digital Micrograph is running and that the 'CCDImageServer' service has been started. The 'Image' button changes its color to green automatically if the connection is established and the 'auto connect' switch in the 'Debug' menu is activated.

9. 'Supply' button: If it is green, the software has taken control of the serial connection to the power supply. All previously sent commands (to the power supply) have been successful. The button toggles its color to red if a command fails. An error will be reported in the log file and displayed in the terminal window.
   If you press the button the GUI tries to connect (or to disconnect) the serial link (This is not a test whether the microcontroller in the power supply cabinet is running).

10. 'HAL' button: It indicates in green or red whether a connection to the **H**ardware **A**bstraction **L**ayer is established or not. Through this connection events from the microscope are sent via the MicroscopeHandler to the GUI (e.g. change of magnification, change of illumination mode). In the opposite direction, the GUI sends commands for changing the beam tilt during a tableau acquisition. The FEI image deflector is owned by the corrector software and not by the FEI user interface.
    If the communication with the microscope is working, the actual magnification and operation mode of the microscope is reported in the 'Config' dialog. If the corrector software does not follow the state of the microscope, see instructions given in Section 6.1.

11. Selector for 'recording time' of one image. A value of e.g. “1s4” denotes a recording time of 1.4 s. Values without unit are understood as milliseconds.

12. Area for auto-alignment tools or manual alignment tools. The buttons No. 1 and No. 2 toggle between different tools.

13. 'Correction' switch. It determines the percentage of the measured aberration coefficients to be compensated for if the next auto-alignment button is pressed.

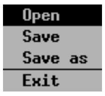
14. 'Step width' for the next change of third order spherical aberration 'C3' using the 'C3' button.

15. Canvas. Graphical information like diffractograms and tableaus is displayed here. On the bottom of the canvas you find the last measured values of defocus and 2fold astigmatism.

16. ’Default save file name’. If a new resource file is opened, the name is automatically used for next ’save’ operation. After the execution of ’Save as’ the new file name is taken as default.

3.1.2 Menu bar

The in- and output of the GUI to alignment files (or ’resources’) is handled by the **file menu***:*



Open... a file with a dataset or ’resources’ for the corrector. The resources consist of

- the actual currents off all elements,
- the influences of the elements on aberrations (effects),
- Several ’setting’ sections like MAG or LOW MAG. They contain currents of all elements (’setting currents’), ’setting effects’ and additional information for each magnification (e.g. Nyquist frequency, offsets for alignment,...)

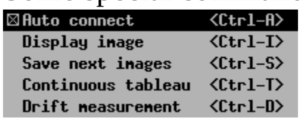
The usual file name extension is ’.sac’.

Save all ’resources’ of the corrector to the default output file which is displayed at the bottom of the GUI’s main window. It does the same as the ’Save’ button. If no default output file is specified, the routine ’Save as...’ is called.

Save as... does the same as ’Save’ except that you can enter or select the output filename in a file selector box. The new filename will replace the default output filename. The usual file name extension ’.sac’ is *not* appended automatically.

Exit terminates the GUI. You will be asked whether you want to save your ’resources’ before exiting.

Some special commands are collected in the **debug menu***:*



As default the ’auto connect’ option is activated. You can toggle each item from ’on’ to ’off’ or vice versa by releasing the left mouse button on one item. Optionally you can use the control sequence indicated on the right if the main window is the active window.

Auto connect forces the GUI to check permanently if the ’image server’ is running. If it is running the connection will be established automatically. This will be indicated by a green ’Image’ button.

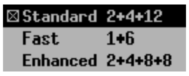
Display Image display the images instead of the diffractograms on the canvas (for test purposes).

Save Next Images starts saving the recorded images to hard disc in 2 byte RAW format in the folder ’/home/cscorr/images’. This folder can physically be located on either the corrector PC or the image acquisition PC.

Continuous tableau starts automatically the acquisition of the next tableau just after the previous tableau has been finished (e.g. for stability or reproducibility checks). The relative image shift between the first images of subsequent tableaus will be calculated and written to the log file (and terminal window).

Drift measurement can be performed during a continuous defocus and astigmatism measurement. Then the absolute image shift with respect to the first image of a series will be calculated and written to the log file (and terminal window).

The 'tableau' menu allows to select three different types of tableaus by releasing the left mouse button on the intended type of tableau:



All tableaus start with the recording of a first image without tilting the beam. We recommend to adjust focus and 2fold astigmatism before taking a tableau. From the diffractogram of an image with tilted incident beam the induced defocus and 2fold astigmatism are calculated. They will be written into the log file (and into the terminal window) with the number of the measurement (e.g. #1).

A tableau consists of one or two untilted measurements and one to three 'circles' with constant tilt angle in between the optical axis and the tilted axis. The numbers in the menu indicate the number of measurements in one circle with different azimuths of the tilt in projection to the specimen plane. In the 'dialog' menu the 'outer tilt angle' θ_0 defines the tilt magnitude (in *mrad*) for the outermost circle (see Section 3.2.1). Below the radii of the inner circle(s) will be given in fractions of θ_0 together with the azimuths. The positive image x-direction defines an azimuth of zero. Positive azimuths are counted counterclockwise if the specimen is observed from above.

Standard: This is the default as it is a good choice for the daily work.
In case of the standard tableau in the beginning and at the end images with untilted beam are taken (measurements #1 and #18 in the log file or terminal window). The measurements #2 to #13 (12) are taken with 'outer tableau tilt' θ_0. The first tilt is performed in positive image x-direction (0°), then the azimuth changes by 30° (counterclockwise) at each step. At an inner circle with a radius of $0.5 \cdot \theta_0$ measurements #14 to #17 are done at azimuths 0°, 90°, 180° and -90°.
If one switches to standard tableau, for the next analysis of the aberrations 'up to' the 5fold astigmatism 'A4' is preselected. This can be changed manually in the 'dialog' menu (see Section 3.2.1).

Fast: The fast tableau can be used for a quick analysis of aberrations up to second order. Therefore for the next analysis of the aberrations, 'up to' axial coma 'B2' is preselect if the fast tableau is activated.
The tableau consists of one untilted measurement (1, #1 in the log file) and six tilted measurements of defocus and 2fold astigmatism (6, #2 to #7) with a tilt of θ_0 and azimuths of 0°, 60°, 120°, ... and -60°.

Enhanced: The enhanced tableau should be used to measure aberrations beyond third order. Therefore the preselection for fitted aberration coefficients is set 'up to' 'A5'. To get reliable results for 5th order aberrations, at the same time very large tilt angles clearly above 30 *mrad* are mandatory.

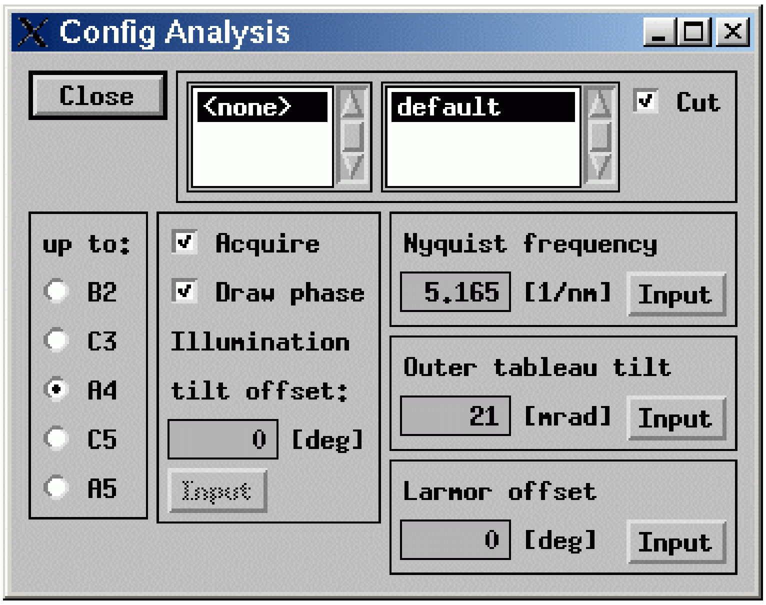


Figure 3: Config dialog.

The tableau consists of two untilted measurements at the begin and at the end with numbers #1 and #22 (2). Measurements #2 to #9 (8) are taken with full 'outer tableau tilt' θ_0. The azimuths are 22.5°, 67.5°, 112.5°, 157.5°, -157.5°, -112.5°, -67.5° and -22.5°. Then for measurements #10 to #13 the inner circle (4) with a tilt of $0.45 \cdot \theta_0$ at azimuths of 60°, 150°, -120° and -30° follows. After that at a radius of $0.8 \cdot \theta_0$ the measurements #14 to #21 (8) are performed with azimuths 0°, 45°, 90°, 135°, 180°, -135°, -90° and -45°.

Additional windows to the main window can be opened in the **'dialog' menu**:

The different dialogs are described in the next section.

3.2 Dialogs

3.2.1 'Config' dialog

The 'Config' dialog (see Figure 3) contains all information for the analysis of diffractograms and tableaus.

The 'Config' dialog can be closed by the 'Close' button. In the upper left the 'setting' of the corrector is displayed. In the upper right you find the actual magnification as a 'label'. In most cases they will be selected automatically (if the connection to the microscope is working). A combination of 'setting' and 'label' reflects the state of the microscope.

The **Nyquist frequencies** f_{Ny} are measured values for each magnification. They are saved together with the (magnification) 'label'. They are determined with respect to images with 512x512 pixels. So the field of view is given by $512/(2 \cdot f_{Ny})$.

The checkbox **CUT** means that the central quarter of the diffractogram will be cutted. This part of the diffractogram will be displayed in the canvas and used for the measurement of defocus and astigmatism. If checked, you can work at higher magnifications as the outer regions of the diffractogram are not used for analysis.[18] The maximum measurable range is increased by a factor of four.

Most entries are concerned with recording and evaluation parameters for tableaus:

up to means that the aberration coefficients are fitted to a recorded tableau 'up to' the selected aberration coefficient (e.g. if 'B2' is selected, the aberrations of first and second order are fitted: defocus ('C1'), 2fold and 3fold astigmatism ('A1', 'A2') and axial coma ('B2'). The default is the 5fold astigmatism 'A4' for the standard tableau.

Acquire: If checked (default), a new tableau is recorded if the 'Tableau' button on the main window is pressed. In case the switch is unchecked, the last accepted tableau is reevaluated. Changed entries in the 'Config' dialog are taken into account for the reevaluation.

Draw phase: If checked, the resulting phase plate is calculated from the measured aberration coefficients and displayed on the canvas. Defocus and astigmatism are neglected.

Illumination Tilt Offset is zero in any case. It is assumed that the illumination is tilted in camera x-direction for the first tilted image of a tableau. This is preconfigured in the HAL. If the 'Acquire' flag it is switched off, the display changes to...

Tilt Offset Correction, where the 'Input' button is active. This allows a service expert to check if the first tilt is performed in camera x-direction and after that to change the configuration of the HAL.

Outer tableau tilt is the tilt in *mrad* which is set at the microscope by changing the beam tilt. Different sensitivities of these coils depending on the state of the microscope can be taken into account. This is done by the HAL and can be configured in the file '/home/cscorr/default.hal' (for service only). The 'Input' button allows to choose a different value for the outer tilt angle.

Larmor Offset belongs to each magnification label. It can be changed to compensate for possible changes in Larmor rotation of the projective. The 'Input' button allows to change the value. The values are stored in the 'resource' file. Take care: Wrong value for the Larmor offset will disable all auto-alignment tools.

3.2.2 'Panel' dialog

The 'Panel' dialog (see Figure 4) or 'Single channel control' shows the currents of all elements of the corrector. To close the 'Panel' dialog use the button 'close'.

The currents are given in Amperes for the round lenses and in Milliamperes for all other elements. Virtual elements like DP12 are given in % of the maximum excitation.

Clear all sets *all* currents to zero, so this means the corrector is switched off completely. This button should be used only to switch off the corrector for a longer time. After you pressed 'clear all' we recommend to quit the GUI without saving the data as otherwise the currents of the active setting will be replaced by zeros.

[18] Those are washed out by the damping envelope of the contrast transfer function.

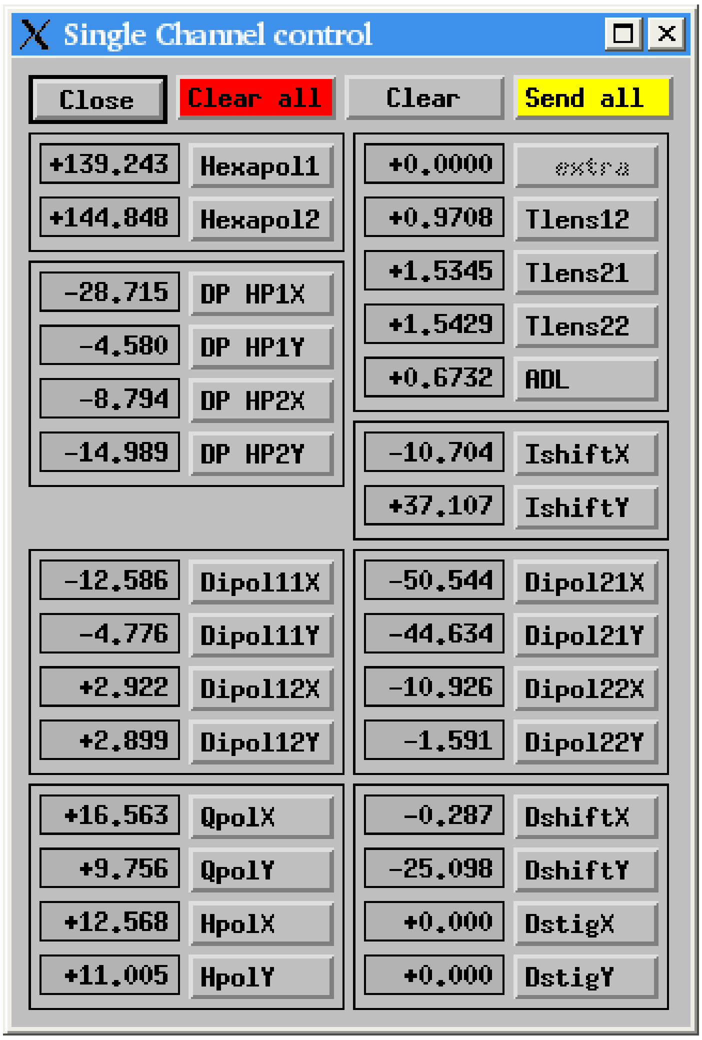


Figure 4: The 'Panel' dialog allows direct view of the excitations of all elements of the corrector. The unit is *mA* for hexapoles, stigmators and deflectors. The currents of the round lenses are given in *A*.

Send all resends all values to the power supply. It should be used if the power supply was switched off and on again or the microcontroller board was reset. This ensures that all values are rewritten to the power supply. It can be used to rewrite the virtual elements which are the hardware of the microscope. E.g. DP12 controls the image deflector of the microscope.

4 Power supply cabinet

Access to the back side of the power supply cabinet is needed for installation and service purposes only. The main switch for the power supply cabinet is located there. A more detailed description of the back side is given in Section 6.4. A layout sketch can be found in the preface in the Section 'Warning and caution labels on the instrument'.

NOTICE: The measurements described below can be performed without removing covers. As all current driving circuits are designed as IEC 61010-1 SELV circuits, no serious hazard for the user can occur.

4.1 Front Panel

From the top to the bottom, the Power Supply Cabinet (PSC) is equipped as follows:

Corrector PC: At the top of the power supply cabinet, the corrector PC is mounted.[19] Its display is exported to the image acquisition PC. The first RS 232 serial port (labeled with COM1 or CETCOR) is connected to the microcontroller in the current driver unit (see below). The network cable has to be connected to the image acquisition PC directly (cross-patched wire) or to the hub of the local network of the microscope. Ask the microscope provider for details.

Base supply: Below the corrector PC the base power supply (Lambda) is located. It transforms the input AC voltage (100 - 240 V, 50/60 Hz) to an output DC voltage of 48 V (nominal value for the CETCOR system, current limitation set to 15 A) which supplies all components in the PSC except the corrector PC. The lenses are driven directly by this base supply. All other elements are driven by additional DC/DC power supplies, which are located in the power distribution unit.

Power distribution unit: Below the base supply you find the Power Distribution Unit (PDU). It consists of five DC/DC power supplies. During normal operation all LEDs of the five supplies have to be on. Left hand side from the power supplies, the lens interlock LED is located (it is labeled as 'Water Cooling Monitoring'). If it is dark, the water flow of at least one lens circuit is too low and hence, all lens circuits are switched off.

The DC/DC power supplies produce stable supply voltages for the digital part and the single current channels. The first one is for the microcontroller and digital logic components, the second and third for the digital-analogue converters and all elements except the hexapoles, and the fourth and fifth for the hexapoles. The output voltages can be measured at the test jacks at the front of the power supplies. The nominal values are given in additional data sheets in the instruction manual.

Current driver unit: The Current Driver Unit (CDU) is below the power distribution unit. It consists of the microcontroller's board on the left and the single channel control boards on the right. The single channel control boards allow the monitoring of all currents driven in the C_S corrector.

Microcontroller: The state of the microcontroller is indicated by three LEDs. During normal operation the green LED should be on permanently, while the yellow LED indicates traffic on the serial link to the corrector PC. The different states are described in more detail in Section 6.2.1.

[19] In case of a double corrected system, which requires two separate PSCs, the corrector PC is usually mounted in the power supply cabinet of the CETCOR.

The pushbutton below the LEDs is for a reset of the microcontroller. Take care, with a reset all currents will be reinitialized to zero (which means to switch off the corrector). Take care: The corrector software is presently not notified about the reset.

The small switch must be set to ’RUN’ any time (lower position of the switch).

Single channel monitoring: Within the current driver unit, two different types of control circuits are used: While the first type is used for hexapole, deflector and stigmator current control (seven control boards, located right hand of the microcontroller board), the second type is used for the control of the lens currents (one control board, located rightmost).

Every single channel control board is equipped with two-pole test jacks for voltage diagnostics of each single channel. These jacks are arranged in columns of up to eight test jacks, whereas the test jacks within one column are always arranged in groups of two.

For the first type of circuits, you can measure the total voltage drop of the circuit (coil plus wiring, in series with the so called ’sense resistor’) at the group upper jack, labeled ’V_{out}’. The voltage drop across the sense resistor can be measured at the group lower jack, labeled ’V_{sense}’. The voltage drop of the load itself (coil plus wiring only) can be measured across the two right poles of the grouped test jacks. If the base supply is switched off, you can measure there the resistance of coil and wiring. The two left poles are connected in parallel to control ground.

For the second type of circuits, the voltage drop of the load itself (coil plus wiring only) can be measured at the group upper jack, labeled ’V_{load}’. At those jacks, the resistance of the coil and wiring can be measured if the base supply is off. The voltage drop across the sense resistor can be measured at the group lower jack, labeled ’V_{sense}’. Measuring diagonally across the grouped test jacks will provide the following voltages: the constant circuit supply voltage (top right - down left) and the variable regulation voltage (top left - down right).

Systematic test and diagnostic procedures are given in Section 6.2.2.

5 Electron optical system

In Figure 5 the CETCOR with its elements is shown schematically. At the zeros of the axial rays there are intermediate images. The excitation of the transfer doublet No. 2 (TL21 and TL22) between the two hexapoles is fixed. It images the central planes of the hexapoles into each other as can be seen from the zeros of the field rays. The excitations of the objective lens and the transfer system No. 1 (LorL and TL1) are fixed as they are chosen to correct the spherical aberration of third order (C3) and to minimize the third order off-axial coma (B3). This allows the largest field of view. Instead of minimizing B3 one can correct the spherical aberration of fifth order (C5). For these purposes the central plane of the first hexapole is imaged to two different planes slightly above the back focal plane (bfp) of the objective lens.

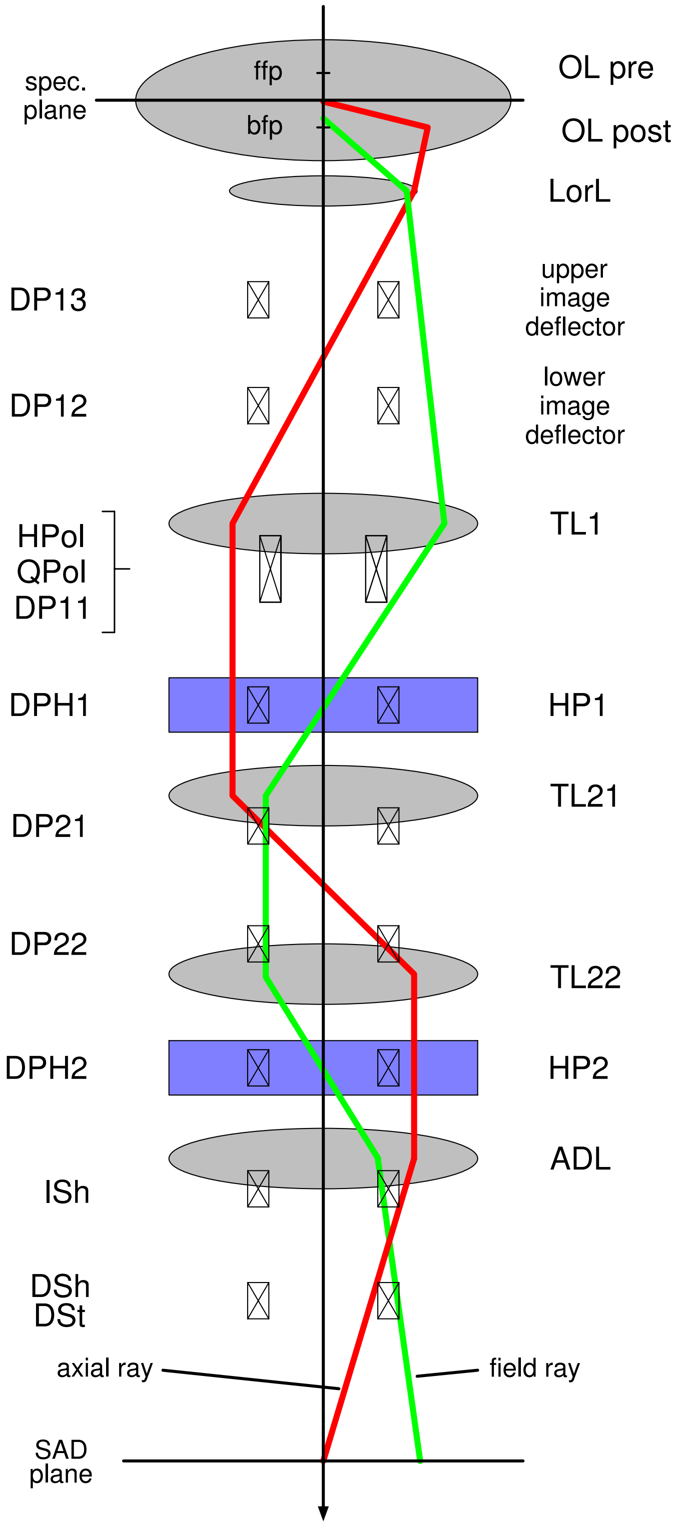


Figure 5: Schematic overview of the electron optical elements of the CETCOR. The corrector is mounted in the column between the objective lens and the projective. The deflectors and stigmators are labeled on the left, round lenses and hexapoles on the right. The image deflector of the microscope is controlled by the CETCOR software using the virtual elements DP12 and DP13.

In Figure 5 all single elements of the CETCOR are shown. For a simple usage of the corrector the CETCOR software combines different elements to so called manual alignment tools which change in most cases just one aberration coefficient or a single property of the path of rays at a time. The manual alignment tools can be seen in Figure 2.

'StigA1' changes the 2fold astigmatism 'A1'. It uses the quadrupole windings 'QPol' and the dipole 'DP11' to avoid image shift.

'StigA2' changes the 3fold astigmatism 'A2'. For this, the two (weak) hexapole stigmation coils 'HPol' are excited. In addition the quadrupole windings 'QPol' and the dipole 'DP11' are changed in order to avoid 2fold astigmatism and image shift.

'DiStig' stigmates the diffraction image using mainly the quadrupole windings 'DSt'. It is compensated for image shift, diffraction shift and 2fold astigmatism in the image.

'Ishift' and 'Dshift' combine the double deflecting system 'ISh' and 'DSh' in a way that a 'pure' shift (without tilt with respect to the SAD plane)[20] or a 'pure' tilt (without shift) of the image is performed.

Auto-alignment tools are based on a composition of one or more alignment tools. They start from a set of measured aberration coefficients and calculate from these the necessary changes of the alignment tools to compensate the desired aberration coefficients. E.g. the auto-alignment tool 'A2' changes the manual alignment tool 'StigA2' to compensate the 3fold astigmatism.

6 Maintenance

NOTICE: The daily and periodic maintenance tasks described in the next two paragraphs can be performed by any user.

The daily checks at the equipment before the start of the work are described in Section 1.

As periodic maintenance task, control the quality of the cooling water at the waterflow control unit at least weekly. The cooling water has to be clear without any color and the flow meters without contamination. This control is necessary to maintain the effectiveness of one design feature of the equipment: This ensures that the lens interlock works ordinarily which prevents the lens circuits from serious damage in case of too low water flow. In case of dirty water improve the quality of cooling water. If the flow meter is contaminated call the service office of the microscope provider.

There are neither personal protective equipment nor consumable parts necessary for normal operation of the CETCOR system. The service people may need protective equipment and consumable parts for cleaning the vacuum liner tube. As the CETCOR system is a subunit of the electron microscope, the specification of protective equipment and consumables is due to the microscope provider. See also Section 7.1.

IMPORTANT: All checks and maintenance tasks described in Part I of this document, the 'User Manual', can be performed in principle by any user of the equipment (if not explicitly specified to be done by service personnel). However, we recommend to nominate special users to be responsible in case of abnormalities. If there are hazards inherent in tasks, the relevant

[20] In some systems this is not adjusted. Then the image shift introduces a tilt with respect to the SAD plane as well.

WARNING or CAUTION summarized in Section 'Safety precautions' at the begin of this manual is repeated and the recommended safety procedure is described. For any case not described here, call your service office of the microscope provider.

⚠ **WARNING**

Electrical shock hazards: Line voltage can be present within the equipment even if the main switch of the Power Supply Cabinet (PSC) is switched off. You may receive an electric shock in contact with the inside of the PSC, which can result in a fatal or serious injury. The equipment may be powered by two sources.

To avoid this hazard the following safety procedure is recommended for all maintenance tasks described in this Section:

- Never remove covers which are not labeled as 'removable'. Except for one cover specified below, it is not allowed and not necessary to remove covers for maintenance tasks.
- One cover can be removed without risk of electrical shock: It is the top cover at the back side of the power supply cabinet above the main switch hiding the back side of the Corrector PC. The removal of this cover is necessary to get access to the main switch of the Corrector PC.

6.1 Software checks

6.1.1 Communication of GUI and microscope software

The 'HAL' button must be green to enable communication with the microscope. If not, press the button to switch it to green. In case this does not work check whether the programs 'hal' and 'MicroscopeHandler' are running (usually they are started and kept running automatically). To stop and restart the 'hal', open a terminal window at the corrector PC and type in 'restart_hal <RETURN>". Make sure that the connection between the corrector PC and the microscope computer has been activated and is working. Press again the 'HAL' button at the GUI. It should change its color to green. Check the connection by changing the magnification. Look at the 'Config' dialog whether the correct magnification label is shown.

6.2 Fault diagnostics at power supply cabinet

6.2.1 Microcontroller

Status of the microcontroller: The microcontroller board is located in the lower left of the power supply cabinet. The small switch must be set to 'RUN' any time (lower position of the switch).

After switching on the main power of the power supply cabinet, at the microcontroller board first all three LEDs (red, yellow and green) are on. Then the red is switched off, after that the yellow is switched off, then the green is switched off. After a short while the green LED will be switched on again.

If data are sent to the microcontroller via the RS 232 link, the yellow LED is switched on. It will be switched off about one second after the last byte has been received. In case the last byte did not complete a command, the red LED will be switched on to indicate a communication error. The incomplete command will be removed from the stack. The next command can be interpreted correctly.

Communication test: For testing the communication, open a GUI and open a resource file. If the communication does not work, an error message will be printed into the log file and the terminal window. After a timeout, the ’Supply’ button toggles to red if the second command fails.

For further analysis, toggle the ’Supply’ button to green again and change a manual alignment tool, e.g. ’Stig A1’ by one step with step width ’Bit 0’. Then just one channel should be changed. Observe the LEDs at the microcontroller board. They should behave as described in the previous section.

If the yellow LED is not changing, check whether the serial RS 232 cable is connected correctly between the correct connector of the corrector PC (labeled with ’COM1’ or ’CETCOR’) and the current driver unit with mircrocontroller board in the lower part of the power supply cabinet. For this check it is necessary to remove some covers of the back panel of the power supply cabinet. Never remove covers which are not labeled as ’removable’. Read and follow the safety precautions given in beginning of the manual and follow the instructions in the installation manual (Part II of this manual).

If the LEDs are changing correctly, reset all channels to zero using the ’Clear all’ button in the ’Panel’ dialog and continue with Step 2 of the hardware test (Section 6.2.2).

6.2.2 Hardware test

For the following tests you need a conventional digital multimeter and a measurement cord set with pins of a diameter of 2 mm.

NOTICE: The measurements described below can be performed without removing covers. As all current driving circuits are designed as IEC 61010-1 SELV circuits, no serious hazard for the user can occur.

IMPORTANT: In case a specially trained user finds deviations from the expected behavior stated below, he has to inform the service agency of the microscope provider. He is not allowed to remove covers from the equipment. This has to be done by specially trained service personnel of the microscope provider. They have to follow the instructions in the Installation Manual before removing covers labeled as ’removable’.

Step 1: Power supply cabinet switched off

- Measure the resistance of all elements at the CDU. The functionality of the two pole test jacks is described in more detail in Section 4.1.
  For hexapole, deflector and stigmator elements (seven control boards, located right hand of the microcontroller board), the resistance of each coil can be measured across the two right poles of the grouped test jacks. For lenses (one control board, located rightmost), the resistance can be measured at the group upper jack, labeled ’V_{load}’.
  Compare the measured values to the corrector data sheet given in the instruction manual and report deviations to your service agency of the microscope provider.

Step 2: Power supply cabinet switched on

Notice: Do not measure voltages relative to the PSC chassis. All checks are performed at the front panel of the power supply. When the power supply unit is switched on, all currents are initialized with zero.

To switch on the power supply, follow the procedure described in Section 6.3.

- Check whether the reading of the output voltage of the base supply is 48 V.
- Check the voltages of the second row power supplies according to the data sheet in the instruction manual.
- Verify $V_{sense} = 0$ for all elements at the lower pins of each element. There can be small offsets of a few Millivolts.

Report different behavior to your service agency of the microscope provider.

Step 3: Testing currents

- Load at the GUI the resource file 'test1.25V.sac': Verify $V_{sense} = \pm\, 1.25\ V$ at all elements.
- Load at the GUI the resource file 'i_max_all.sac': Verify $V_{sense} = \pm\, 10\ V$ at all elements except lenses. TL21 and TL22 should have $V_{sense} = \pm\, 9.4\ V$. All constant power channels TL1a/b and ADLa/b should have $V_{sense} = \pm\, 6.65\ V$.

Report deviations to your service agency of the microscope provider.

6.3 Startup procedure of the power supply cabinet

1. Verify that all wires have been connected according to the safety precautions and the Installation Manual by specially trained service personnel of the microscope provider. Do not remove covers. If something seems to be different than described in this manual contact the service agent of the microscope provider. Do not continue with the startup procedure.
2. Verify that the cooling water hoses have been connected according to the Installation Manual by specially trained service personnel of the microscope provider. Do not remove covers. If something seems to be different than described in this Instruction Manual contact the service agent of the microscope provider. Do not continue with the startup procedure.

CAUTION

Cooling water circuits: Disconnection under load may cause equipment damage.

If the cooling water hoses are disconnected or disrupted, water can enter the into the microscope overall equipment and cause serious corrosion and electric short circuits.

Check and adjust the water flow at the CETCOR water flow control unit if necessary.
If the water has been removed from the system by the deenergizing procedure described

in Section 6.4.2, make sure that the air inlet is closed and all hoses are connected correctly. Open at the waterflow control unit the water outlet valve before the water inlet valve.
Adjust the water flow at the regulators to the nominal flow of 15 l/h.

3. Never switch on power in case you find the switches locked out or tagged out. Check whether the main switch of the overall microscope is switched on and the input power lines for the CETCOR system are powered following the instructions of the microscope provider. Switch on (or verify that it is set to on) the main switch of the power supply cabinet at its back side.

4. Switch on the base supply:
Turn the base supply AC power switch to ON. Enable the base supply output by pressing the OUT pushbutton. Make sure that the OUT LED illuminates and the VOLT display reads 48.0V. All green LEDs of the power distribution unit should be illuminated.

5. Start the corrector PC (if not running):
Read as well the user manual of the corrector PC (KONTRON).
Switch on the computer's main switch at its back side (if off). For this you have to remove the top cover at the back side of the power supply cabinet (labeled as 'removable').

⚠ **WARNING: electrical shock hazards**. Never remove covers different from this one. Follow the safety precautions in the beginning of this maintenance section.

It can happen that the computer boots automatically if the switch was in off position. If the image acquisition PC *and* the corrector PC are switched off, boot the image acquisition PC prior to the corrector PC.
In case the computer's main switch is in 'on' position and the computer is off, press the 'Power switch' pushbutton behind the lockable drivers door right hand side at the front panel of the computer.

6. If the computer was not switched off, check whether a display of the corrector PC has already been exported to the monitor of the image acquisition PC by means of the VNC-Viewer. If the computer has been booted, follow the login procedure described in Section 1.2.

6.4 Shutdown procedure and deenergizing of the equipment

Except cooling water and electrical input power the CETCOR system itself introduces no hazardous energy sources.

As a subsystem of an electron microscope the C_S-corrector contains in its center a vacuum liner tube and may be a potential source of X-rays (below the allowable limits during normal operation). For prevention of hazards, refer to the precautions in the foreword and the safety precautions in the beginning of this document. Read the instructions of the microscope provider carefully. The shutdown of the electron source and the vacuum system is due to the microscope provider.

6.4.1 Shutdown procedure

For a complete shutdown of the CETCOR system, the following steps have to be performed:

1. Set all currents to zero:
   Save your 'resources' at the GUI. Disconnect in the GUI from the 'hal' by pressing the 'HAL' button.[21] Its color should toggle to red. Open in the GUI the 'Panel' dialog and press 'Clear all'. Then quit the GUI immediately *without* saving the data.
   All currents of the CETCOR system are controlled to be zero.
   Comment: If the computer is not working, you can use the 'Reset' button at the micro-controller board at the front panel of the power supply cabinet for the same purpose. All currents will be reinitialized to zero.

2. Shut down the corrector PC.
   Close all open applications. Logout of the system (e.g. mouse click on 'K'-Logout). Check the option 'Turn off computer' in the logout window. Wait until the computer switches off automatically. For deenergizing the corrector PC completely, switch off the computers main switch at the back side of corrector PC. For this you have to remove the top cover at the back side of the power supply cabinet (labeled as 'removable').

   ⚠ **WARNING: electrical shock hazards**. Never remove covers different from this one. Follow the safety precautions in the beginning of this maintenance section.

3. Switch off the power supply cabinet.

   (a) Switch off the base supply:
   Switch off the base supply output by pressing the OUT pushbutton at the front panel of the base supply. Make sure that the OUT LED extinguishes and the VOLT display reads OFF. Turn the base supply AC power switch to OFF. Although switched to OFF, the base supply fan may still be running for up to 30 seconds.[22]

   (b) Switch off the main switch of the power supply cabinet at the back side.
   The input power for the power supply cabinet (two connections, one for the corrector PC and a second for the base supply and the service IEC power outlets, both single phase) are disconnected at the main switch.
   The main switch is designed to affix energy isolation ('lockout/tagout') devices in the off position. For this, the red insert of the black main switch handle has to be pulled out to its stop position. Now, a padlock or similar can be attached to the red insert.

4. Close cooling water valves:
   At the waterflow control unit, there are two *manual* hand valves: Close first the water inlet (upper valve) and then the water outlet (lower valve).
   In this state, the corrector is not completely deenergized, as the pressure of the water outlet line remains in the system. Follow the description in Section 6.4.2 for fully deenergizing the water circuit.

Notice: Status of electrical deenergizing

The electrical system of the CETCOR system is deenergized as much as possible after the shutdown procedure described above. The two single phase input power lines are disconnected

[21] This prevents from changing the double deflection system of the microscope between corrector and objective lens, which is used by the virtual elements 'DP12' and 'DP13' of the CETCOR software.

[22] Read the instruction manual of the Lambda base supply carefully.

from the system at the main switch of the power supply cabinet. The IEC service power outlets at the back panel are switched off. Refer to the general safety precautions in the beginning of this manual.

As the CETCOR system is a subsystem of the electron microscope, the switch off of the two single phase input power lines is due to the microscope provider.

6.4.2 Deenergizing of the water circuit

Different from point No. 4 above, do the following for removing the cooling water from the lens circuit:

- Close the water inlet manual hand valve. Close the regulators for the three individual water circuits (ADL, TL2, TL1).
- Connect compressed air (pressure adjustable up to 0.2 *MPa*, inner diameter of the hose: 4 *mm*) to the second manual screw driven valve at the water inlet.
  Open the screw driven valve carefully. Ensure that the pressure does not exceed 0.2 *MPa*.
- Open the regulators one after the other. The water is blown off through the water outlet. Wait until in all flow meters the water has been blown off.
- Close the screw driven inlet valve for the air. Close the manual water outlet hand valve.
- Fully deenergize the cooling water circuit: Disconnect the compressed air hose and open the screw driven manual valve for a while to release the pressure (build up by the water outlet line in the previous step). Close the screw driven valve again. Close all regulators.

7 Replacement parts

7.1 Consumables

Consumables are needed for cleaning the vacuum liner tube of the C_S-corrector. As the liner tube is integrated in the vacuum system of the electron microscope, follow the manual of the microscope provider for the procedures and consumables to use for vacuum cleaning. Avoid using items other than specified by the microscope provider. For vacuum cleaning, use the personal protective equipment as specified by the microscope provider.

7.2 Spares

The following spares should be prepared in appropriate quantities for long use of the instrument. Avoid using items other than specified.

7.2.1 Fuse ratings

Notice: Except the fuse F1 at the back side of the power supply cabinet, fuses are not allowed to be exchanged by the user. Internal fuses are sized for fault protection and if a fuse was opened it would indicate that service is required. Fuse replacement of internal fuses has to be made by service personnel.

Warning: Before changing fuses, shutdown the equipment correctly to avoid electric shock hazards. Refer to Section 6.4.1 for the shutdown procedure.

Fuse holders: If not specified differently, the following fuse holder

- 600V, 30A/690V, 32A (UL/IEC); fuse size 10x38mm (13/32" x 1-1/2")

is used.

F1:

AC service outlet fuse: Size 10x38mm, time-delay, 500V AC, interrupting rating 10kA AC:

- For a nominal source voltage of 100V (UL) use:
  1x Bussmann FNQ-10 / Littlefuse FLQ-10
- For a nominal source voltage of 240V (IEC) use:
  1x gl-gG 4A (120kA breaking capacity).

F2:

DC power input fuse - DC/DC supply: Size 10x38mm, 1x Bussmann KLM-15 / Littlefuse KLKD-15, fuse holder see: AC power outlet fuse holder

F3:

DC power input fuse - lens supply: Size 10x38mm,
for 4 lenses: 1x Bussmann KLM-10 / Littlefuse KLKD-10
for 5 or 6 lenses: 1x Bussmann KLM-15 / Littlefuse KLKD-15

F4 ... F9:

DC lens circuit fuses: Size 5x20mm, time delay, 250V AC, interrupting rating 35A AC
4x to 6x Wickmann No. 195 2A

8 Technical data

8.1 Installation requirements

8.1.1 General conditions

IMPORTANT

As the CETCOR system is a subunit of the electron microscope and not intended to be used as stand-alone equipment, it has no emergency-off (EMO) circuit. It is due to the microscope provider to include the CETCOR system into the general emergency-off (EMO) functionality of the overall microscope system and to fulfill the requirements of the entire section 12 of SEMI S2-0703.

The CETCOR system has to be powered by the microscope main supply unit. Therefore it is due to the microscope provider to provide the necessary main overcurrent protection devices and main disconnect devices rated for at least 10000 rms symmetrical amperes interrupting capacity and to observe the requirements of SEMI S2-0703, sections 13.4.1 and 13.4.11. If the main disconnect of the overall microscope system is placed to the off position it should interrupt all power to the CETCOR system. The main disconnect of the overall microscope system should fulfill the requirements for affixing energy isolating (’lockout/tagout’) devices.

In addition take care and notice of the following:

⚠ **WARNING**

The equipment is delivered with two power feeds, one for the corrector PC and one for the power supply cabinet. It is within the responsibility of the microscope manufacturer to provide one or two appropriate AC sources with the overall microscope equipment for optimization of electron optical performance.

Therefore the CETCOR system may be powered by two sources with following RATINGS:

- corrector PC, line ’-W1_PC’: 4A
- power supply cabinet, line ’-W1_PSC’: 20A.

8.1.2 Cooling water

NOTICE

The CETCOR system is a subunit of the microscope and therefore the water is taken from the cooling water system of the microscope.

The cooling water for the CETCOR system has to fulfill the following specifications:

- Water volume: 45 l/h nominal, 75 l/h maximum.
- Water pressure: 0.05 ... 0.2 MPa adjustable, no pulsation in short time; 0.4 MPa maximum.
- Water temperature: 15 to 23 °C, temperature variation below 0.1 °C/min.
- Water inlet/outlet: hoses with inner diameter of 9 mm.
- Cooling power: 120 W nominal, 250 W maximum.

8.1.3 Electrical power

See Section 8.2 for specifications.

8.1.4 Other requirements

The CETCOR system requires nothing else than electrical power and cooling water. It uses no process gases and no compressed air. All other requirements do not concern the CETCOR system. They may be used by the microscope provider.

8.2 Power supply cabinet

Main switch: The main switch of the power supply cabinet at the back side of the power supply can be tagged. Both input power lines for the base supply (and service power outlets) and the corrector PC are switched off. Phase and neutral wires are switched.

For the specification to be met by the main input power lines to the main switch, read Section 8.1.1.

Input power sources:

1. For the power supply: 1/N/PE, 100 - 240 V AC, 50/60 Hz, 1500 W max.,
   thereof for the base supply: 750VA/700W max.

   - Notice: The CETCOR system is a subunit of the microscope and therefore powered from the main supply of the microscope.

2. For the personal computer: 1/N/PE, 100 - 240 V AC, 50/60 Hz, 250 VA/200 W.

Maximum output power:

1. Service power outlets: 3x IEC 60320, 100 - 240V, 50/60 Hz, tracks power supply input voltage; total 750 W max.

2. Base supply: 50 V/ 30 A, SELV (serves input power for power distribution unit and lens circuits).

3. Power distribution unit:
   1x 5 V/8 A
   1x 15 V/4 A
   1x -15 V/4 A
   1x 24 V/2.5 A
   1x -24 V/2.5 A
   1x 50 V/10 to 15 A for 4 to 6 lens circuits; separate fuses (2 A) for each lens.

4. Current driver unit (open circuit):

   - 4 to 6 channels with 50 V max.
   - 16 to 20 channels with 13 V, 150 mA per channel.
   - 4 channels with 13 V, 30 mA per channel.

Fuses:

See spare parts in Section 7.1.

Weight and size:

100 to 110 kg, 553mm x 780 mm x 1075 mm (width x depth x height, height including rollers and eyebolts).

8.3 Contents of delivery

1. C_S-corrector and corrector wiring set:

   - Column extension with lenses, hexapoles, deflectors and stigmators.
   - Terminal box.
   - Cable harness for connection of the terminal box with the power supply cabinet.

2. Power supply cabinet (PSC):

- 19” personal computer (corrector PC)
- 19” base supply
- 19” power distribution unit (PDU)
- 19” current driver unit (CDU)
- 19” cabinet fan with fan wiring set
- PC-to-CDU RS-232 serial cable
- PDU-to-CDU wiring set

3. External wiring set:
    - PC power supply cable
    - PC crossover network patch cable
    - PSC power supply cable
    - Ground wire
4. Waterflow control unit:
    - Framework with supply/return gate valves
    - Flow meters
    - Liquid level switches with PDU signaling cable
    - Hoses with pluggable taps for lens cooling
5. Accessories
    - PC keyboard and PC mouse
6. Instruction manuals
    - Instruction manual, including
        - Instruction manual CETCOR
        - Windows 2000/XP installation manual with CD-ROM
        - Backup manual
        - Data sheets
        - Installation CD-ROMs for corrector PC
    - User manual for base supply (Lambda GEN50-30)
    - User manual for corrector PC (KONTRON PxV 414)

Part II
Installation Manual

9 Hardware installation and inspection

9.1 General

This chapter contains instructions for initial inspection and preparation for use.

In addition, the Installation Manual can be seen as an instruction for the inspection, whether all connections of the CETCOR system are still in an ordinary state (see Sections 9.6 to 9.8).

Read the following safety precautions before installation or inspection carefully. Do not start to work at the CETCOR system before the 'safe deenergizing procedure' given at the end of the following safety precautions has been performed or verified.

⚠ SAFETY PRECAUTIONS

NOTICE

All tasks of the entire Section 9 of the Installation Manual have to be carried out by specially trained service personnel nominated by the microscope provider or the manufacturer. The user is not allowed to perform any of the tasks described in this section.

IMPORTANT

Before inspection, repair or preparation for use of the CETCOR system the system has to be deenergized. Do not remove any connectors or covers at the CETCOR system while the system is energized. Follow the 'safe deenergizing procedure' given below after the safety precautions in case the system is not fully deenergized. This is necessary to avoid the following hazards:

⚠ WARNING

Electric shock hazards: Line voltage can be present within the equipment even if the main switch is switched off. You may receive an electric shock in contact with the inside of the power supply cabinet, which can result in a fatal or serious injury. The equipment may be powered by two sources.

Lock out power at the equipment of the microscope provider before servicing. Do not remove any cover from the corrector hardware or the power supply cabinet, while power is turned on.

⚠ CAUTIONS

Electric shock hazards: Improper grounding may cause electrical shock.

Do not remove the grounding wires from the equipment.

Electric shock hazards: IEC power outlets at the back side of the power supply cabinet are powered with the input main voltage.

These plugs are for servicing equipment only. Check main input voltage before connecting servicing equipment and make sure that the equipment is designed for this voltage.

Ionizing radiation: Attention to X-rays. This equipment mounted in the electron microscope can produce radiation when the microscope is energized. The electron beam accelerated to 200 kV in the microscope can produce high-energy X-rays. If the cautionary instructions below are not observed, X-rays may leak outside.

Exposure to high-energy X-rays could damage the skin, eye or generative organs.

Do not remove any protective covers or parts from the instrument during operation. Observe the general regulations stated in the section ’Precautions’ of the foreword of this manual. Read the manual of the microscope provider for further precautions.

CAUTIONS

Inductive circuits: Disconnection of the corrector wiring under load may cause equipment damage.

The connectors and/or lens circuits can be seriously damaged.

Power down the corrector correctly and switch off the power supply cabinet before servicing.

Cooling water circuits: Disconnection under load may cause equipment damage.

If the water is not blown off correctly or the inlet and outlet are not closed, water can enter the microscope column and cause serious corrosion and electric short circuits. It is due to the microscope provider to minimize the above mentioned hazards caused by a failure of the liquid fittings of the CETCOR system.

Power down the corrector correctly and switch off the power supply cabinet. Close the water inlet of the corrector, blow off the water from the lens system and close the water outlet following the instructions in the maintenance section before servicing.

Safe deenergizing procedure

As first step, the CETCOR system as a subunit of the overall microscope equipment must be deenergized. This is described in Section 6.4.1. As second step, lock out the AC power lines for the CETCOR system at the overall microscope equipment. It is due to the microscope provider to prepare and provide the necessary instructions and hardware for this task. No warranty is taken by the manufacturer if the requirements specified by the manufacturer are not fulfilled by the microscope provider and/or user. The requirements are summarized in the ’Foreword’ (ionizing radiation), the Section ’Safety precautions’ in the beginning of the Instruction Manual and Section 8 (emergency-off functionality, overcurrent protection, current interrupting capacity, electrical and non-electrical energy isolation, cooling water). Read these sections before servicing the CETCOR equipment.

Following the procedure described above, all hazards listed in the Section ’Safety precautions’ in the beginning of the Instruction Manual (and repeated here) are effectively avoided.

IMPORTANT

Make arrangements so that no other person than the worker in charge of inspection or repair can access and operate any of the energy isolation devices of the equipment.

9.2 Preparation for use

In order to be operational the corrector power supply must be connected to an appropriate AC source. The AC source voltage should be within the power supply specification. Do not apply power before reading Sections 8 and 9.5 to 9.6.

The basic setup procedure consists of four steps. Follow the instructions in the sequence given below to prepare the CETCOR system for use.

1. Inspection:
   Initial inspection of the equipment.
   See Section 9.3.

2. Preparation:
   Check of environment. Preparation of electric connections and supply of cooling water.
   See Sections 9.4 to 9.5.

3. Installation:
   Internal wiring, external electric connection, supply of cooling water.
   See Sections 9.6 to 9.7.

4. Testing:
   Check of basic functionality of the system.
   See Section 9.8.

9.3 Initial inspection

Prior to shipment the equipment was inspected and found free of mechanical or electrical defects. Upon unpacking of the equipment, inspect for any damage which may have occurred in transit. The inspection should confirm that there is no exterior damage to the equipment such as broken knobs or connectors and that the front and back panels are not scratched or cracked. Keep all packing material until the inspection has been completed. If damage is detected, file a claim with carrier immediately and notify the microscope provider sales or service facility nearest to you. The contents of delivery can be found in Section 8.3.

9.4 Location, mounting and cooling

⚠ CAUTION

Heavy weight equipment:

- Power supply cabinet: max. weight 110 *kg*
- C_S-corrector: max. weight 150 *kg*

Heavy equipment can cause injury. Do not lift by hand.

The power supply cabinet has on top four eyebolts for transport. Use these four eyebolts for lifting the power supply cabinet with a crane and suitable lifting equipment, which is rated for a weight of 110 *kg* at least. All four eyebolts have to be used for lifting. It is not allowed to lift the power supply cabinet using less than four eyebolts.

For the C_S-corrector, use sufficiently rated special equipment of the microscope provider which is used for other microscope column parts. The same safety precautions as for the mounting of the electron microscope itself hold true. Refer to the installation manual of the microscope provider.

The location requirements should be tested and prepared by the microscope provider. The requirements of the CETCOR system are listed in Section 8. For the location of the components of the CETCOR system, see Figure 6. It is within the responsibility of the microscope provider to deliver the components of the CETCOR system to the customer. The C_S-corrector can be shipped separately or as part of the microscope column. The C_S-corrector should be mounted into the microscope column with the same special equipment as the other microscope column parts.

IMPORTANT

In addition to the regulations of the microscope provider, the following has to be fulfilled:
As the Power Supply Cabinet (PSC) is equipped with transport rollers, it has to be positioned at a flat leveled surface. It is not allowed to mount the PSC on top of any other equipment. The transport roller holding brakes have to be locked before starting the installation. After installation, it is not allowed to move the PSC. Before moving the PSC, the CETCOR system has to be shut down. All external wiring of the PSC has to be disconnected.

The power supply cabinet is fan cooled. The air intake is at the front panel and the exhaust is at the rear panel. Upon installation allow cooling air to reach the front panel ventilation inlets. Allow minimum 25cm (10 Inch) of unrestricted air space at the front and the rear of the unit.

NOTICE

For unrestricted service access the following has to be observed:

- The minimum required upper body clearance (shoulder width) should be 890 mm (35 in).
- The minimum required forward horizontal clearance during standing service tasks should be 810 mm (32 in). The minimum required forward horizontal clearance during sitting service tasks should be 810 mm (32 in).
- The minimum clearance for two hands arm to shoulders access should be:
  - reach: maximum 610 mm (24.0 in)
  - width: minimum 483 mm (19 in)
  - height: minimum 114 mm (4.5 in)

9.4.1 Seismic Protection

For the C_S-corrector of the CETCOR system no seismic calculation has been made by the manufacturer. Therefore it is due to the microscope provider to observe the requirements of sections 19.1 - 19.4 of SEMI S2-0703 after the C_S-corrector has been installed in the microscope column.

For the Power Supply Cabinet (PSC) of the CETCOR system a seismic calculation has been made by the manufacturer, indicating that the PSC needs to be secured to prevent hazards during a seismic event. Seismic attachment point hardware including an installation manual for this hardware can be obtained from the manufacturer upon request. Additional information about weight distribution, center of mass and technical drawings of the anchorage points can be found in that manual also. For seismic protection, instead of the four transport rollers, two bars will be mounted on bottom of the PSC, which can be screwed down to the floor.

IMPORTANT

Please note, that the replacement of the transport rollers by the mounting bars requires to lift the PSC off the floor. It is not allowed to move or lift the PSC with any external connection already established.

9.5 AC source for the power supply cabinet

IMPORTANT

Connection of the power supply cabinet to an AC power source should be made by an electrician or other qualified personnel.

9.5.1 AC source requirements

Both, the corrector PC and the base power supply can be operated from a nominal 100V to 240V, 1/N/PE, 47~63Hz AC source. For further specifications refer to Section 8.

EMERGENCY-OFF FUNCTIONALITY, OVERCURRENT PROTECTION, AND CURRENT INTERRUPTING CAPACITY

As the CETCOR system is a subunit of the electron microscope and not intended to be used as stand-alone equipment, it has no emergency-off (EMO) circuit. It is due to the microscope provider to include the CETCOR system into the general emergency-off (EMO) functionality of the overall microscope system and to fulfill the requirements of the entire section 12 of SEMI S2-0703.

The CETCOR system has to be powered by the microscope main supply unit. Therefore it is due to the microscope provider to provide the necessary main overcurrent protection devices and main disconnect devices rated for at least 10000 rms symmetrical amperes interrupting capacity and to observe the requirements of SEMI S2-0703, sections 13.4.1 and 13.4.11. If the main disconnect of the overall microscope system is placed to the off position it should interrupt all power to the CETCOR system. The main disconnect of the overall microscope system should fulfill the requirements for affixing energy isolating ('lockout/tagout') devices.

No warranty is taken by CEOS GmbH if this functionality is not provided by the microscope provider. It is not allowed to use the CETCOR system without these measures.

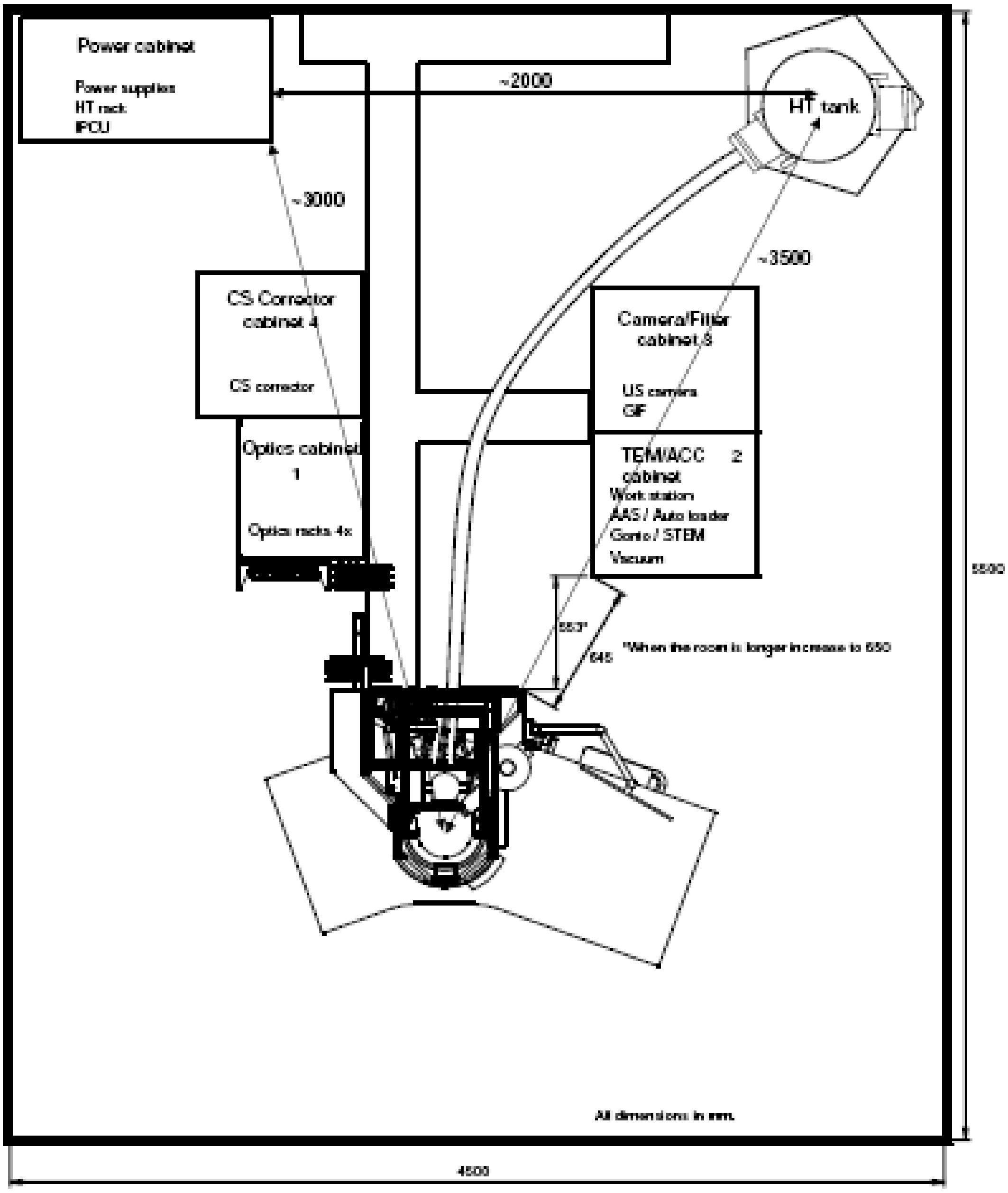


Figure 6: Schematic layout of the electron microscope equipped with a C_S-corrector.

ENERGY ISOLATION

It is due to the microscope provider and/or user to ensure that the energy isolating devices of the overall microscope system are located in a place where the person actuating or inspecting the devices is not exposed to serious risks or contact to hazardous equipment.

It is due to the microscope provider to verify that the main disconnect of the overall microscope system should be in a location that is readily accessible and lockable only in the deenergized position.

9.6 Wiring of the power supply

9.6.1 Preparations

Verify that the CETCOR system has been deenergized. Follow the 'save deenergizing procedure' in Section 9.1 if the CETCOR system is energized.

Remove all panels on the back side of the PSC which are labeled as 'removable'. It is not allowed to remove panels which are not labeled as 'removable'.

IMPORTANT

Depending on the output voltage of the AC source provided for powering the CETCOR system, the rating of the fuse F1 has to be chosen. Two different types of fuses according to the ratings given in Section 7.1 are shipped with the corrector: According to the output voltage of the AC source select the suitable fuse and insert it into the fuse holder next to the main switch at the back panel of the power supply cabinet:

- For a nominal source voltage of 100V (UL) use:
  1x Bussmann FNQ-10 / Littlefuse FLQ-10

- For a nominal source voltage of 240V (IEC) use:
  1x gl-gG 4A (120kA breaking capacity).

CAUTION

Never try to remove the panel where the main switch and the service power outlets are mounted on.

NOTICE

The power supply cabinet will be delivered with the grounding wire and the AC feed cables already mounted and connected to the internal circuitry.

9.6.2 Connections

⚠ CAUTION

Electrical shock hazard: There is a potential shock hazard as long as the PSC chassis (with panels and covers in place) is not connected to an electrical safety ground.

Proper grounding of the PSC is mandatory. Connect the safety ground before connecting anything else following No. 1. below.

1. Connect the PSC ground and the microscope ground (central grounding point at the column) with the cable provided. The cable is labeled as ’-W1E_COL’.
2. Connect the CDU outputs (left at the back side of the CDU) and the corrector inputs (terminal box) with the cable harness delivered. Each harness cable is labeled with an identifier (e.g. ’TL1 DEF’) on either end. On the column side of the harness the letter ’C’ (for ’column’) is added to each label. All connectors are color, key and size coded. Where the cable harness leaves the PSC, secure it carefully with the metal clip provided. Do not tighten the screw more than necessary for locating the harness in position.
3. Connect the PDU signaling cable provided with the waterflow control unit with the PDU (labeled as ’lens cooling monitoring’, connector -X_S15 at right hand side at the back).
4. Prior to connecting the AC power feed cables to the microscope main power supply, make sure that the PSC main switch, the PC main switch and the base supply main switch are in the OFF position.

⚠ WARNING

Electric shock hazards: Line voltage can be present at the microscope main power supply. You may receive an electric shock, which can result in a fatal or serious injury.

Lock out power at the equipment of the microscope provider before connecting the CETCOR system.

The connection points have to be specified by the microscope provider. Follow the safety instruction of the microscope provider to avoid electric shock hazards at the main power supply of the microscope.
Connect the PSC feed (-W1_PSC) and the corrector PC feed (-W1_PC) cables to the power supply main input line and the corrector PC main input line of the main power supply of the microscope. The wires labeled with ’L’ and ’1’ should be connected to the potential further away from ground (phase), while the wires labeled with ’N’ and ’2’ should be connected to the potential closer to ground (neutral). Do not connect the ground wire (green-yellow) of the feed cables.

9.7 Water cooling

CAUTION

Cooling water circuits: Improper connected cooling water circuits may cause equipment damage.

If water enters the microscope column it can cause serious corrosion and electric short circuits.

Prepare connections of the cooling water system carefully following the procedure given below. Deenergize the cooling water lines of the microscope equipment which are provided for the CETCOR system before connecting the waterflow control unit to the cooling water lines of the microscope.

9.7.1 Internal connections

Plug the column side connectors of the cooling water hoses into the column. The double O-rings should be carefully greased. Fixate each connector using the special fixating screw. Verify that

- the connector and the lens coil have no mechanical contact except the O-rings (then, with the fixating screw mounted, the connector still can be turned slightly about the axis of the screw),
- both O-rings are in contact with the inlet in the lens coil.

9.7.2 Requirement for external connections

The CETCOR system has to be connected by two hoses with an inner diameter of 9 mm to the cooling water system of the electron microscope. For further specifications refer to Section 8.

ENERGY ISOLATION

It is due to the microscope provider and/or user to ensure that the energy isolating devices of the overall microscope system are located in a place where the person actuating or inspecting the devices is not exposed to serious risks or contact to hazardous equipment.

It is due to the microscope provider to verify that the energy isolating devices of the cooling water supplies should be in a location that is readily accessible and lockable in a position in which the hazardous energy is isolated.

9.7.3 Preparation of external connections

Prepare deenergized cooling water lines at the microscope equipment before connecting the waterflow control unit to the cooling water lines of the microscope equipment. Refer to the installation manual of the microscope provider how to prepare an deenergized water line for the CETCOR system.

Connect and fixate two hoses (inner diameter of 9 mm) supported from the microscope cooling water system to the water inlet and outlet of the waterflow control unit.

Verify that the air inlet valve, the water inlet and water outlet valves are closed before energizing the cooling water line of the CETCOR system.

9.8 Testing

IMPORTANT

Before testing, mount all panels at the back side of the power supply cabinet which have been removed earlier except the top one. The screws with lock washer for panel grounding (of each panel) have to be mounted in the upper right corners of the panels above the grounding symbol.

For testing the functionality of the equipment, follow the procedure explained in Section 6.2.2. From the second step on, it is necessary to power the CETCOR power supply. For this, follow the procedure given in Section 6.3.

IMPORTANT

After booting the corrector PC, mount the top panel at the back side of the power supply cabinet. The screw with lock washer for panel grounding has to be mounted in the upper right corner of the panel above the grounding symbol.