MANUAL for BESO the »Bochum Echelle Spectroscopic Observer«

Updated: January 7, 2009

Contents

Contents **2**

1 Introduction **7**

2 Instrument Description **9**
2.1 Optical Layout 10
2.2 Mechanical Layout 10
2.3 Interface to the Hexapod-Telescope 10
2.4 Imaging electronics 11
2.5 Instrument workstation 11

3 Instrument Control **13**
3.1 Detector Readout Software (Voodoo) 13
3.2 Data reduction (MIDAS) 15
3.3 AK-Nord Port Server 15
3.4 Fiber Viewer 16
3.5 Exposure Time Calculator 16

4 Observations **19**
4.1 Essentials 19
4.2 When arriving at the observatory (before your observation-run) . . 19
4.3 Before observing (at the beginning of every night) 19
4.4 When leaving the observatory (after your observation-run) 20

5 Maintenance **21**
5.1 Daily (before and after observations) 21
5.2 Weekly (before and after observing runs) 21
5.3 Regular service tasks (every 6 months) 21

6 Step by step instructions **23**
6.1 Starting the Cryo-System 23
6.2 Stopping the Cryo-System 23
6.3 Heating the Cryo-System 24
6.4 Evacuating the Cryo-System 24

6.5 Mounting the fibers to the telescope . . . 25
6.6 Unmounting the fibers from the telescope . . . 25
6.7 Taking bias frames . . . 25
6.8 Measuring dark current . . . 25
6.9 Taking flat fields . . . 26
6.10 Measuring relative fiber transmission . . . 26
6.11 Measuring the instrument response curve . . . 26
6.12 Vibration-damping system . . . 27

7 Optical Design 29

8 Mechanical Design 33
8.1 Fiber Exit Unit . . . 33
8.2 Main Collimator . . . 39
8.3 Echelle Grating Unit . . . 41
8.4 Fold Mirror . . . 44
8.5 Transfer Collimator . . . 49
8.6 Axial Supports . . . 50
8.7 Prism Support . . . 54
8.8 Camera . . . 57
8.9 CCD Cryo-System . . . 62
8.10 Clamps . . . 65
8.11 Stop / Stopadjust . . . 67
8.12 Enclosure . . . 69
8.13 Tools . . . 71
8.14 Fiber Head . . . 72
8.15 Calibration Unit . . . 73

9 Imaging System 81
9.1 CCD . . . 81
9.2 Cryo-System . . . 81
9.3 Electronics . . . 81
9.4 Shutter . . . 82

10 Instrument Alignment 83
10.1 Fiber Exit Unit Head . . . 83
10.2 Detector . . . 83
10.3 Instrument . . . 84
10.3.1 FEU . . . 84
10.3.2 Fibers - FEU . . . 84
10.3.3 FEU - Main Collimator . . . 84
10.3.4 FEU - Folding Mirror . . . 85
10.3.5 FEU - Transfer Collimator . . . 85
10.3.6 Echelle . . . 85

10.3.7 Prism 85
10.3.8 Detector + Camera 85
10.4 Telescope Adapter 85
10.5 Calibration Unit 85

11 Safety **87**
11.1 Handling of heavy and sensitive parts 87
11.2 Clibration lamps: High voltage, radioactive elements, UV rays . . 87
11.3 Earthquakes 87

12 Appendix **89**

Chapter 1

Introduction

BESO, the »Bochum Echelle Spectroscopic Observer«, is a spectrograph for the 1.5 m Hexapod-Telescope. The design of BESO follows the design of FEROS, the Fiber-fed Extended Range Optical Spectrograph, that was built for the European Southern Observatory at La Silla.

BESO is built by the astronomical institute of the Ruhr-Universität Bochum together with the Landessternwarte Heidelberg. BESO enables the Hexapod-Telescope to perform high-resolution spectroscopic observations of objects as faint as 16th magnitude.

BESO has been built by Rolf Chini (PI at Ruhr-Universität Bochum), Ingo Steiner (Ruhr-Universität Bochum), Walter Seifert (Landessternwarte Heidelberg), Otmar Stahl (Landessternwarte Heidelberg) and many helping hands. The instrument arrived at Cerro Armazones Observatory in December 2007. The project has been financed with a grant from Alfried Krupp von Bohlen und Halbach foundation.

Up-to-date information is available from the Instrument website: `http://www.astro.rub.de/beso/`.

Chapter 2

Instrument Description

BESO is a cross-dispersed echelle spectrograph with a two-beam, two-slice image slicer. It is bench mounted in a separate, thermally stabilized room. The instrument is fiber-fed by two fibers. One fiber guides the light from the object, the other fiber is used for background light from the nearby sky.
The configuration of BESO is fixed. No user-moveable parts exist beside the CCD-shutter. Online data-reduction software is supplied for a quick reduction of the recorded spectra.

Table 2.1: BESO performance specifications.

Wavelength range (one exposure)	370 – 860 nm
Resolution	$\lambda/\Delta\lambda$ = 48,000
Radial velocity resolution	$<$ 50 m/s
Limiting magnitude	16 mag (1 h, S/N = 10)
	17 mag (1 h, 2x2 binning)
Entrance aperture	3.4 arcsec
Fiber distance	3.5 arcmin
Fiber input/output focal ratio	f/4.6
Spectrograph beam size	136 mm
Off-axis collimators	f/11
Camera focal ratio	f/3
Camera focal length	410 mm
Camera field diameter	69 mm
CCD size	4096 x 2048 15 μm pixel
CCD operating temperature	-100 °C
CCD readout-noise	4.2 e^-
Overall efficency estimate	6% at 370 nm
(without telescope)	21% at 500 nm
	9% at 900 nm

2.1 Optical Layout

BESO is a bench-mounted spectrograph using an echelle grating as main dispersing element and a prism for cross-dispersion. BESO is mounted in a temperature-stabilized room located 20 meters away from the Hexapod-Telescope. The starlight and light from the nearby sky-background is guided in two separate 100 μm glass-fibers from the telescope into the spectrograph. Both sky and object spectra are recorded simultaneously.
Microlenses on top of each fiber convert the f/8 telescope beam into a f/4.6 beam, which is best for transmission through the fiber. At the fiber-exit in the instrument a focal-enlarger lens system converts this beam to f/11. An image-slicer halves the width of the beam in the direction of dispersion to double the spectral resolution of the instrument.
The echelle grating is used in quasi-Littrow condition ($\gamma = 0.6^\circ$ off Littrow-angle) with 79 lines/mm. The entrance-pupil is re-imaged on this grating via an off-axis collimator. The beam diameter is 136 mm. The dispersed light is going back via the off-axis collimator and a flat folding mirror to the transfer off-axis collimator.
The light is cross-dispersed by a prism. The two-dimensional echellogram is imaged onto the detector by a f/3 camera. The field lens serves as entrance window of the closed-cycle cooled dewar. The detector is a CCD with 2048 x 4096 15 μm pixels.

2.2 Mechanical Layout

The mechanical layout of the spectrograph has been designed and all parts have been manufactured to guarantee best possible long-term stability of the instrument. All optical elements are mounted on one bench, which is equipped with a vibration damping system. This optical bench stands on a concrete base that is decoupled from the surrounding building for vibration insulation. The spectrograph is located in a separate room, which is temperature stabilised to +/-0.1 °C/h and +/-0.5 °C/day. The camera-unit is equipped with a focusing mechanism that automatically corrects for residual temperature drifts.
The optical elements are held in stiff housings made from stress relieved aluminum. The housings are clamped to the optical bench. Each housing allows a fine and reproducible adjustment of the optical element.
An aluminum enclosure covers the optical bench to avoid stray light, turbulent air and dust from interfering with the instrument. The enclosure also enhances the thermal stability of the instrument.

2.3 Interface to the Hexapod-Telescope

The mechanical interface of BESO to the Hexapod-Telescope consists of two parts. One is the plug to mount the fiber-pair in the focal-plane of the telescope. The top

of the plug is an electroformed plate that serves as pupil for the microlenses on top of the fibers and as mirror for a precise positioning of the object-fiber to the desired object. The fiber-head is monitored continuously during the exposure with a fast CCD-Camera. The second part of the interface is the calibration sources for BESO. Two halogen-tungsten lamps for flatfielding and one thorium arc-lamp with neon-argon filling for wavelength calibration are used.

2.4 Imaging electronics

The CCD-camera for monitoring of the fiber-head is a commercial device from Santa Barbara Instrument Group that is capable of imaging at 1 frame/sec due to the small chip size and USB 2.0 data transfer.
The spectrum is imaged to a 4k x 2k CCD from e2v technologies. It is read-out by a 16 bit AD-converter from Astronomical Research Cameras. The data is transferred from the AD-converter to the instrument workstation via a fiber-optic link.

2.5 Instrument workstation

The instrument workstation is a personal computer that allows the observer to control all functions of the instrument. Fiber-head monitoring, exposure-control of the science CCD and the storage and reduction of data can be done from this machine.

Chapter 3

Instrument Control

The instrument workstation is a personal computer running Windows XP and all software necessary to operate the instrument and reduce the data. The desktop is shown in fig. 3.1. Data can be archived to DVDs.

3.1 Detector Readout Software (Voodoo)

The software shipped with the detector readout electronics is called Voodoo. When started the software allocates a certain memory space for data transfer from the readout electronics. Unfortunately the detector size of BESO is larger than this default memory space - so an error message appears during startup (see fig. 3.2).

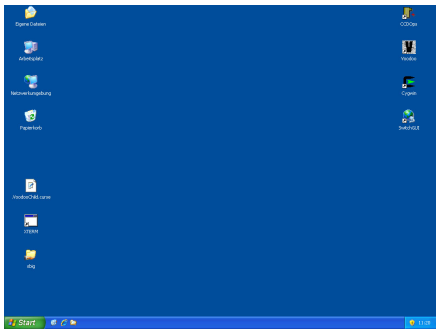


Figure 3.1: Workstation Windows Desktop.

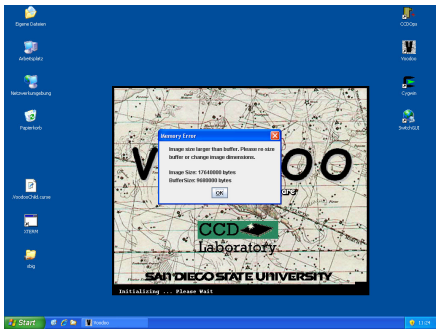


Figure 3.2: Error message during startup.

After clicking 'Ok' the observer needs to open the 'Setup' and click on 'Apply'. All settings are stored in the software and also the image buffer is now adjusted to the required size (see fig. 3.3).
To work around an initialization bug in Voodoo the observer needs to open 'Parameters', go to the 'Readout'-Tab, click on Readout-Mode 'Right' and 'Apply'. Then on 'Left' and 'Apply'. Now the proper readout-mode has been communicated to the readout electronics (see fig. 3.4).

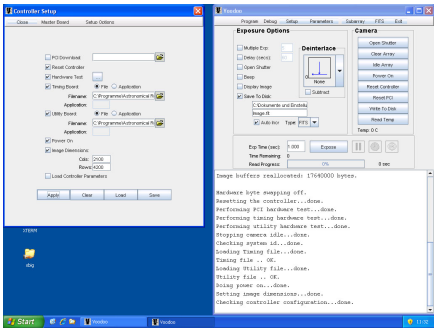


Figure 3.3: Detector Setup.

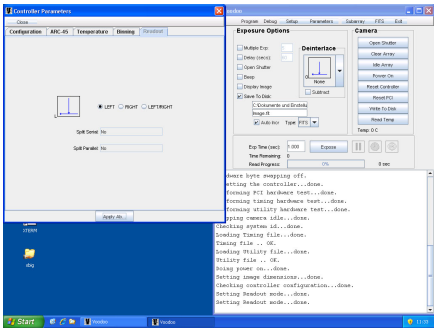


Figure 3.4: Detector readout parameters.

To make sure that the CCD temperature is set properly go to the 'Temperature'-Tab in 'Parameters', enter the operating temperature of the CCD, check 'Control Array Temperature' and click 'Apply' (see fig. 3.5).
After this procedure, that has to be repeated whenever the Voodoo software is started, the science operation can begin using Voodoo's main panel (see fig. 3.6).

- Enter a suitable, existing directory as location for your files.
- Make sure 'Auto Incr' is checked for the filename.
- Make sure 'Open Shutter' is checked when taking spectra.
- Check the CCD temperature regularly with the 'Read Temp'-Button.
- Set the exposure time as indicated by the online exposure time calculator.
- Press 'Clear Array' button as the software is not performing this reliably.
- Press 'Start Exposure' button when the telescope is in position.

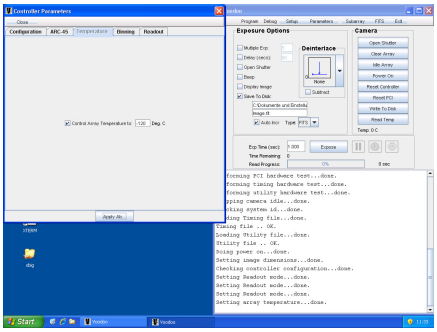


Figure 3.5: Temperature parameters.

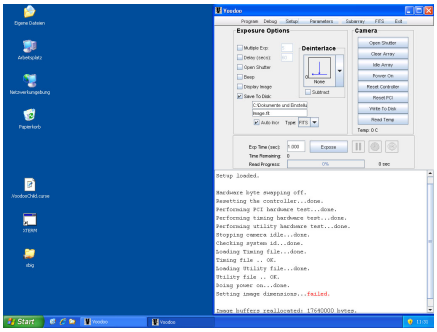


Figure 3.6: Detector control main panel.

Optional settings:
- 2 Channel readout (reduces readout time from 30sec to 15sec)
- Binning (for faint sources - no pipline support)
- window-mode (for testing)

3.2 Data reduction (MIDAS)

Images can be reduced automatically by the data reduction pipeline. To prepare the pipeline for an observation save the actual flat-field (named 'flat.fit') and wavelength calibration (named 'thar.fit') frame to the directory '//acs01xp/observation/'.

Start a cygwin window and type 'cd pipeline', then 'inmidas 00'.
Start a second cygwin window and type 'cd pipeline', then './poll'.

The script monitor the directory '//acs01xp/observation/' and processes new files in MIDAS. The output spectra are saved to '//acs01xp/observation_reduced/' with the extension _m1 and _m2 for the two fibers of the instrument.

Don't forget to move the files to another directory at the end of the night. As they are easily overwritten by new files from the next day!

To view the spectra use the following MIDAS commands as quick reference:

- inmidas (start MIDAS)
- create/display (open display window)
- load/image xxx.fits (load and display FITS-File)

- create/graph (open window for graphs)
- plot/row file y x1,x2 (plot section of the spectrum)
- assign/graph postscript (switch output to postscript)

3.3 AK-Nord Port Server

The AK-Nord software can be used to scan for the IP address of the port server. The Java-Tool FCU-Gui can be used to switch the lamps and motors in the calibration unit.

Settings at the Port Server:
- Password: XT
- Input Timeout: 100
- Baudrate: 19200
- Databits: 8
- Parity: N
- Stopbits: 1
- Flow Control: N
- Emulation: NO
- Lines: RTS:0 DCD:0 DTR:2 DSR:0

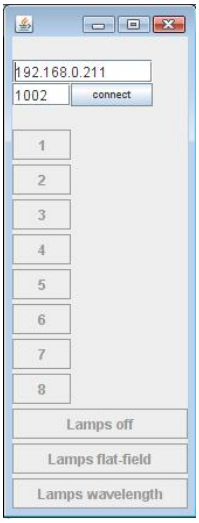


Figure 3.7: FCU-Gui to control the calibration unit.

3.4 Fiber Viewer

The SBIG software CCDops can be used to read the camera continously. (Menu option 'Focus').

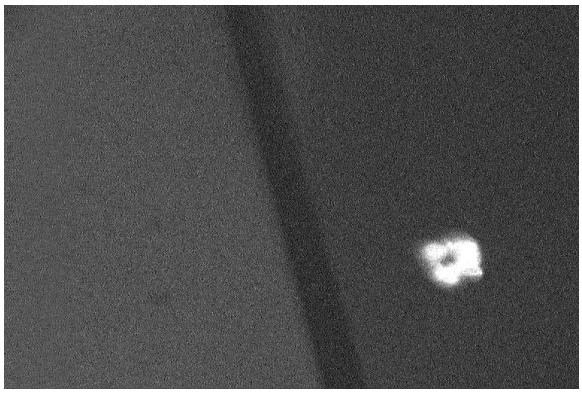


Figure 3.8: Fiber-Viewer image with one star positioned on the fiber.

3.5 Exposure Time Calculator

The exposuretime calculator on the internet can be used to plan your observations. It is accessible from the AIRUB website `http://www.astro.rub.de/beso/`.

preliminary BESO Exposure Time Calculator

The calculator computes the S/N per pixel (1 resolution element = 2.2 pixels) for a given exposure time.
Calculations are based on measured performances during the FEROS Commissioning.

Object	**Observing conditions**	**CCD**
Magnitude in V: 12	Moon brightness: grey	readout noise (electrons): 4.2
spectral type: O	seeing (arcsec): 1.5	dark current (electrons/hour/pixel): 88.
reddening E(B-V): 0.0	airmass: 1.5	full well capacity (electrons): 115000
Exposure	Temperature (centigrade): 15	**Telescope**
	atmospheric pressure (hPa): 773	
Exposure time (sec): 600	relative humidity (percent): 5	mirror diameter (cm): 150
Number of fibers: 1 2		telescope efficiency: 0.6

Display result Reset all fields

Expected S/N per pixel in UBVRI					
	U	**B**	**V**	**R**	**I**
Flux from star (electrons/bin)	52	1486	1135	924	480
Flux from sky (electrons/bin)	0	2	2	4	4
Dark current (electrons/bin)	191	191	191	191	191
Readout noise (electrons/bin)	15	15	15	15	15
Expected S/N (per pixel)	1.7	30.8	25.5	22.0	13.2
Additional information					
The slit losses due to the seeing are 2.9 percent.					
0.1 percent of your CCD pixels (1.8 percent of your wavelength bins) are hit by cosmic rays.					
atmospheric refraction: 50.0 arcsec at lambda = 3600 Angstrom, 48.1 arcsec at lambda = 9200 Angstrom length of spectrum = 1.9 arcsec, fiber diameter = 3.4 arcsec					

Figure 3.9: Web-based exposure time calculator for BESO.

Chapter 4

Observations

Observing with BESO is easy, because the observer does not need to worry about all technical details explained in this manual. Please use the following section as a quick guide to get accustomed with BESO. Plan for enough time to do all required tasks.

4.1 Essentials

- The Chapter “Instrument Description” (2) will give you a rough idea how this instrument works.
- Please read the chapter “Instrument Control” (3) to get accustomed to the instrument controls and the data reduction procedure.

4.2 When arriving at the observatory (before your observation-run)

- Check the maintenance plan (5) for what needs to be done.
- Evacuate the Cryo-System (6.4). This process takes approx. 12 hours.
- Start the Cryo-System (6.1). This process takes approx. 6 hours.
- Switch on the instrument power supply and the instrument workstation.

4.3 Before observing (at the beginning of every night)

- Check the maintenance plan (5) for what needs to be done.
- Prepare your flat-field and wavelength calibration frames for the automatic data reduction.

4.4 When leaving the observatory (after your observation-run)

- Check the maintenance plan (5) for what needs to be done. This is to make sure that the next observer finds the instrument in perfect shape and to make sure that all your data has perfect quality.
- Stop the Cryo-System (6.2).
- Switch off the instrument power supply and the instrument workstation.

Chapter 5

Maintenance

5.1 Daily (before and after observations)

- Check BESO room temperature
- Check BESO CCD temperature
- Check bias frame. (see 6.7)
- Check flatfield. (see 6.9)

5.2 Weekly (before and after observing runs)

- Check that cables are mounted to the telescope correctly.
- Check instrument focus.
- Check order position, both along dispersion and crossdispersion.
- Monitor number of lines used by MIDAS.
- Check spectrum of flatfield lamps.
- Check the dark current of the CCD system. (see 6.8)

5.3 Regular service tasks (every 6 months)

- Check pressure of vibration-damping system. (see 6.12)
- Check if shutter opens completely and is light-tight when closed.
- Check relative fiber transmission. (see 6.10)
- Check if flatfield lamps need to be re-tuned.
- Check spare-part list.
- Do calibration with standard-stars.

Chapter 6

Step by step instructions

This chapter shall provide step-by-step instructions for the most common procedures. Although they should be easy to follow a deeper understanding of the instrument is crucial to avoid damage.

6.1 Starting the Cryo-System

The imaging detector can only operate at cryogenic temperatures. A stable temperature is crucial for a stable instrument performance.
This procedure assumes that the instrument has been out of operation for an extended period (weeks or more), no works have been done on the cryo-system and that power-supply, cables and cold-head are intact and the refrigerant pressure is about 280 psig.

1. Start the instrument workstation and power on the imaging electronics. Set the CCD temperature to operating temperature (-100..-120°C).

2. Turn the power-switch on the Cryo-Tiger front panel to ON.

Now you should hear a noticeable compressor sound and the refrigerant-pressure must drop to about 0 psig quickly.
If the power to the Cryo-Tiger is interrupted during operation, the compressor will restart automatically after the pressure at intake and outlet has equalized and the temperature in the compressor housing is normal. It may take several minutes for this condition to establish - but no user action is required unless there is any malfunction.

6.2 Stopping the Cryo-System

The Cryo-System should only be stopped if the instrument is out of use for an extended period (weeks or longer) as a stable detector temperature is crucial for

a stable instrument performance. During warm-up the detector temperature must always be warmer than any other component in the dewar to avoid contamination of the detector-surface.
This procedure assumes that the instrument has been in operation for an extended period, that the dewar cold-plate is at about -150 °C and the detector at operating temperature.

1. Set the CCD temperature to 30 °C. Wait several minutes until the CCD-Temperature has warmed up significantly.
2. Turn the power-switch on the Cryo-Tiger front panel to OFF.
3. Leave the imaging electronics and the instrument workstation ON until the detector temperature has reached 30 °C.

The refrigerant-pressure must raise to about 280 psig slowly.

6.3 Heating the Cryo-System

If the CCD surface is visibly contaminated the whole cryo-system can be heated to remove adsorbed vapor. This may take 24 hours or more.
This procedure assumes that the cryostat has been in use and gaseous contaminants have been adsorbed by surfaces other than the charcoal getter.

1. Stop the Cryo-System cooler.
2. Connect the heater pad on the cryostat to DC current, cover the cryostat with insulation foil and pump the cryostat while heating. 15 W heating power results in approx. 20 K above ambient temperature.
3. Monitor CCD temperature and check the CCD surface visually.
4. Disconnect the heating and start the Cryo-System cooler when all contaminant has been removed and the pressure has dropped below $10^{-}5$ mbar.
5. Close the cryostat valve and stop the vacuum pump when the dewar is cold.

6.4 Evacuating the Cryo-System

Over time the vaccuum in the cryo system might degrade. If the system does not cool down to operating tempereture the systems needs to be evacuated. The vaccuum pump and the pressure gauge are permanently attached to the dewar. The pressure gauge does not give a reading if the pressure is above 10^{-3} mbar.
Depending on the time the system has been filled with air this process can take 12-24 hours.

1. Make sure the CCD is at room temperatue. If it is not turn off the cryo-system (6.2) and wait until the CCD has warmed up (several hours).
2. Turn on the vaccuum pump.
3. Turn on the pressure gauge. Press the right button on the front-panel for several seconds to power up the gauge.
4. Wait until the pressure reading is below 10^{-5} mbar.
5. Then open the valve at the dewar fully.
6. Wait until the pressure reading is below 10^{-5} mbar (this can take 12-24 hours).
7. Then turn on the cryo-system (6.1).
8. Close the valve, when the CCD has reached operating temperature (this can take 6 hours).
9. Turn off the vaccuum pump.
10. Turn off the vaccuum gauge.

6.5 Mounting the fibers to the telescope

6.6 Unmounting the fibers from the telescope

6.7 Taking bias frames

Bias frames are an important check to detect bad pixels on the CCD. Bias frames should be stored to monitor the system performance on longer time scales.

1. Take 10 frames with 0 sec exposure time and shutter closed.
2. Median-average 5 frames and average the resulting two frames. The resulting frame is the bias frame. If it shows any kind of pattern, the cause needs to be investigated.

6.8 Measuring dark current

The dark current of the CCD system should low enough to be neglected even for long science exposures. To verify this the dark current should be monitored regularly.

1. Take 4 frames with 1800 sec (30 min) exposure time and shutter closed. Take 5 bias exposures before each 30 min frame.

2. Median-average the 5 bias frames and substract the median-bias from the respective 30 min frame. The four bias-corrected dark frames should be median-averaged to exclude charged particle events. The resulting frame needs to be multiplied with the gain of the CCD-System and scaled to the exposure time to get the dark current in e^-/h.

6.9 Taking flat fields

Flat field frames are used by the data reduction pipeline to determin where the orders of the spectra are on the CCD. The flat field lamps in the calibration unit produce a flat spectrum that illuminates every wavelength bin on the CCD. The flat field also allows a quick check if both fibers are illuminated homogeniously.

1. Switch the calibration unit to flat field mode and allow the tungsten lamps at one minute to heat up.

2. Take 5 frames so that the brightest pixels reach about 45.000 ADU with exposure times longer than 5 sec to avoid shutter patterns on the spectrum.

3. Check the flat fields visually. Are all orders illuminated? Are both fibers equally bright? Have the orders shifted since the last flat field? Is the instrument focused correctly?

6.10 Measuring relative fiber transmission

Both fibers of the instrument do not have the same transmission. A correction factor must be determined regularly to detect possible degradation (e.g. due to dust).

1. Use sky light with exposure time about 30 sec.

2. Extract orders without flatfielding. Devide each order by the same order of the second fiber. The mean factor is the relative transmission.

3. Check if the fiber transmission curve has changed.

6.11 Measuring the instrument response curve

For scientific measurements it is important to know the overall efficiency and the response curve of the system (telescope + fiber + instrument). For this measurement good seeing (better than 1.2 arcsec) and a stable good focussing of the telescope is required.

1. Take 3-4 different standard stars (see Appendix) and wavelength calibration frames.

2. Use standards reduction procedure. To compute overall efficiency use MIDAS procedure /FEROS/MIDAS_prg/efficiency.prg.

3. Compare output for different standards and of previous checks for consistency.

6.12 Vibration-damping system

The four struts of the optical bench feature a vibration damping system. The air cussion should be filled to at least 10 psi above the pressure that lifts the optical table from the lower limit stop. The load of the instrument is not distributed equally on the tabletop. A pump with pressure gauge is stored with the instrument. Regular car tyre valves are used. The tabletop must float easily when the air cussions are propperly filled.

Chapter 7

Optical Design

BESO is a bench-mounted spectrograph using an echelle grating as main dispersing element and a prism for cross-dispersion. The starlight and light from the nearby sky-background is guided in two separate 100 μm glass-fibers from the telescope into the spectrograph. Both sky and object spectra are recorded simultaneously.

Microlenses on top of each fiber convert the f/8 telescope beam into a f/4.6 beam, which is best for transmission through the fiber. The Polymicro FBP fiber was chosen because of it's reduced absorption in the 700 nm regime. At the fiber-exit in the instrument a focal-enlarger lens system converts this beam to f/11. An image-slicer halves the width of the beam in the direction of dispersion to double the spectral resolution of the instrument.

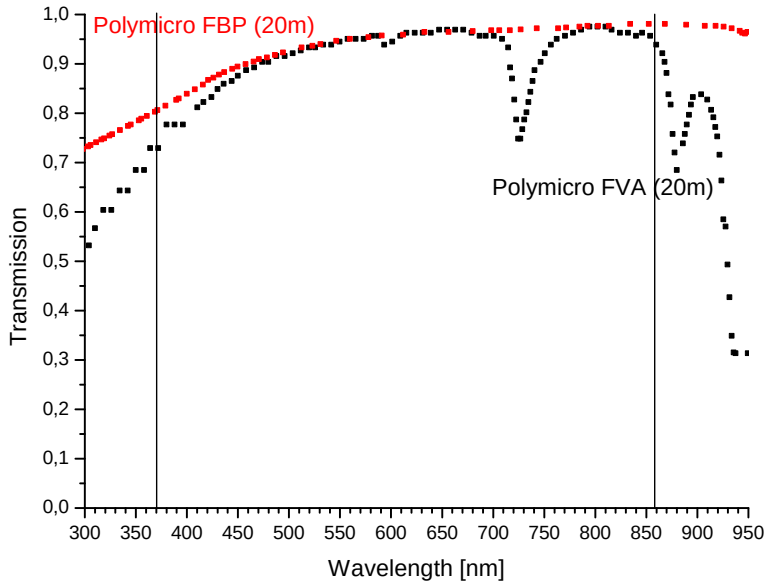


Figure 7.1: Theoretical transmission of the new fiber type.

The echelle grating is used in quasi-Littrow condition ($\gamma = 0.6^\circ$ off Littrow-angle) with 79 lines/mm. The entrance-pupil is re-imaged on this grating via an off-axis collimator. The beam diameter is 136 mm. The dispersed light is going back via the off-axis collimator and a flat folding mirror to the transfer off-axis collimator. The collimators are manufactured by Optical Surfaces, UK. They are cut from one parabolic f/2.2 mirror with 680 mm diameter.
The light is cross-dispersed by a LF 5 prism, made by Winlight, France. The size is 230 mm length, 173 mm height, 55° angle. The prism is hand polished and produces wavefront transmission abberations of less than $\lambda/4$ (peak to valley). The two-dimensional echellogram is imaged onto the detector by a fully dioptric f/3 camera. The camera is manufactured by Fisba Optik, Switzerland. The field lens serves as entrance window of the closed-cycle cooled dewar. The detector is an e2v technologies CCD with 2048 x 4096 15 μm pixels. The CCD is coated using e2v's astronomy broadband coating.
The echellogram on the CCD consists of 40 orders. The slit image on the detector spans 2.2 x 10.9 pixels. The inter-order distance is 30 pixels in the red and 100 pixels in the blue. Sky and object-spectra are separated by 16.4 pixels.

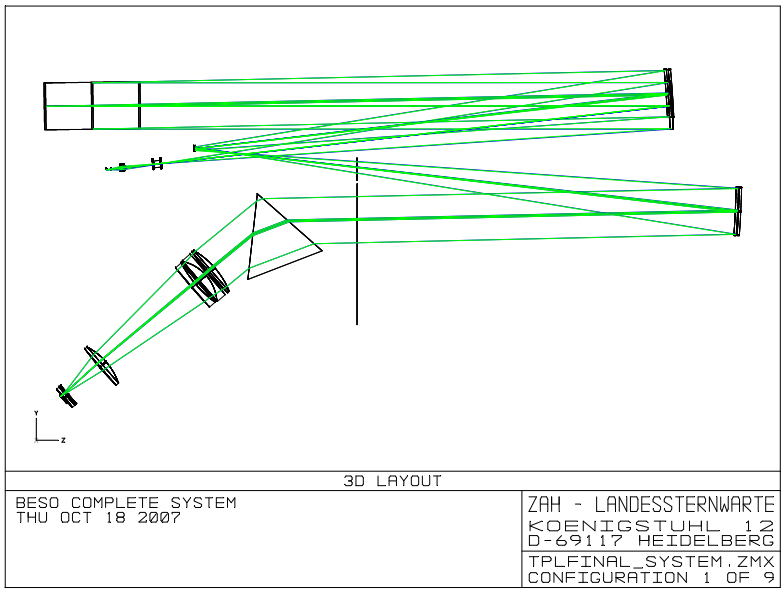


Figure 7.2: Optical design as simulated in ZEMAX.

System/Prescription Data

File : C:\ZEMAX\walter\FEROS\HPT-FEROS\CAMERA_24_tplmeltct.ZMX
Title: BESO Camera
Date : THU OCT 18 2007

GENERAL LENS DATA:

Surfaces	:	16
Stop	:	1
System Aperture	:	Entrance Pupil Diameter = 136
Glass Catalogs	:	SCHOTT MISC CORNING INFRARED OHARA HPT-FEROS
Ray Aiming	:	Off
Apodization	:	Uniform, factor = 0.00000E+000
Temperature (C)	:	2.00000E+001
Pressure (ATM)	:	1.00000E+000
Adjust Index Data To Environment	:	Off
Effective Focal Length	:	-412.2772 (in air at system temperature and pressure)
Effective Focal Length	:	-412.2772 (in image space)
Back Focal Length	:	-5.108279
Total Track	:	690.2584
Image Space F/#	:	3.03145
Paraxial Working F/#	:	3.03145
Working F/#	:	3.030334
Image Space NA	:	0.1627388
Object Space NA	:	6.8e-009
Stop Radius	:	68
Paraxial Image Height	:	34.61988
Paraxial Magnification	:	0
Entrance Pupil Diameter	:	136
Entrance Pupil Position	:	0
Exit Pupil Diameter	:	82.34541
Exit Pupil Position	:	249.5177
Field Type	:	Angle in degrees
Maximum Radial Field	:	4.8
Primary Wavelength	:	0.656 µm
Lens Units	:	Millimeters
Angular Magnification	:	1.65158

Fields : 3
Field Type: Angle in degrees

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000
2	0.000000	3.500000	1.000000
3	0.000000	4.800000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY	VAN
1	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000	0.000000	0.000000
3	0.000000	0.000000	0.000000	0.000000	0.000000

Wavelengths : 5
Units: µm

#	Value	Weight
1	0.656000	1.000000
2	0.852000	1.000000
3	0.486000	1.000000
4	0.405000	1.000000
5	0.365000	1.000000

SURFACE DATA SUMMARY:

Surf	Type	Comment	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD		Infinity	Infinity		0	0
STO	STANDARD		Infinity	-100		136	0
2	STANDARD	FISBA RADIEN	-244.89	-25.09	CAM-SFPL53_NEW	160	0
3	STANDARD		633.82	-1		160	0
4	STANDARD		-1098.55	-8.07	CAM-NPSK3	158	0
5	STANDARD		-130.03	-30.08	CAM-SFPL52	153	0
6	STANDARD		1999.52	-10		153	0
7	STANDARD		349.74	-15.07	CAM-NBK7	153	0
8	STANDARD		1766.22	-332.1791		153	0
9	COORDBRK	0.35	-	0		-	-
10	STANDARD		-191.35	-25.05	CAM-NFK5	141	0
11	STANDARD		1001	-126.5393		141	0
12	COORDBRK	-.35	-	0		-	-
13	STANDARD		135.01	-2.09	CAM-SLAL59	74	0
14	STANDARD		Infinity	-10.09	SILICA	74	0
15	STANDARD		Infinity	-5		74	0
IMA	STANDARD		Infinity			69	0

Figure 7.3: System simulation data from ZEMAX.

```
System/Prescription Data

File : C:\ZEMAX\walter\FEROS\HPT-FEROS\FN-SYS_10.ZMX
Title: feros fn system
Date : THU OCT 18 2007


GENERAL LENS DATA:

Surfaces                 :               7
Stop                     :               1
System Aperture          : Entrance Pupil Diameter = 2.9
Glass Catalogs           : SCHOTT OHARA
Ray Aiming               : Off
Apodization              : Uniform, factor =   0.00000E+000
Temperature (C)          :    2.00000E+001
Pressure (ATM)           :    1.00000E+000
 Adjust Index Data To Environment  : Off
Effective Focal Length  :        31.31426 (in air at system temperature and pressure)
Effective Focal Length  :        31.31426 (in image space)
Back Focal Length       :        25.84499
Total Track             :           140.8
Image Space F/#         :        10.79802
Paraxial Working F/#    :        10.90186
Working F/#             :        11.01581
Image Space NA          :      0.04581558
Object Space NA         :       0.1083804
Stop Radius             :            1.45
Paraxial Image Height   :       0.4509353
Paraxial Magnification  :       -2.377097
Entrance Pupil Diameter :             2.9
Entrance Pupil Position :               0
Exit Pupil Diameter     :         716.867
Exit Pupil Position     :        -7814.9
Field Type              : Object height in Millimeters
Maximum Radial Field    :          0.1897
Primary Wavelength      :           0.365 µm
Lens Units              :   Millimeters
Angular Magnification   :     0.004045381

Fields          : 3
Field Type: Object height in Millimeters
#         X-Value         Y-Value          Weight
 1       0.000000        0.189700        1.000000
 2       0.000000       -0.189700        1.000000
 3       0.000000        0.000000        1.000000

Vignetting Factors
#         VDX         VDY         VCX         VCY         VAN
1   0.000000    0.000000    0.000000    0.000000    0.000000
2   0.000000    0.000000    0.000000    0.000000    0.000000
3   0.000000    0.000000    0.000000    0.000000    0.000000

Wavelengths     : 5
Units: µm
#           Value          Weight
 1       0.365000        1.000000
 2       0.405000        1.000000
 3       0.486000        1.000000
 4       0.656000        1.000000
 5       0.852000        1.000000

SURFACE DATA SUMMARY:

Surf      Type              Comment          Radius      Thickness                 Glass      Diameter          Conic
 OBJ STANDARD                             Infinity           13.3                              0.3794              0
 STO STANDARD                             Infinity           26.3                                 2.9              0
   2 STANDARD              POG 8580         171.161              4             S-FPL52              15              0
   3 STANDARD              POG 3680        -33.523            0.5                                  15              0
   4 STANDARD              POG 4450          43.529              3                LF5              15              0
   5 STANDARD              POG 2080          15.305              7             S-FPL52              15              0
   6 STANDARD              POG 3960        -36.813            100                                  15              0
 IMA STANDARD                             Infinity                                               10              0
```

Figure 7.4: System simulation data from ZEMAX.

Chapter 8

Mechanical Design

The first unit along the light path is the fiber exit unit' (see 8.1). Next is the main collimator (see 8.2), the Echelle Grating Unit (see 8.3), the fold mirror (see 8.4 and the transfer collimator (see 8.5). The respective optical elements are glued with 3M Scotch Weld 2216 B/A to invar pads. Axial supports (see 8.6) hold the optical components in their unit and allow adjustment.
The follwing unit holds the prism (see 8.7) next to the camera (see 8.8). Last is the cryo-unit (see 8.9) with the image sensor.
All units are attached to and adjusted on the optical bench with clamps (see 8.10) or stops (see 8.11). The optical bench is covered by an enclosure (see 8.12). Several tools (see 8.13) are provided for adjustments and alignment.
The spectrograph is connected to the telescope via the telescope adapter (see **??**). Reference images can be optained using the calibration unit at the telescope flange (see 8.15).

8.1 Fiber Exit Unit

The fiber exit unit consists of two parts. The support and the head. The support is screwed to the optical bench and defines the position of the head in direction, height and tilt. The head hold the optical fibers, the relay optics and the image slicer. The fibers can be adjusted for the seperation distance and the distance to the diaphragm. Relay optics and image slicer are individually adjustable in six degrees of freedom.

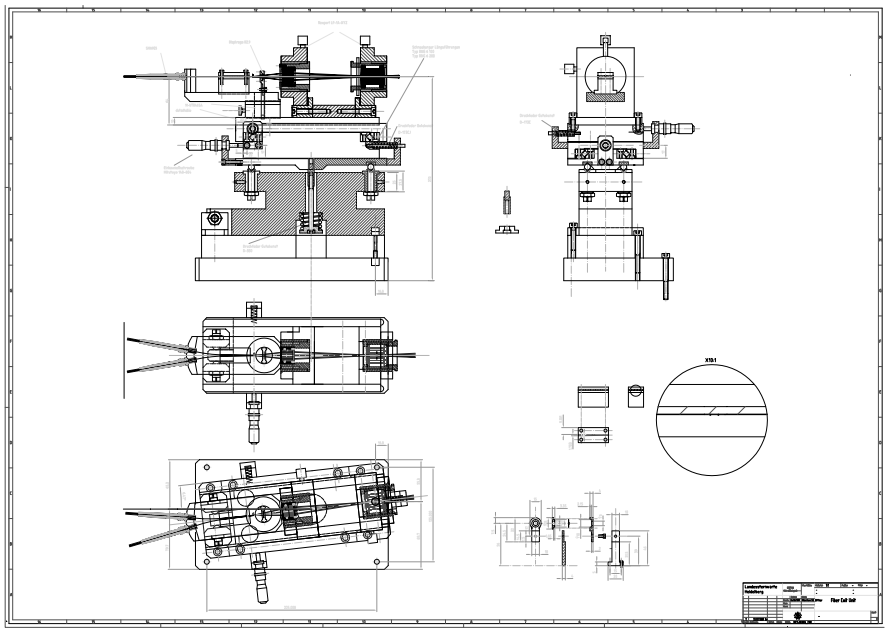


Figure 8.1: BESO-FEU

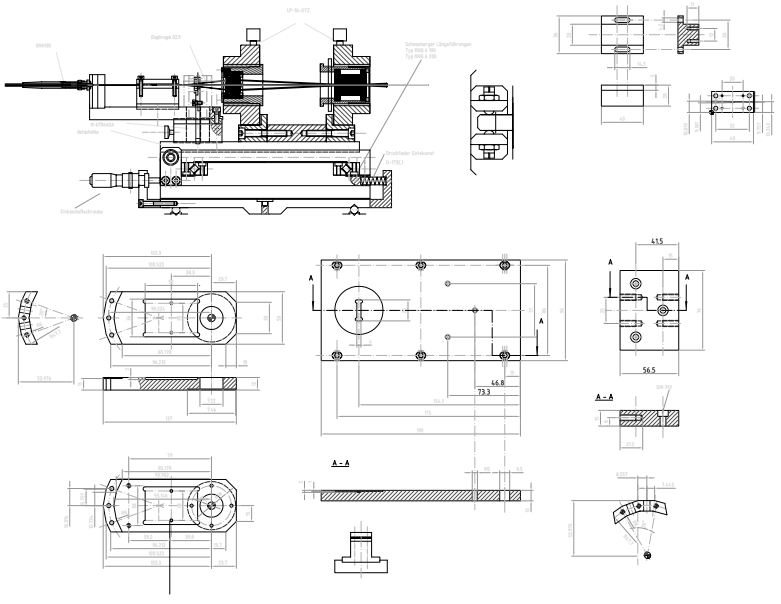


Figure 8.2: BESO-FEU-1

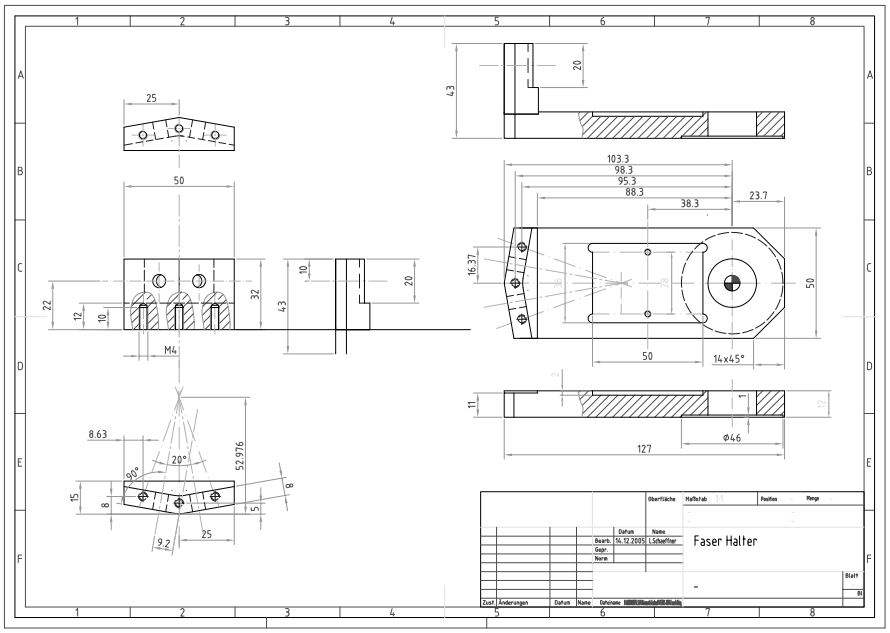


Figure 8.3: BESO-FEU-FaserHalterNeu

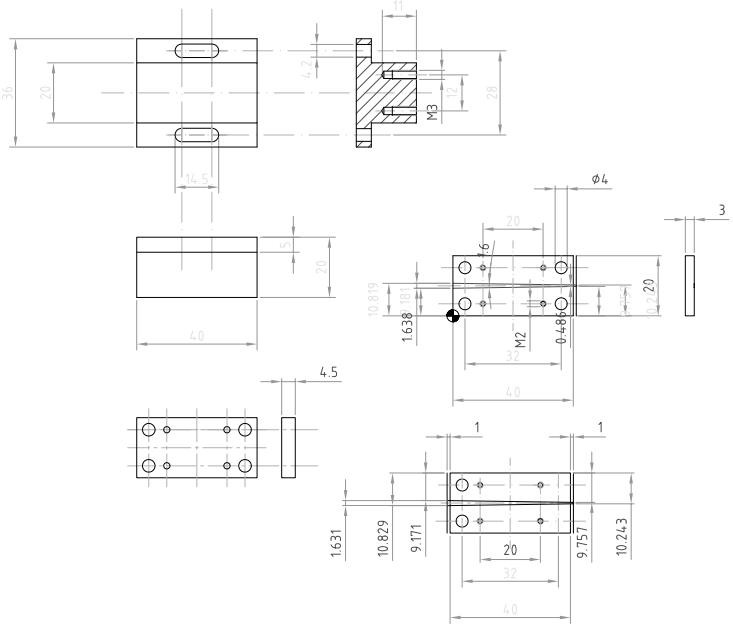


Figure 8.4: BESO-FEU-Faserklemmung

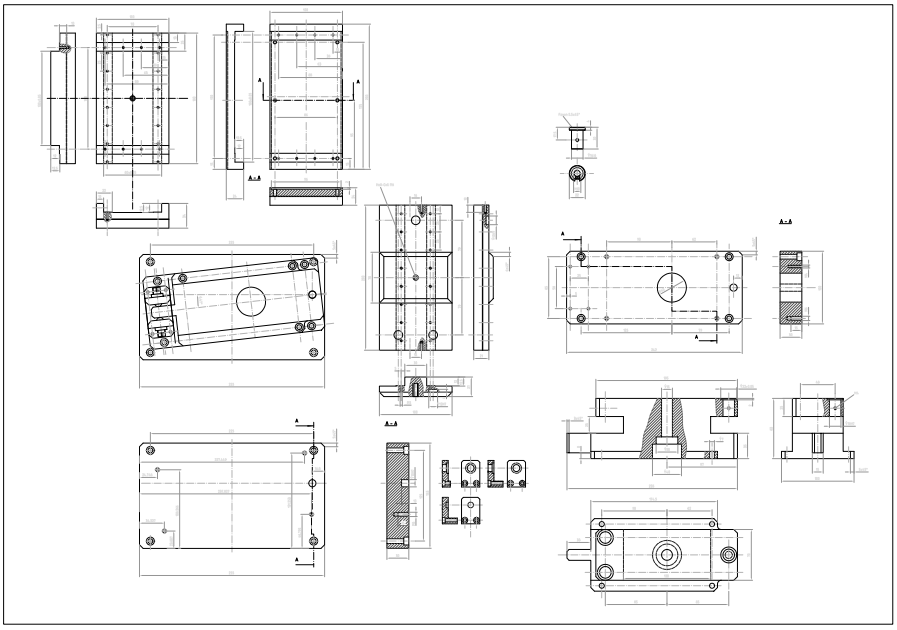


Figure 8.5: BESO-FEU-2

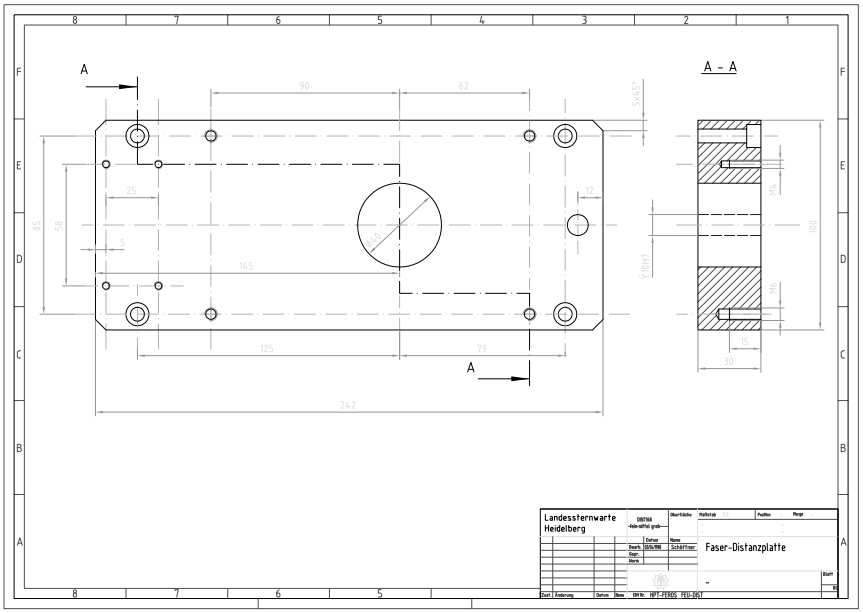


Figure 8.6: BESO-FEU-DIST

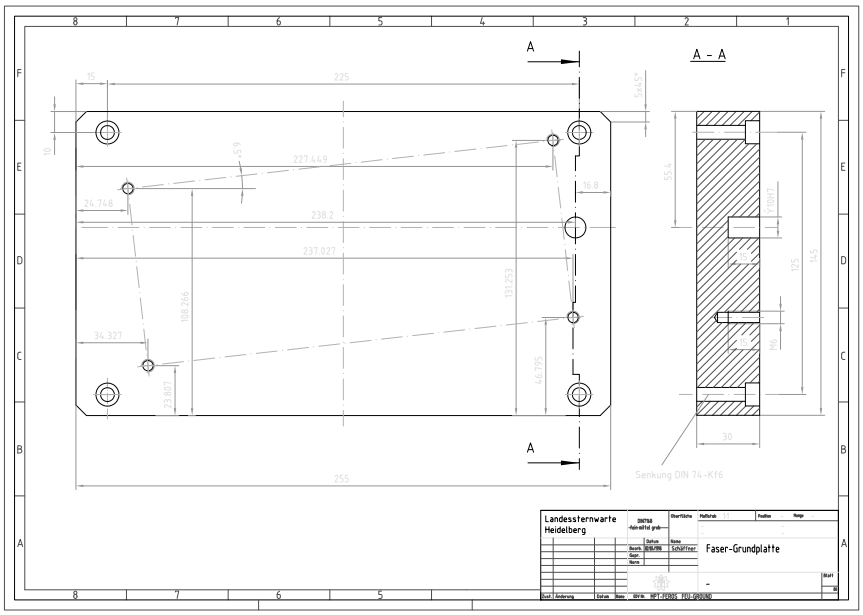


Figure 8.7: BESO-FEU-GROUND

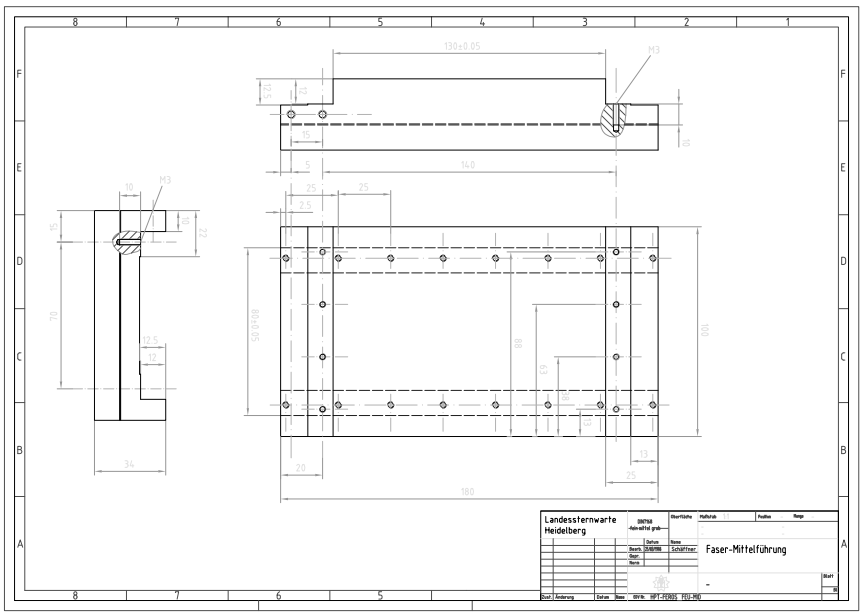


Figure 8.8: BESO-FEU-MID

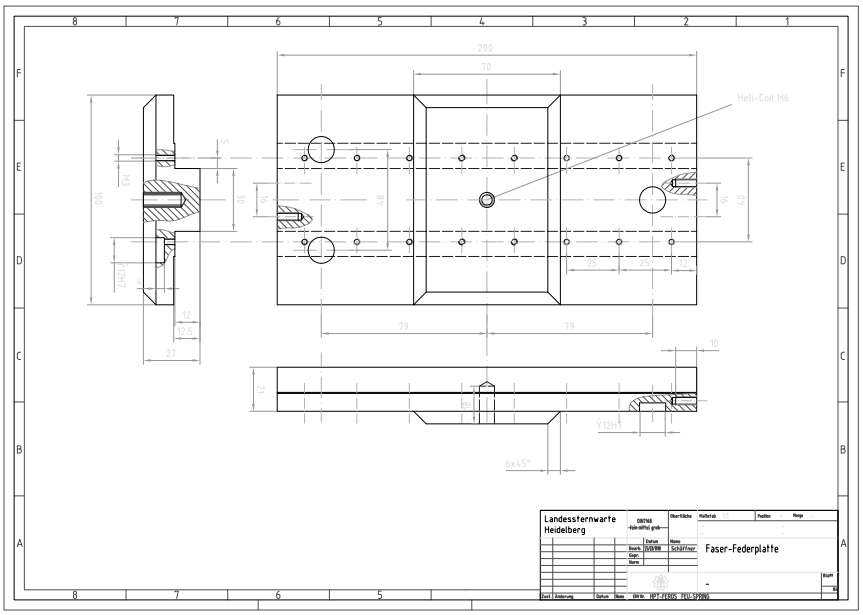


Figure 8.9: BESO-FEU-SPRING

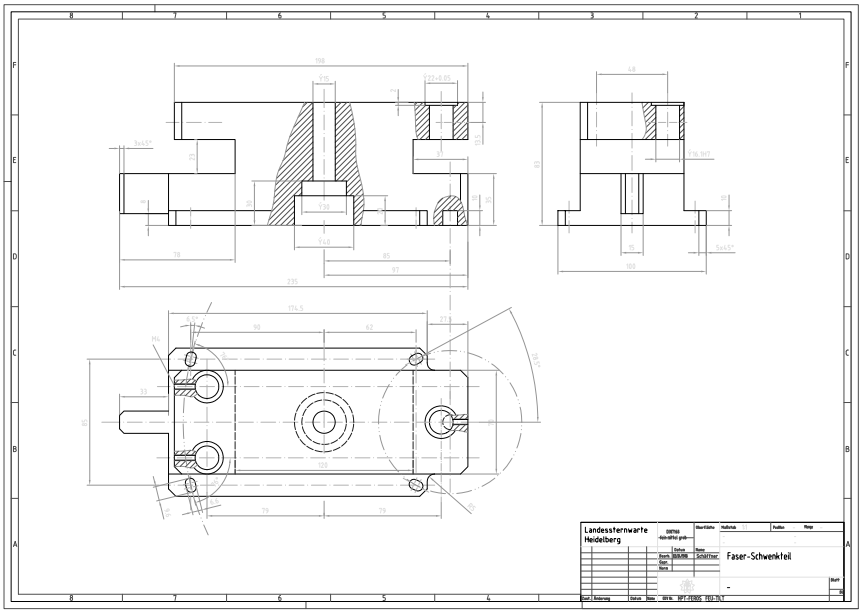


Figure 8.10: BESO-FEU-TILT

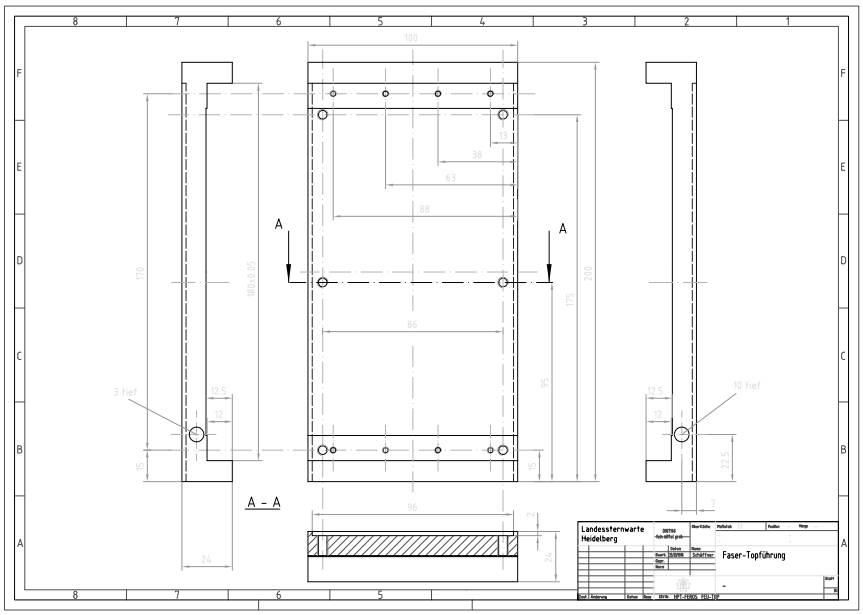


Figure 8.11: BESO-FEU-TOP

8.2 Main Collimator

The main collimator housing holds one part of the parabolic collimator mirror. Invar pads are glued to the mirror and fixed to the housing with axial supports. When propperly placed on the optical bench only minimal adjustment with the axial supports should be necessary. Be carefull when adjusting the axial supports, as little torque on the adjustment screws may result in extreme stress on the glass when used impropperly.

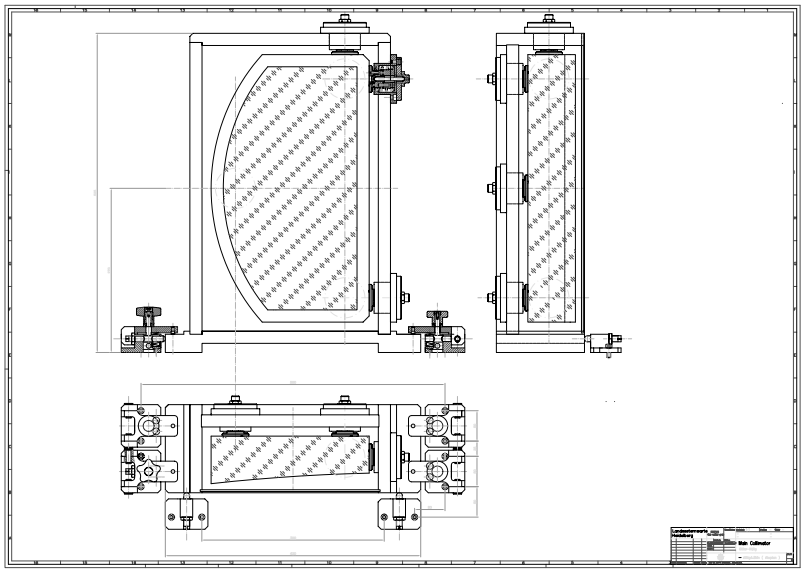


Figure 8.12: BESO-MAINCOLLIMATOR-0

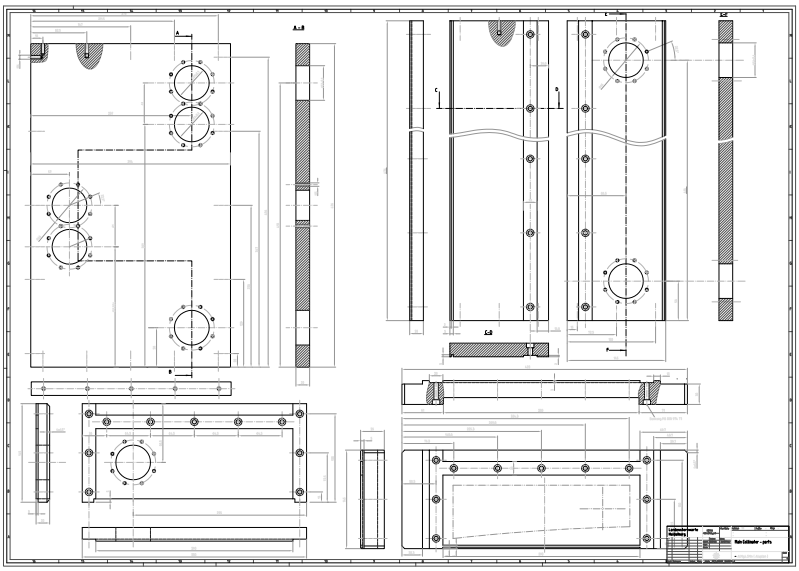


Figure 8.13: BESO-MAINCOLLIMATOR-1

8.3 Echelle Grating Unit

The echelle grating unit consists of a lower and an upper part. The lower part is screwed to the optical bench and may be adjusted for tilt. The upper part hold the grating and allows adjustment in six degrees of freedom via axial supports.e

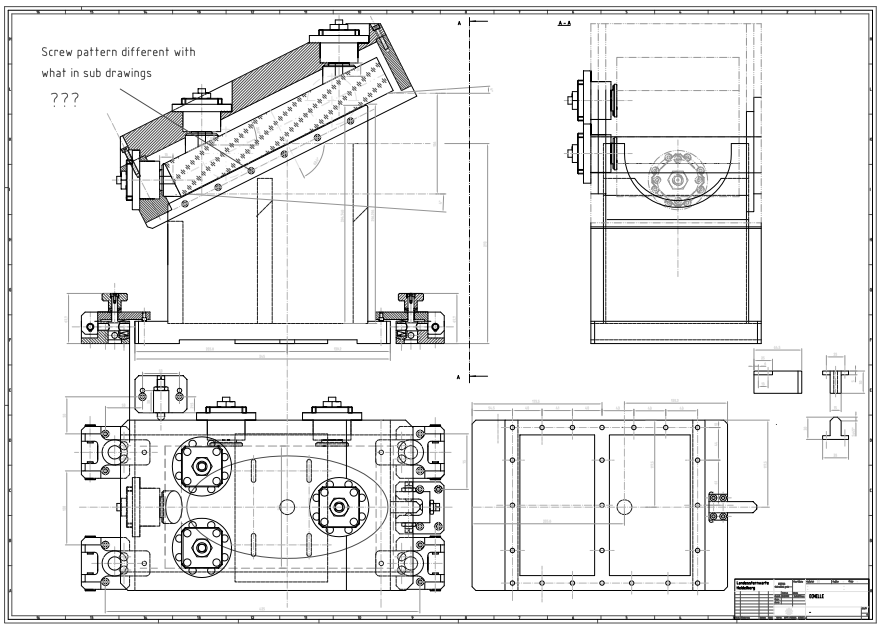


Figure 8.14: BESO-ECHELLE

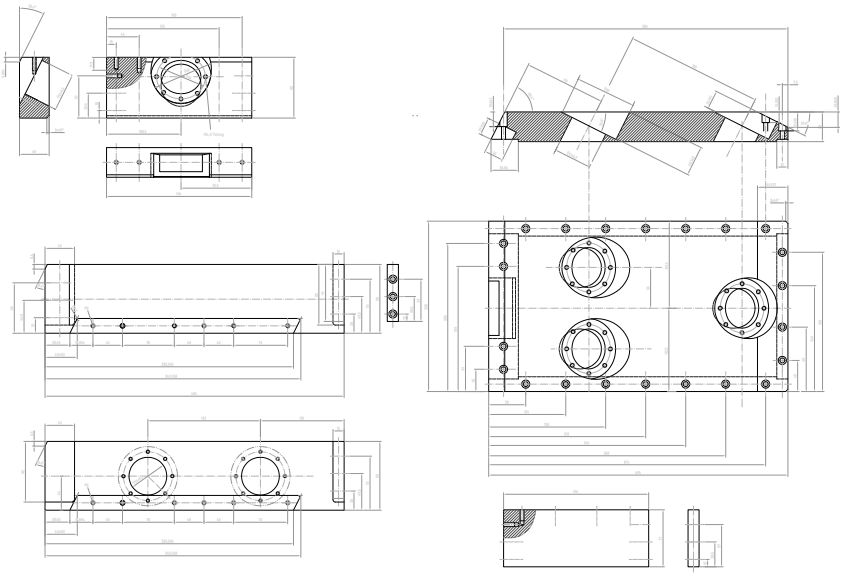


Figure 8.15: BESO-ECHELLE-1

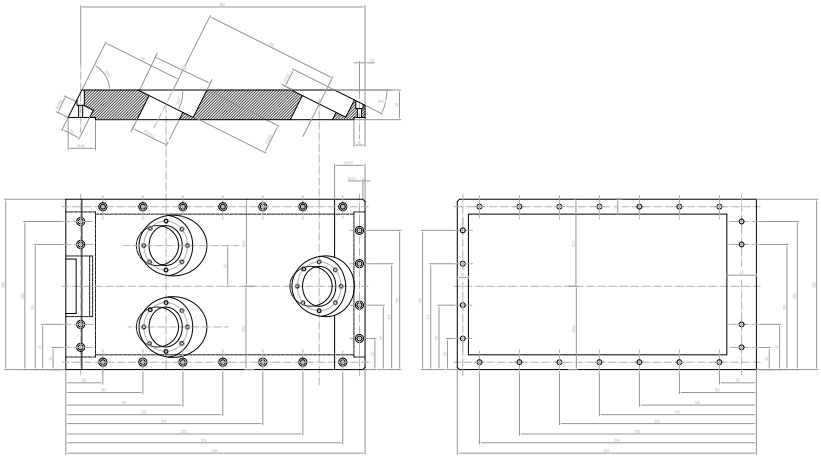


Figure 8.16: BESO-ECHELLE-2

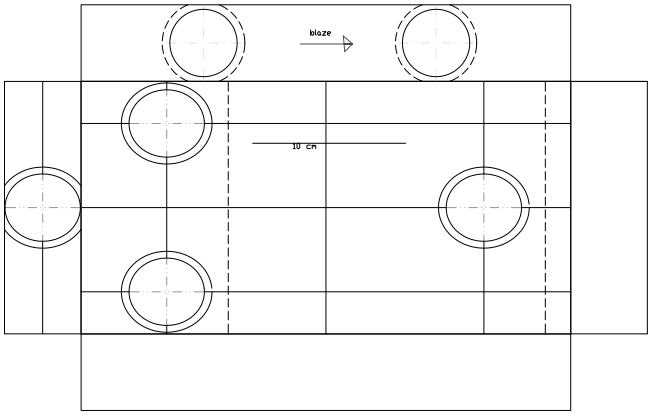


Figure 8.17: BESO-ECHELLE-GLUEMASK

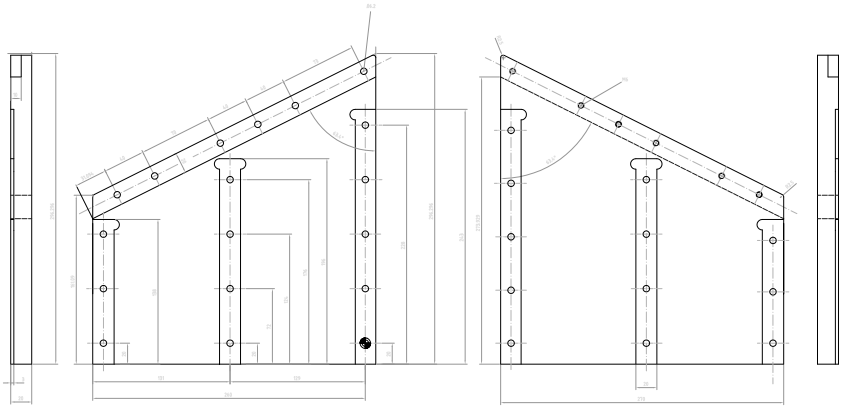


Figure 8.18: BESO-ECHELLE-SIDE

8.4 Fold Mirror

The fold mirror is screwed to is's housing via two invar pads, which are glued to the back side of the mirror. The upper part of the housing can be tilted against the lower part. The lower part can be rotated against the base plate, which is screwed to the optical bench.

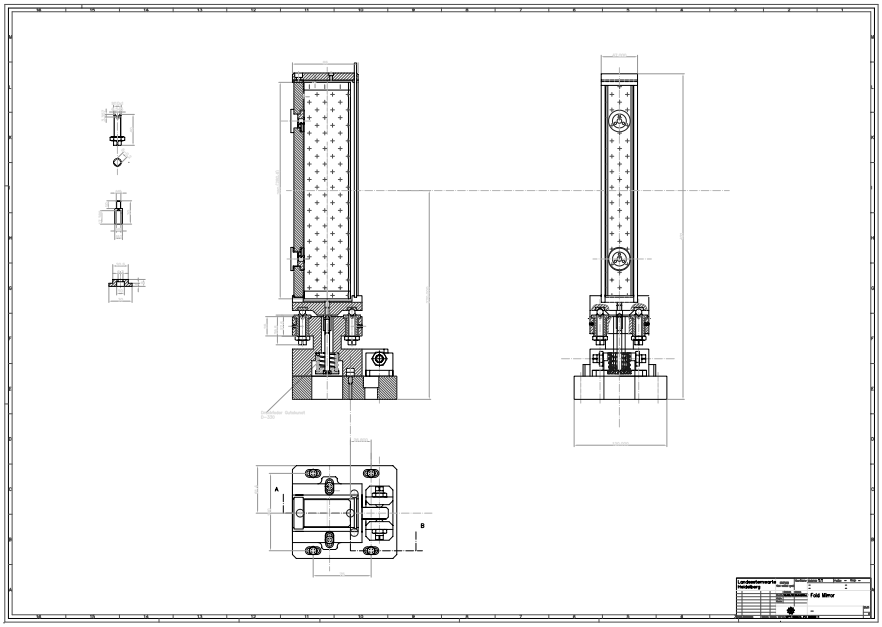


Figure 8.19: BESO-FOLDMIRROR-0

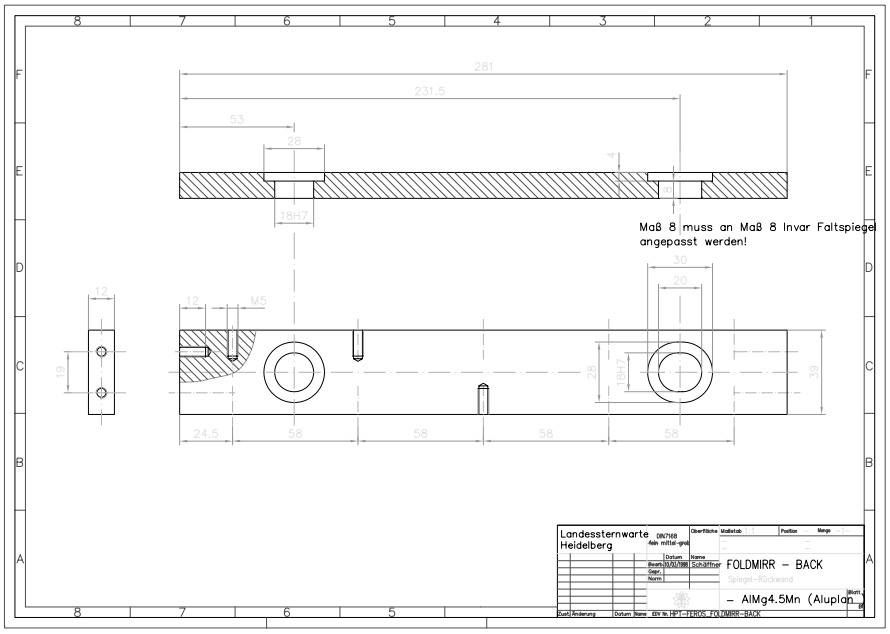


Figure 8.20: BESO-FOLDMIRROR-1-BACK

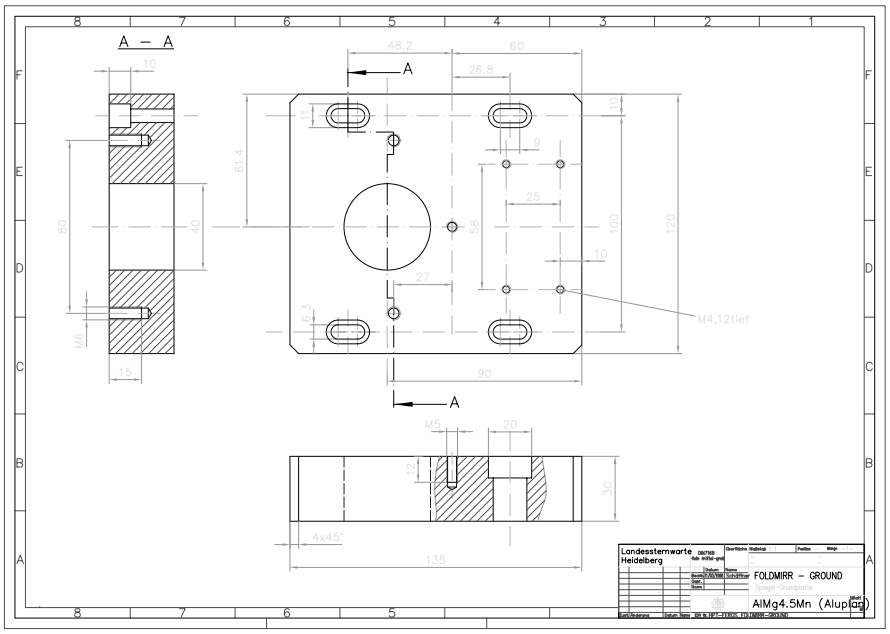


Figure 8.21: BESO-FOLDMIRROR-2-GROUND

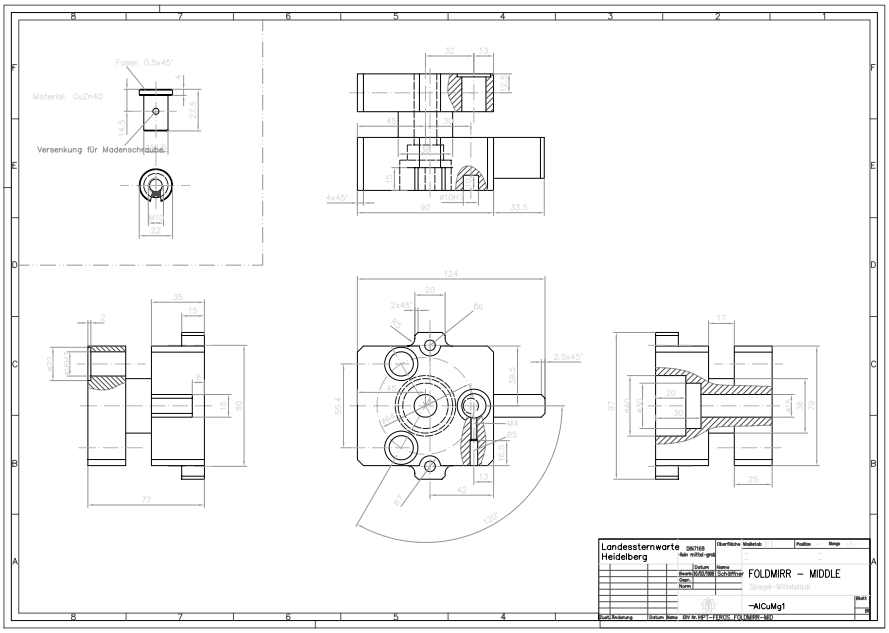


Figure 8.22: BESO-FOLDMIRROR-3-MID

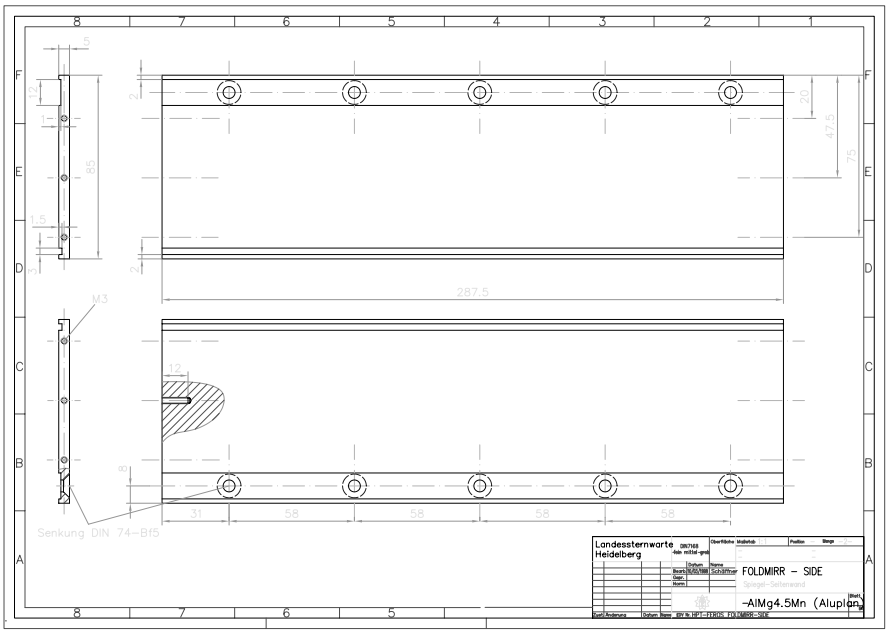


Figure 8.23: BESO-FOLDMIRROR-4-SIDE

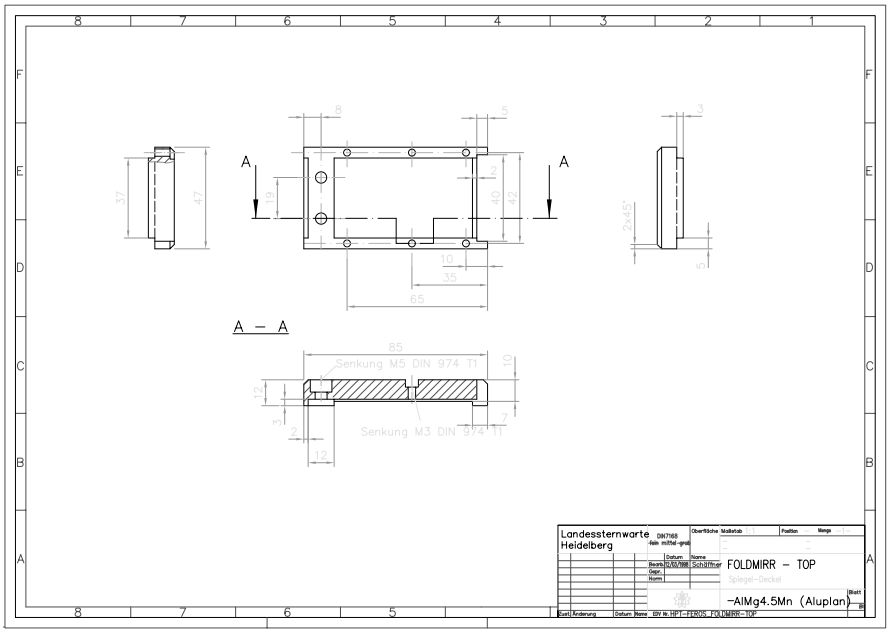


Figure 8.24: BESO-FOLDMIRROR-5-TOP

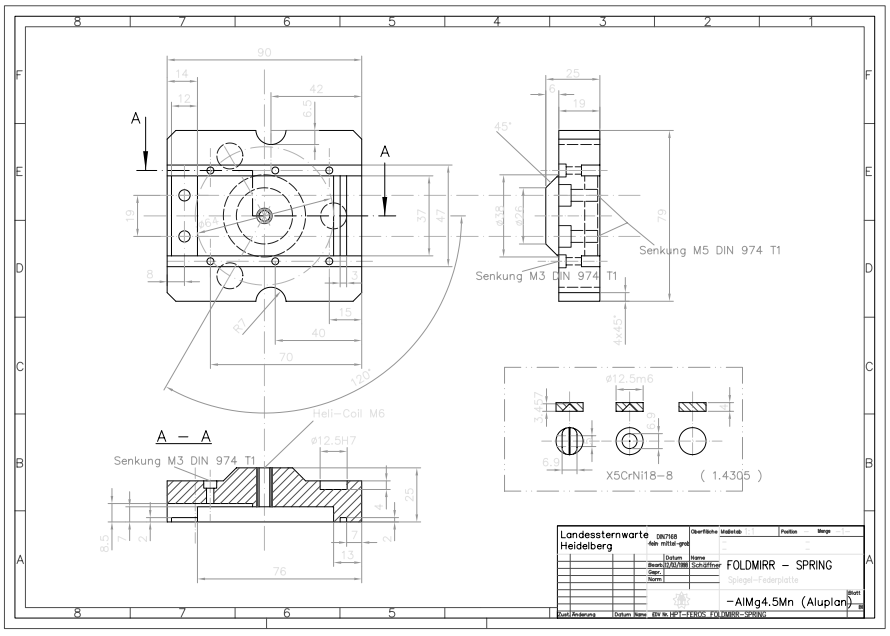


Figure 8.25: BESO-FOLDMIRROR-6-SPRING

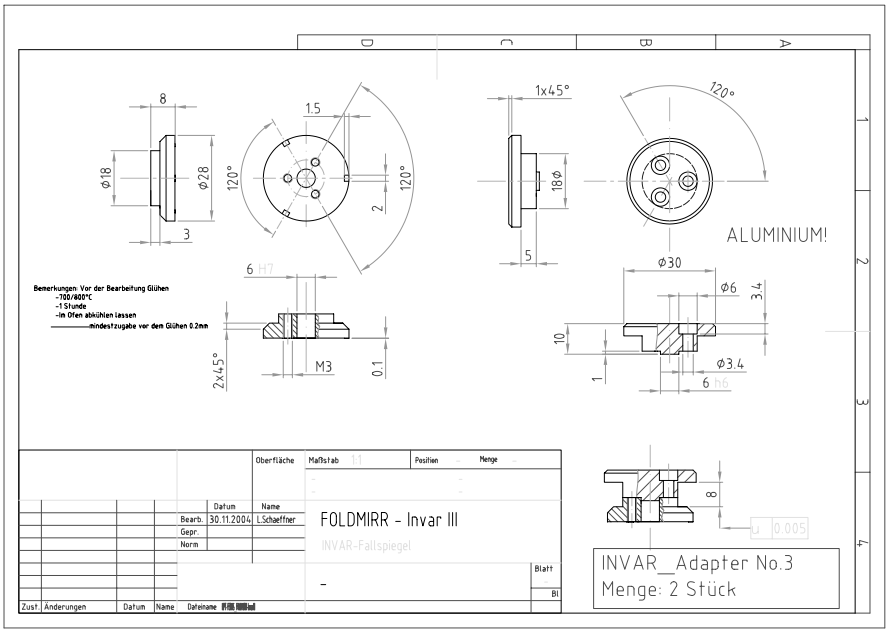


Figure 8.26: BESO-FOLDMIRROR-7-INVAR

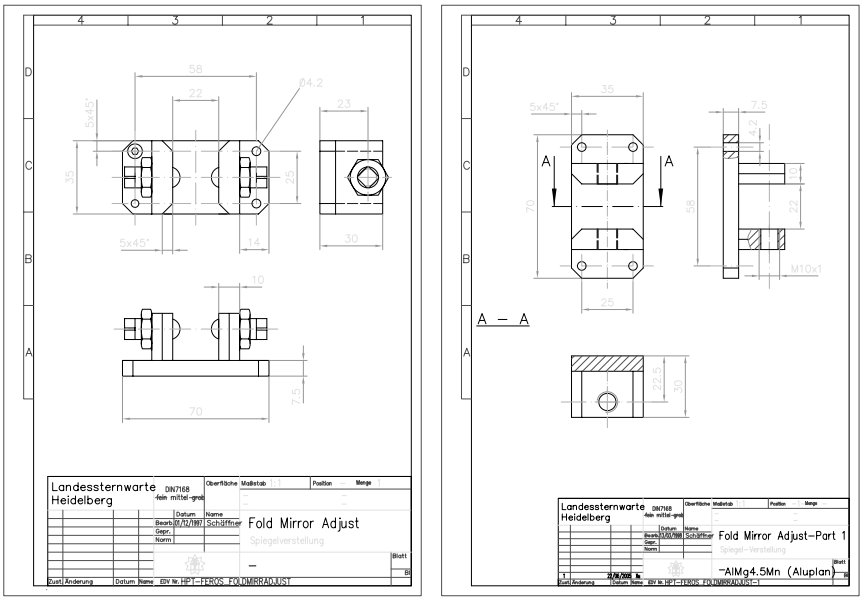


Figure 8.27: BESO-FOLDMIRROR-8-ADJUST-0, BESO-FOLDMIRROR-9-ADJUST-1

8.5 Transfer Collimator

The transfer collimator housing holds the second part of the parabolic collimator mirror. Invar pads are glued to the mirror and fixed to the housing with axial supports.

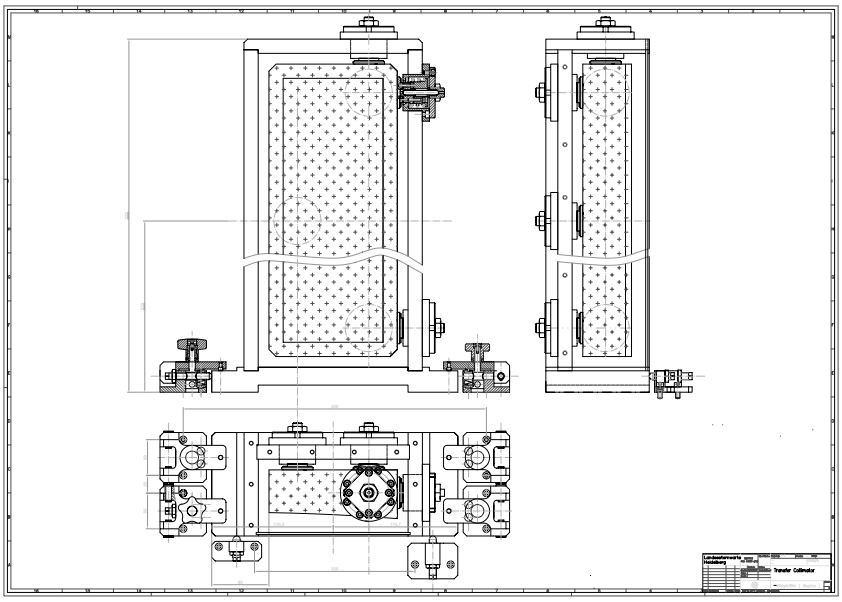


Figure 8.28: BESO-TRANSFERCOLLIMATOR-0

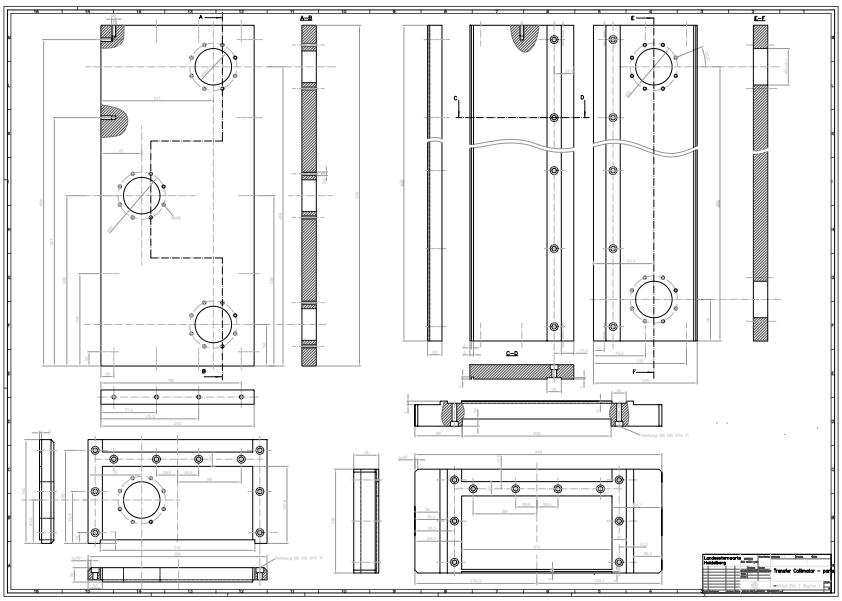


Figure 8.29: BESO-TRANSFERCOLLIMATOR-1

8.6 Axial Supports

18 axial supports hold the two collimator mirrors and the echelle grating in their housings. Each axial support consists of a preloaded spring and an adjustable rod that determines the distance of the housing to the invar adapter glued to the optical element. Six axial supports per optical element allow adjustment in six degrees of freedom. Be careful when disassembling the preloaded spring!

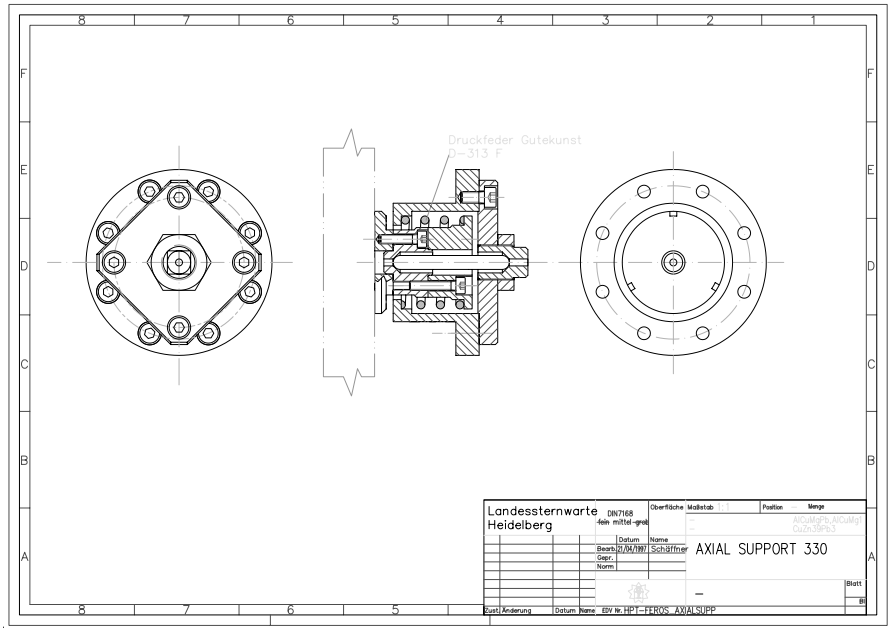


Figure 8.30: BESO-AXIALSUPPORT-0

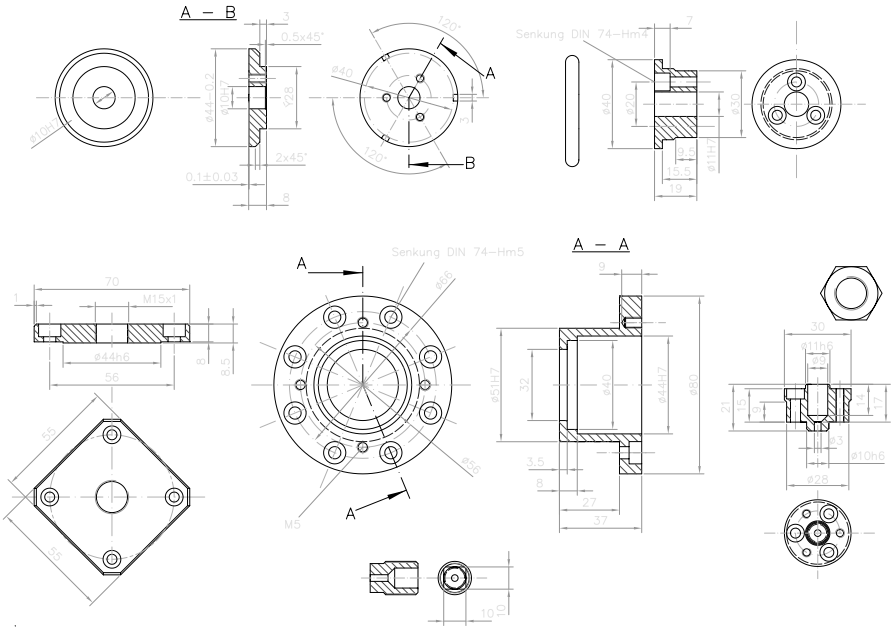


Figure 8.31: BESO-AXIALSUPPORT-1

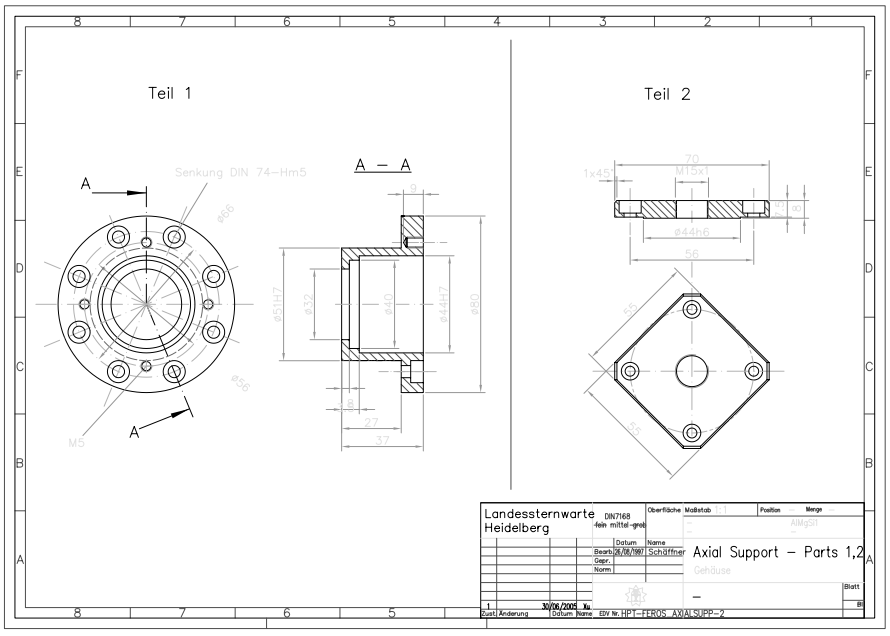


Figure 8.32: BESO-AXIALSUPPORT-2

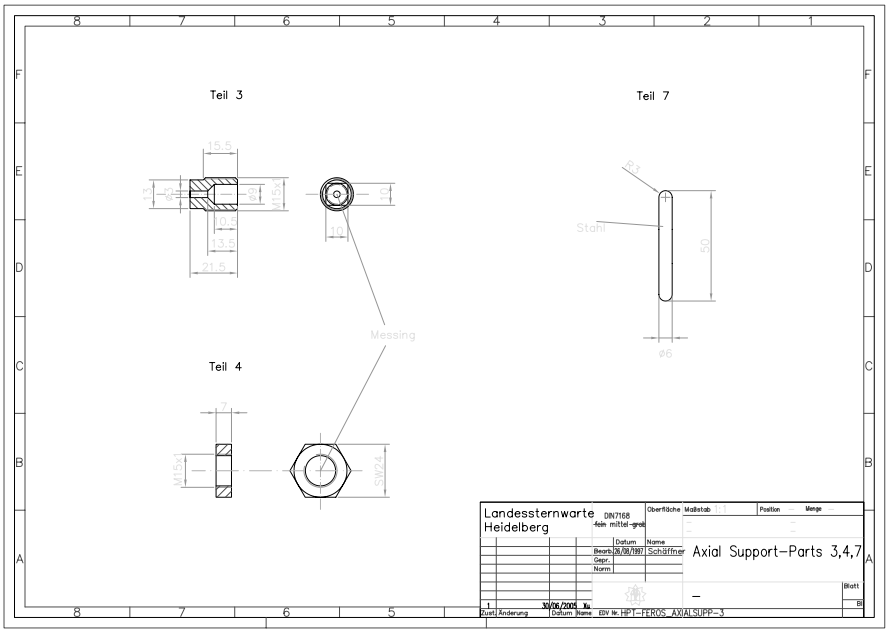


Figure 8.33: BESO-AXIALSUPPORT-3

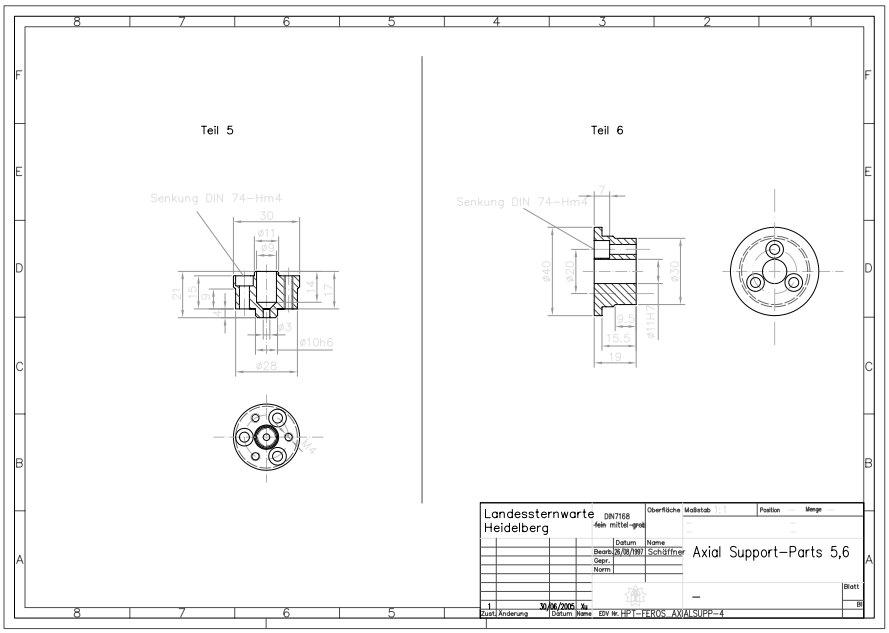


Figure 8.34: BESO-AXIALSUPPORT-4

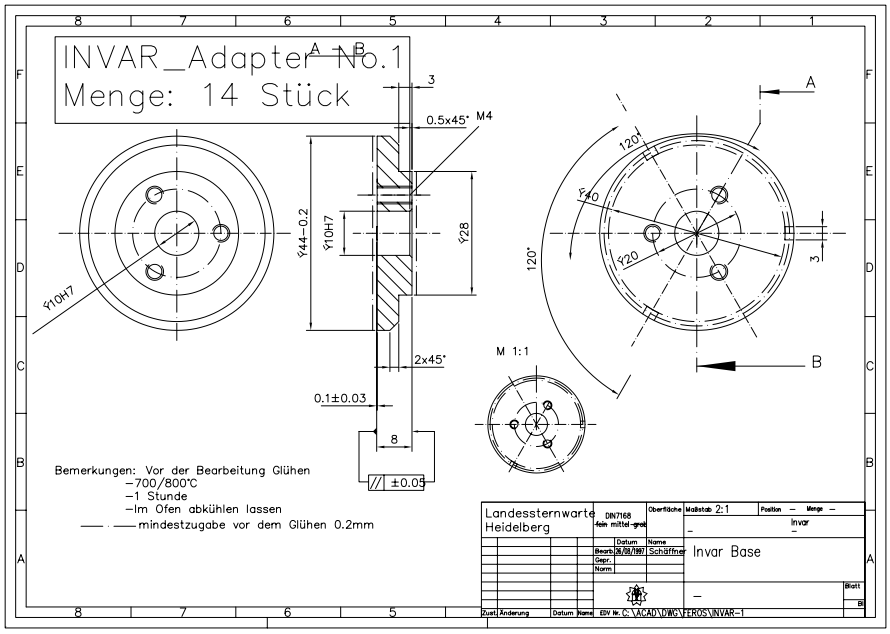


Figure 8.35: BESO-AXIALSUPPORT-INVAR-1

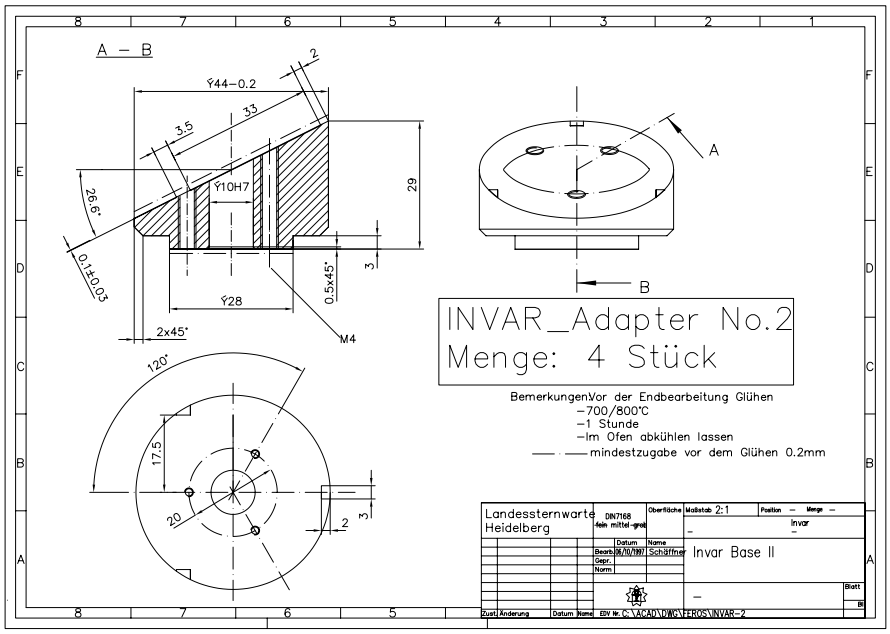


Figure 8.36: BESO-AXIALSUPPORT-INVAR-2

8.7 Prism Support

The prism support is clamped to the optical bench and allows rotation of the prism via a rotary stage.

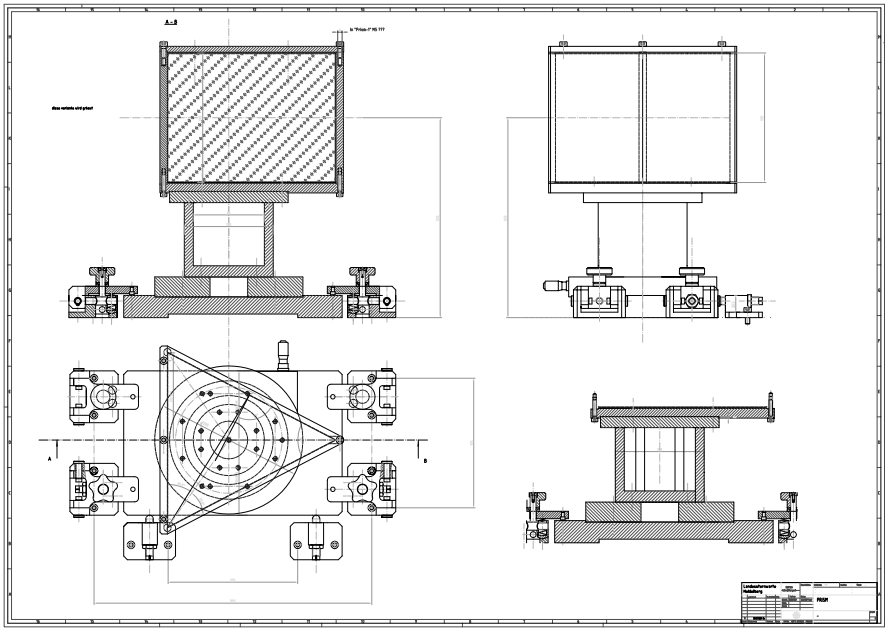


Figure 8.37: BESO-PRISM-1

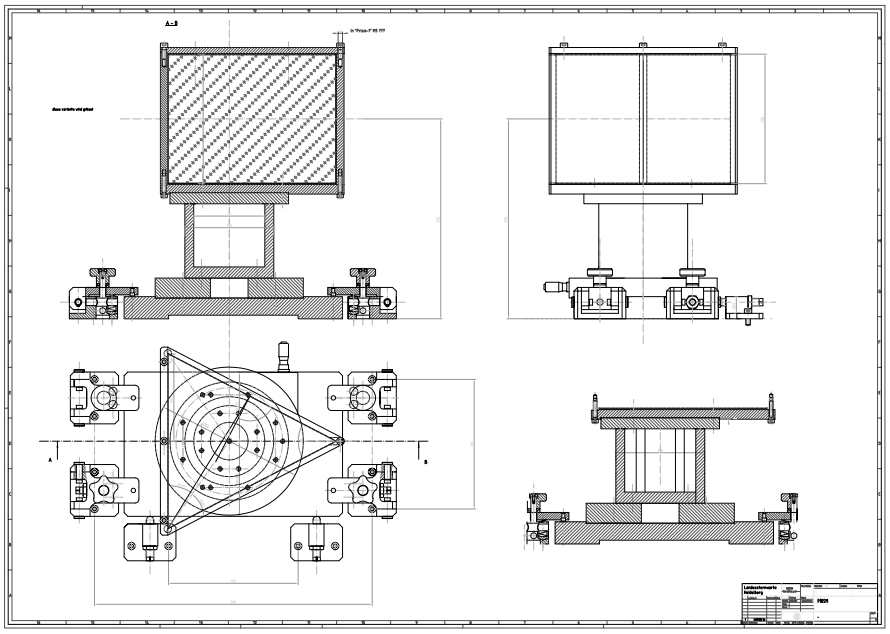


Figure 8.38: BESO-PRISM-2

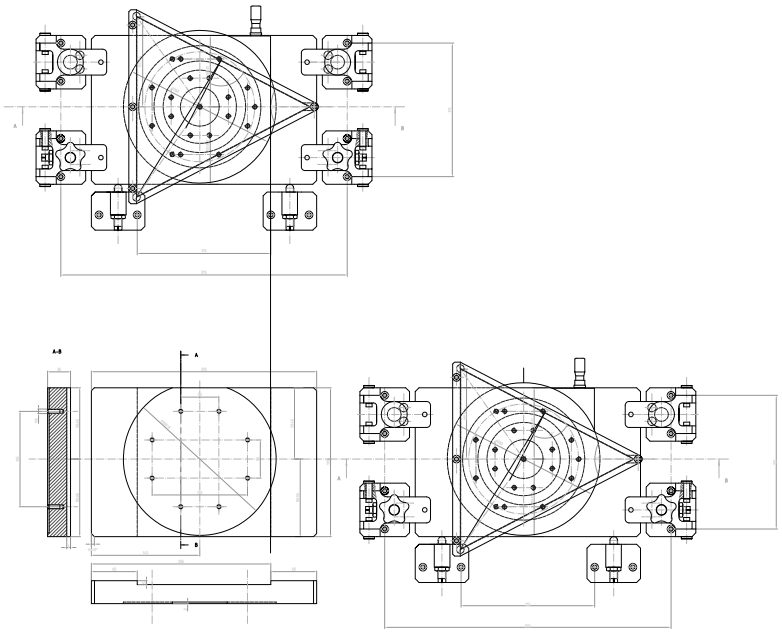


Figure 8.39: BESO-PRISM-3

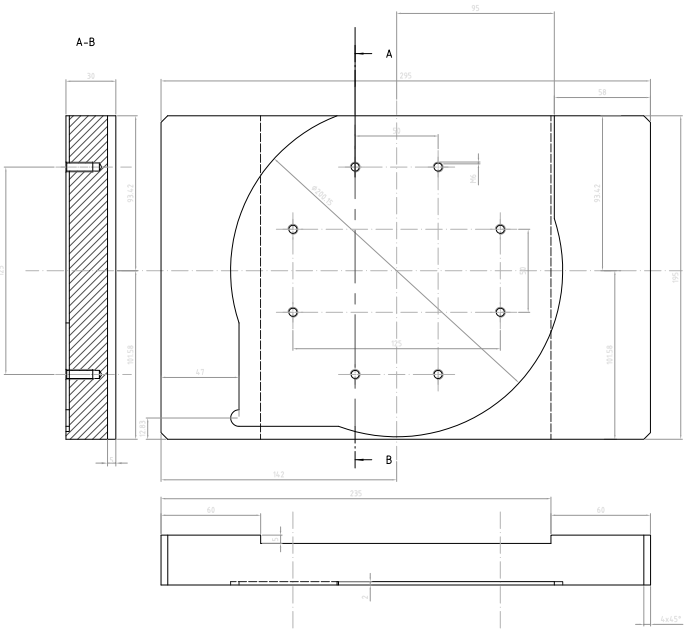


Figure 8.40: BESO-PRISM-4

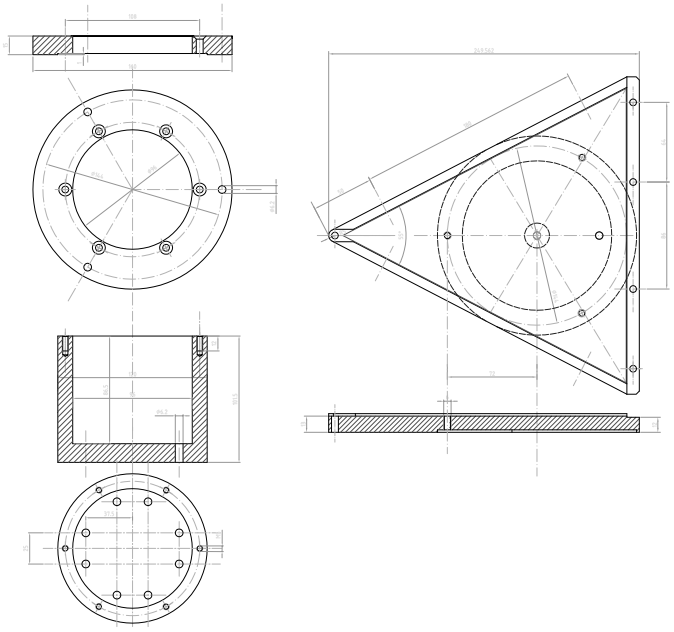


Figure 8.41: BESO-PRISM-5

8.8 Camera

The camera images the cross-dispersed spectrum onto the CCD. The support module for the camera optics compensates temperature variations by shifting the camera lens. The camera has been manufactured by Fisba Optik, Switzerland.

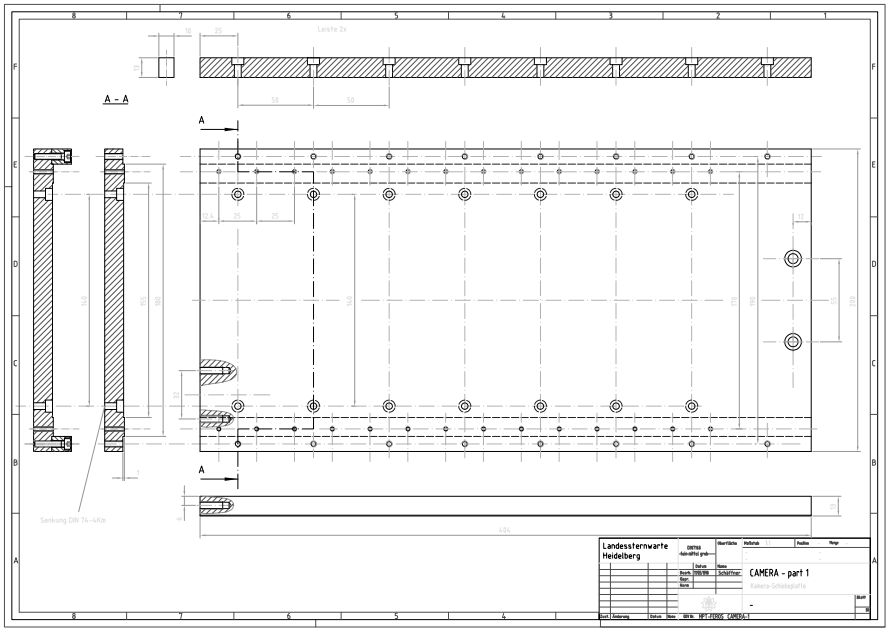


Figure 8.42: BESO-CAMERA-1

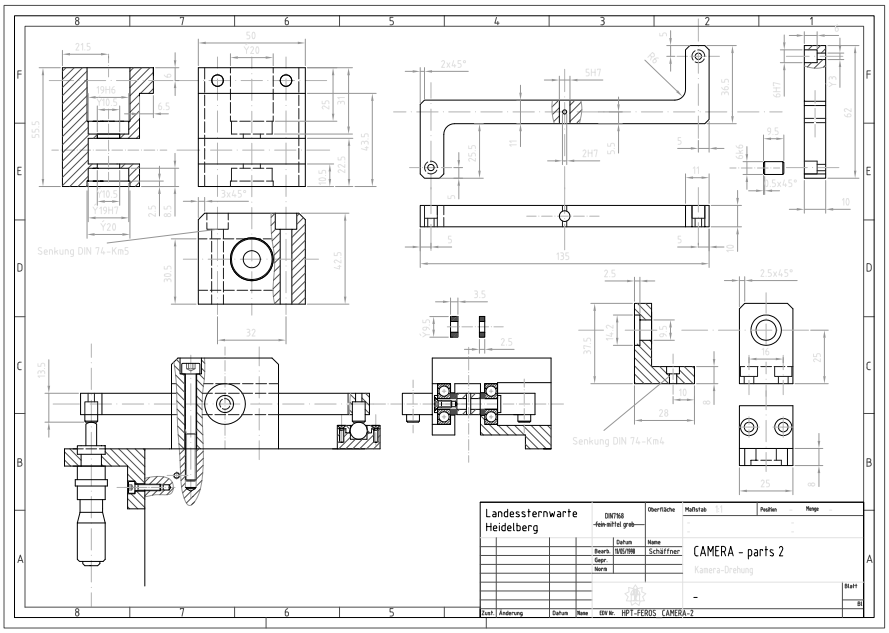


Figure 8.43: BESO-CAMERA-2

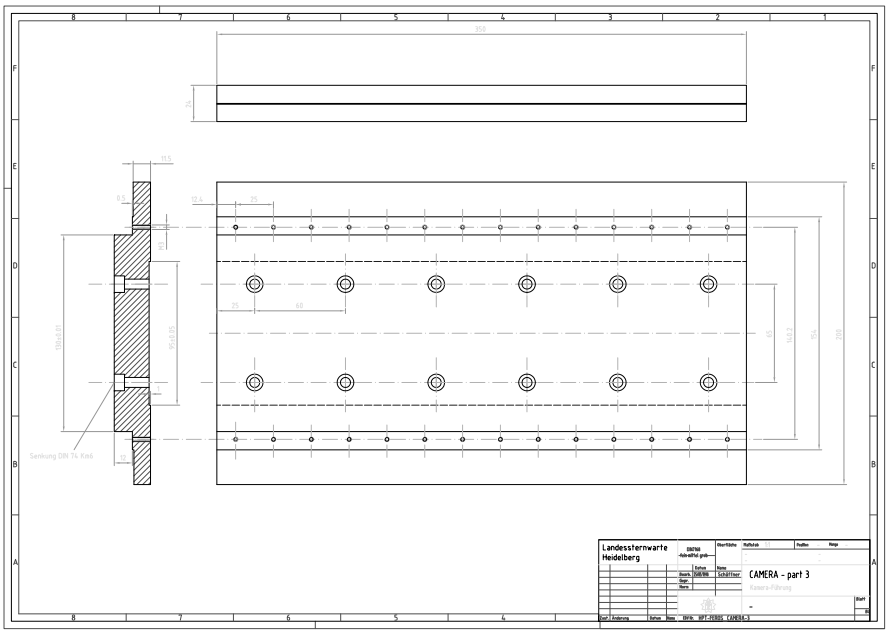


Figure 8.44: BESO-CAMERA-3

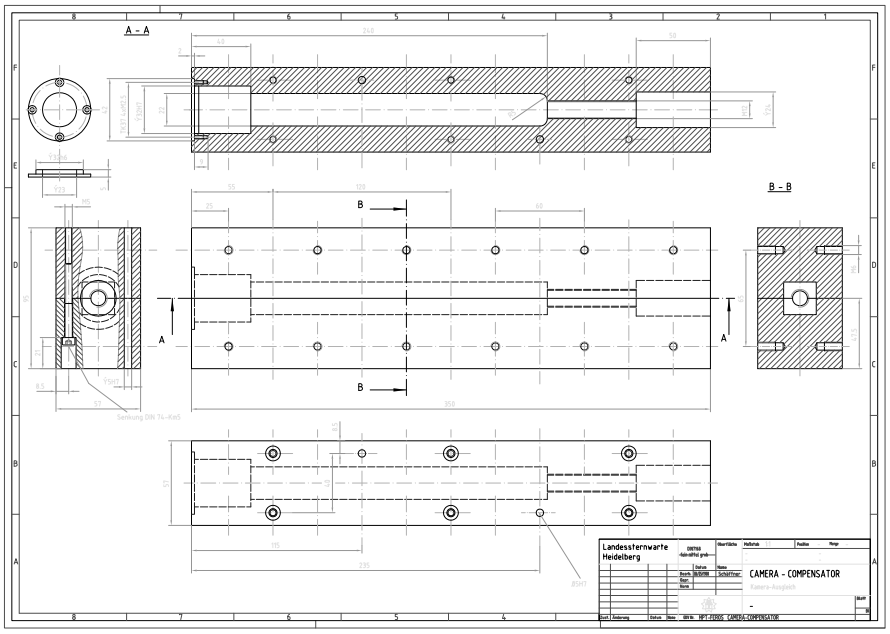


Figure 8.45: BESO-CAMERA-COMPENSATOR

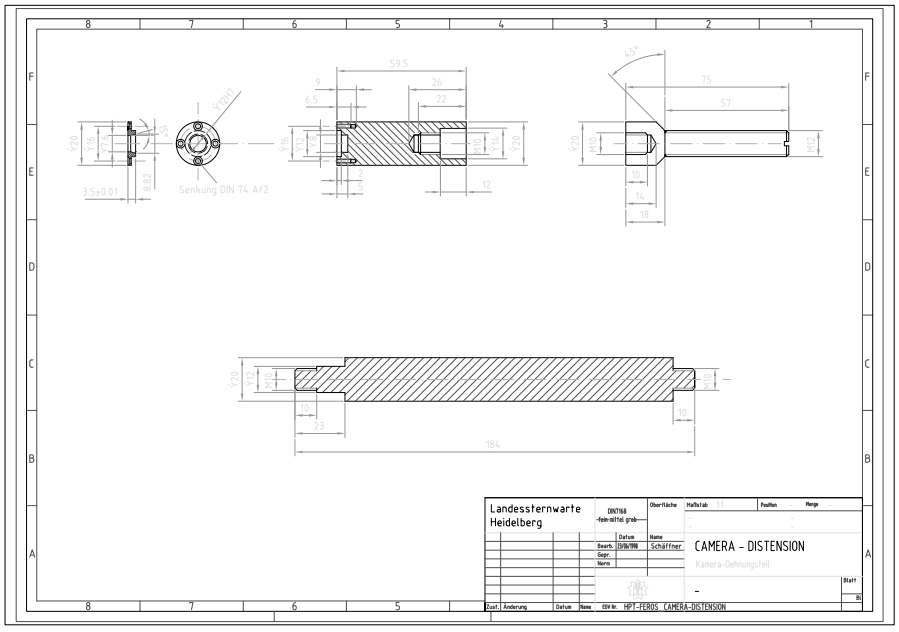


Figure 8.46: BESO-CAMERA-DISTENSION

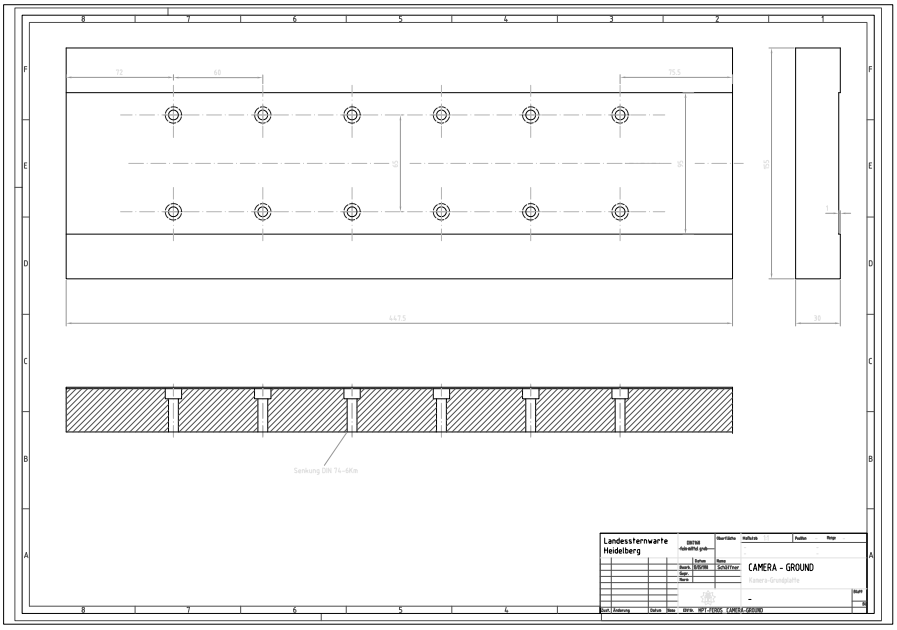


Figure 8.47: BESO-CAMERA-GROUND

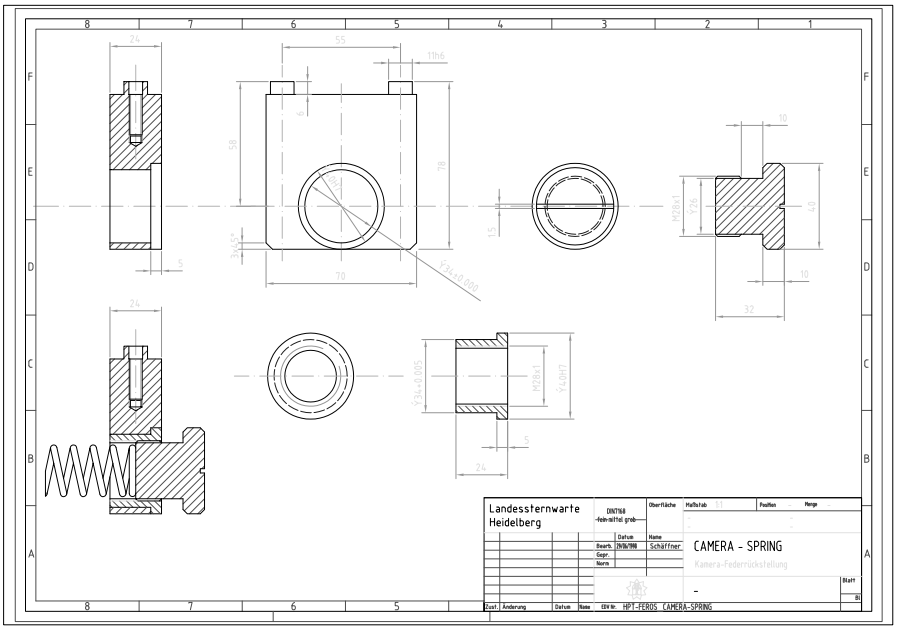


Figure 8.48: BESO-CAMERA-SPRING

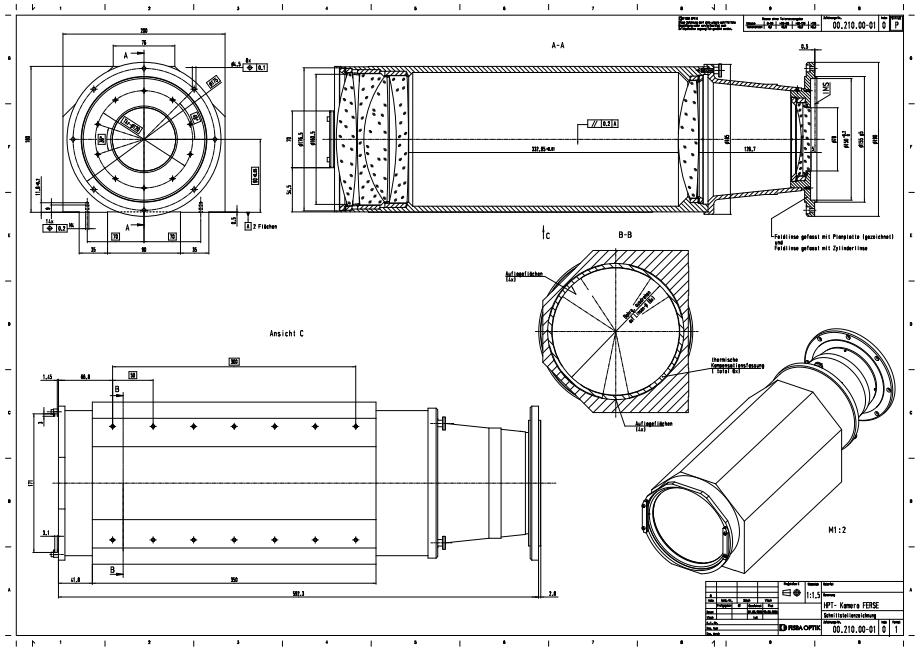


Figure 8.49: FERSE-00-210-00-01

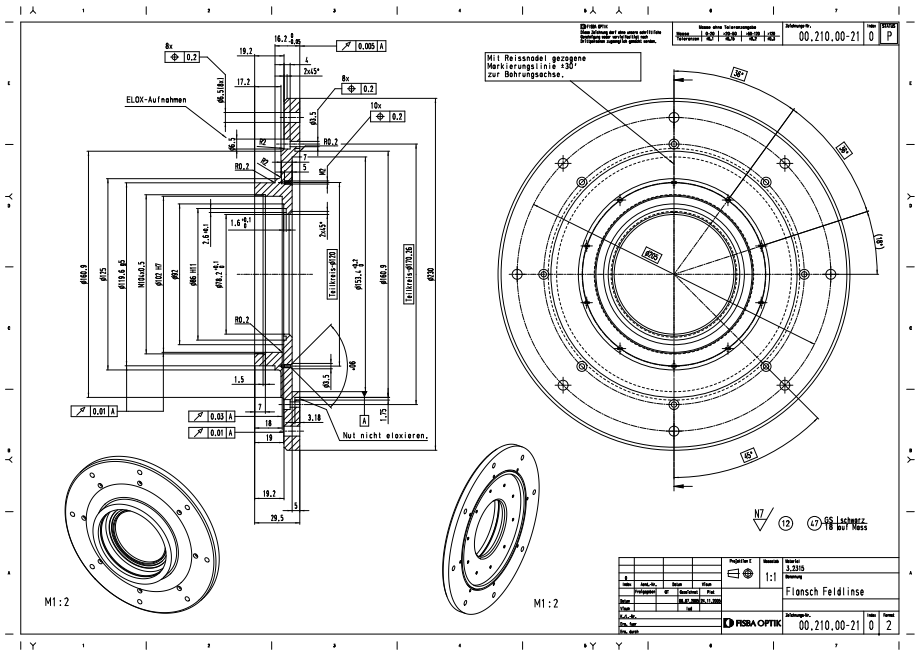


Figure 8.50: FlanschFeldlinseFISBAv1

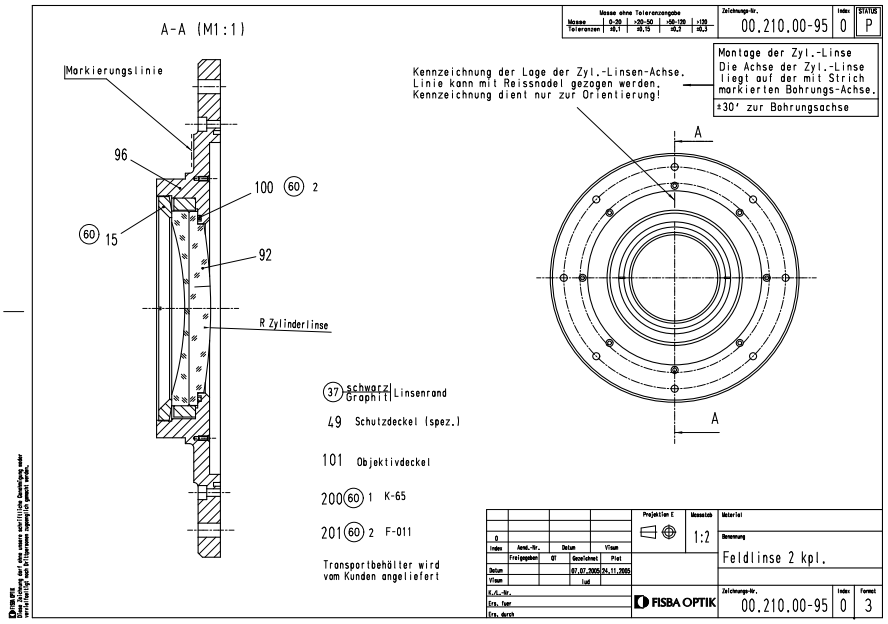


Figure 8.51: Feldlinse2

8.9 CCD Cryo-System

The Cyro System for the CCD consists of the dewar and the readout electronic that are mounted outside the enclosure. The entrance window of the dewar is also the last lens of the camera. The dewar must be aligned precisely with respect to the camera with the centering tool and can not be turned.
The dewar may be evacuated with a vaccuum pump and heated with a heater foil on the outside of the vacuum vessel. The cooler is a closed cycle 'Cryotiger' system.

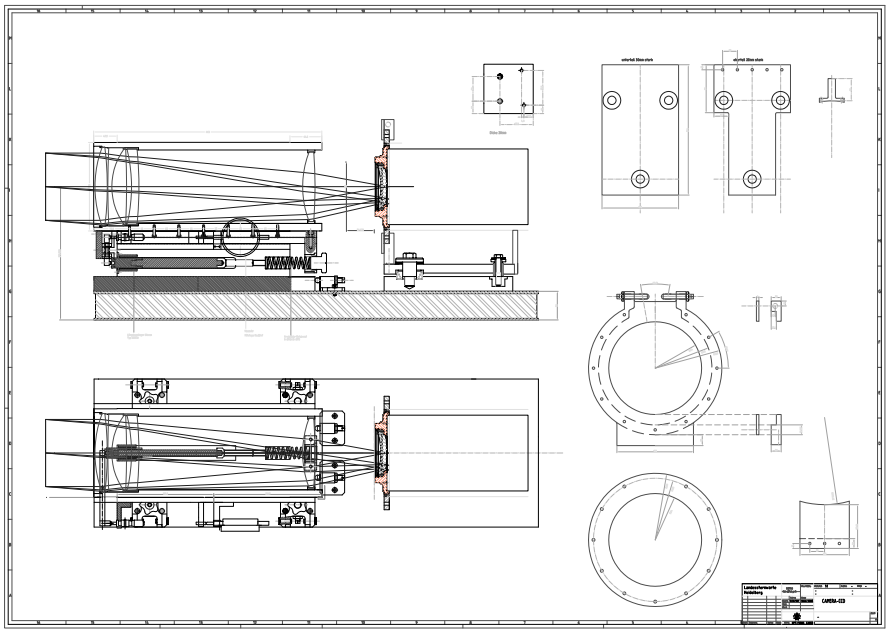


Figure 8.52: BESO-CCD

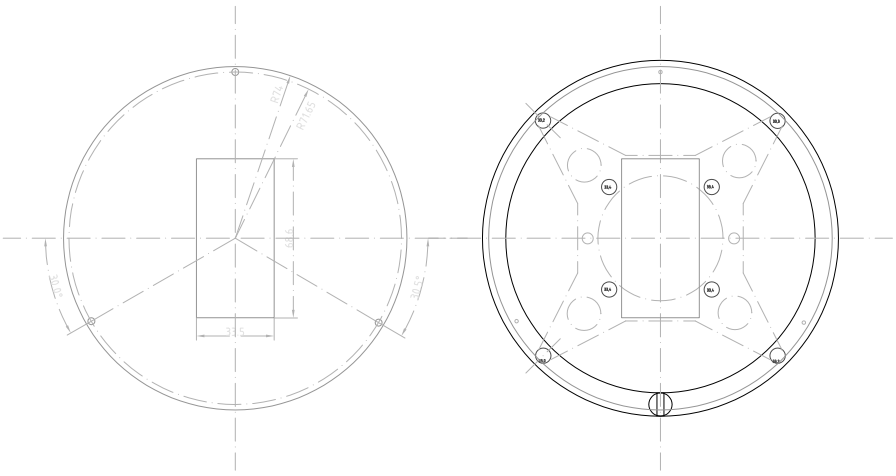


Figure 8.53: BESO-CCD-MOUNT

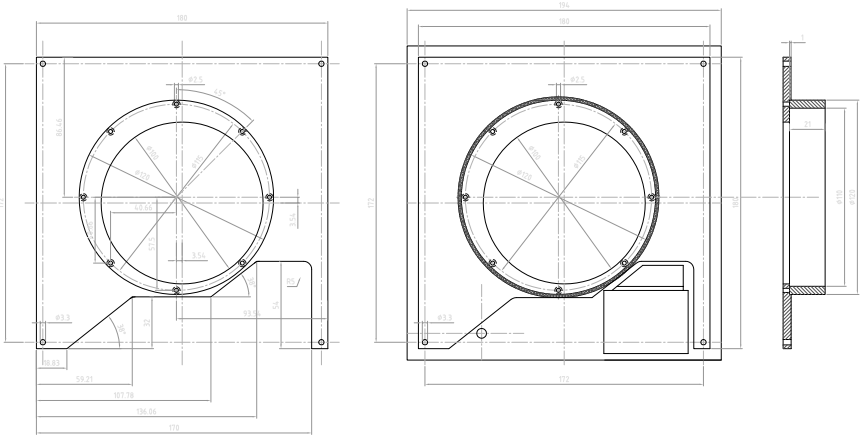


Figure 8.54: BESO-SHUTTER

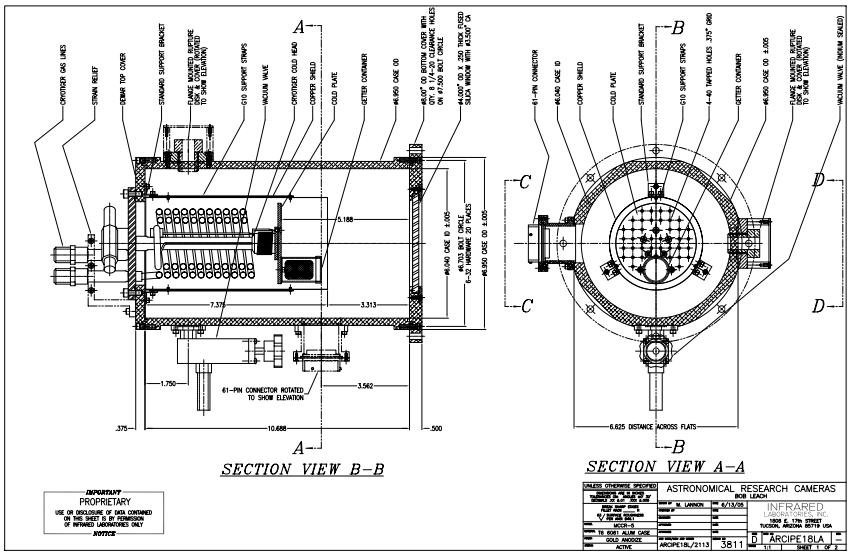


Figure 8.55: cryotiger1

8.10 Clamps

The clamps are used to fasten all modules to the optical bench. The clamps are screwed to the bench, but the modules can be fixed in their positions according to the optical alignment.

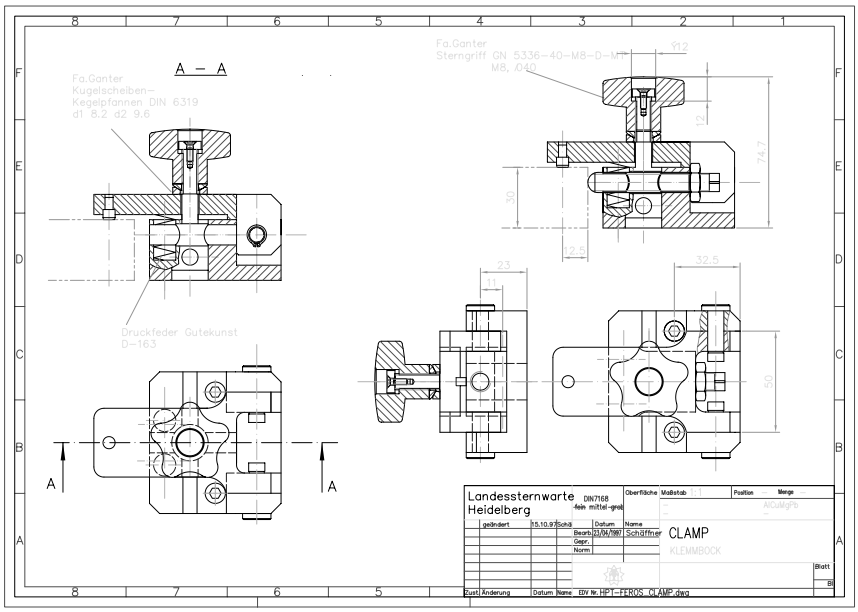


Figure 8.56: BESO-CLAMP-0

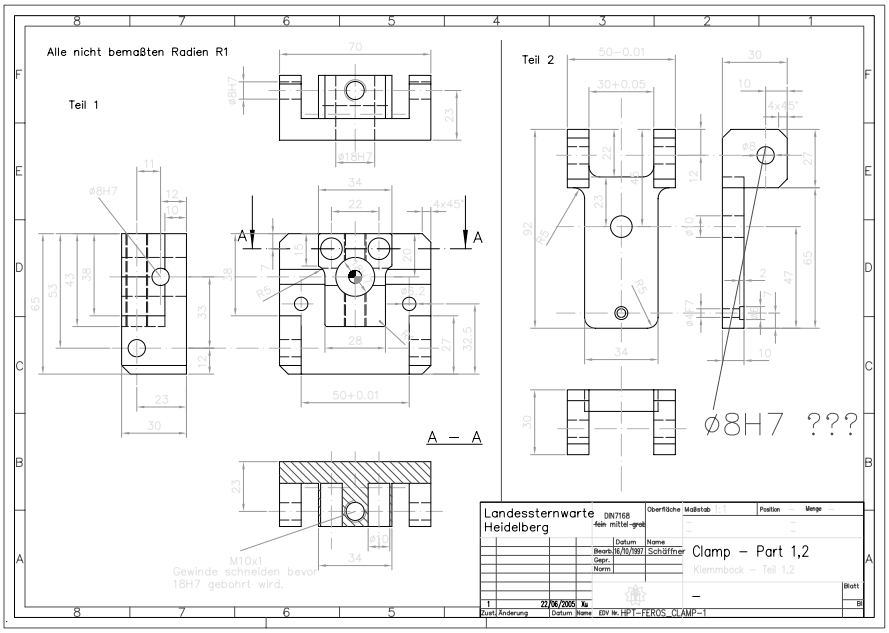


Figure 8.57: BESO-CLAMP-1

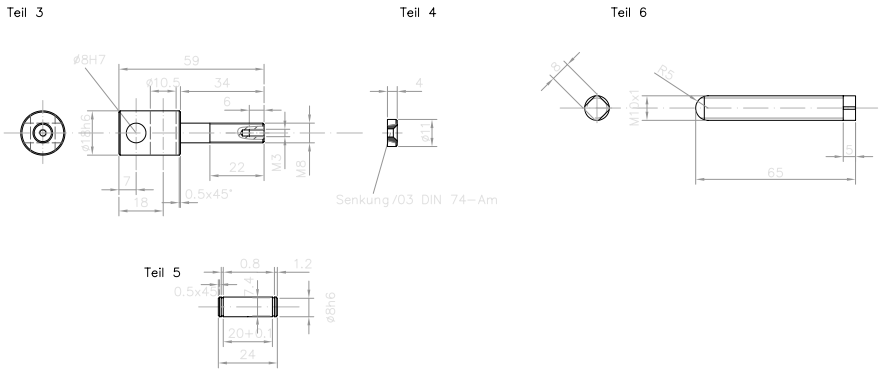


Figure 8.58: BESO-CLAMP-2

8.11 Stop / Stopadjust

Stop and stopadjust are used to position heavy modules (e.g. collimators).

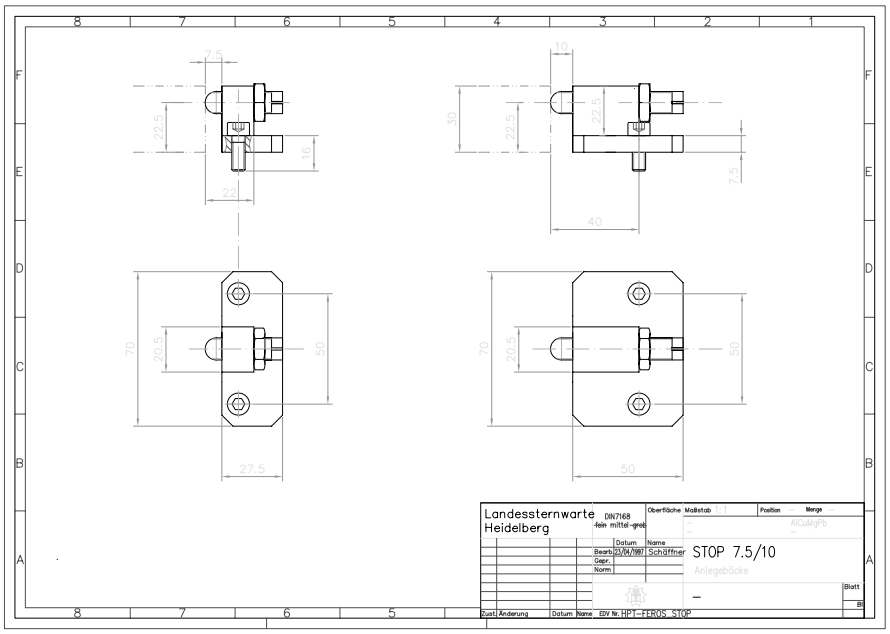


Figure 8.59: BESO-STOP-0

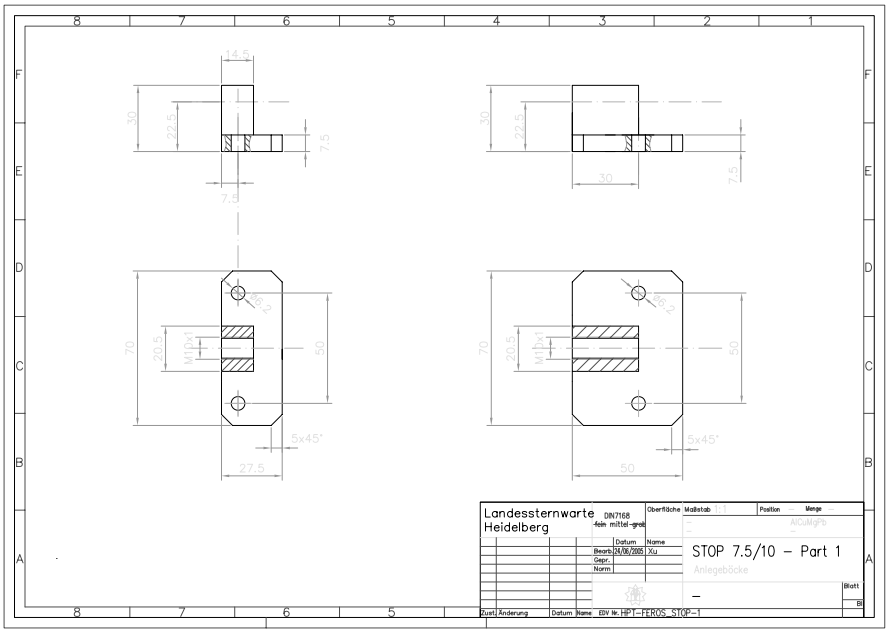


Figure 8.60: BESO-STOP-1

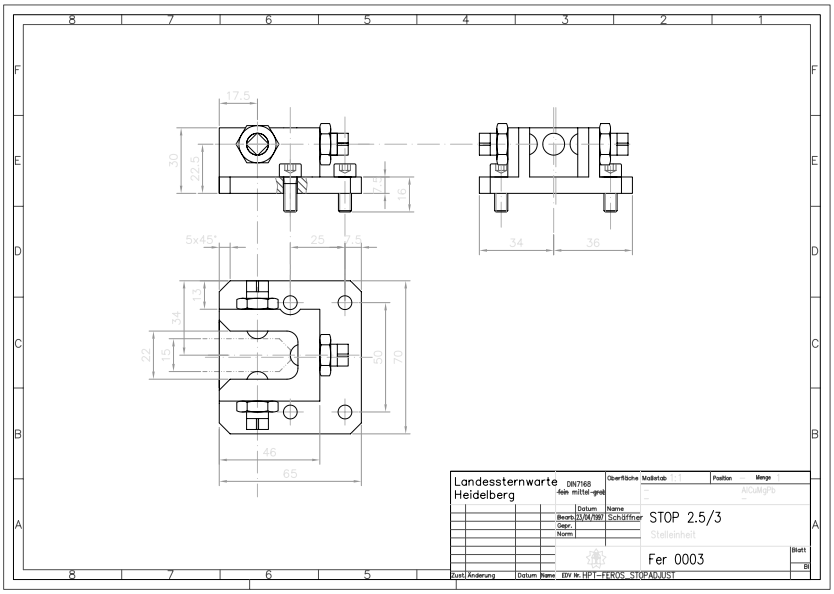


Figure 8.61: BESO-STOPADJUST-0

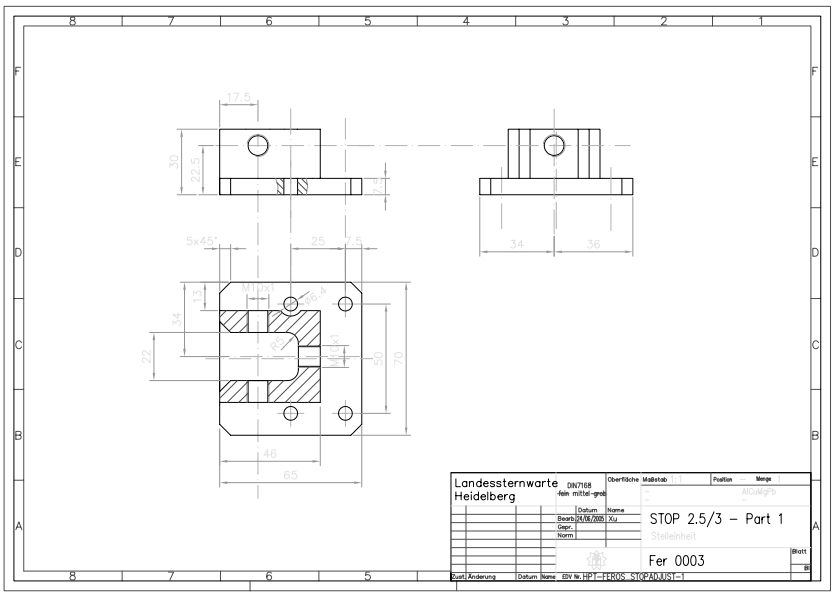


Figure 8.62: BESO-STOPADJUST-1

8.12 Enclosure

The enclosure is made from aluminum stuts and anodized sheets. The enlosure segment next to the prism can be removed easily to allow modifications of the covered wavelength-band, if necessary.

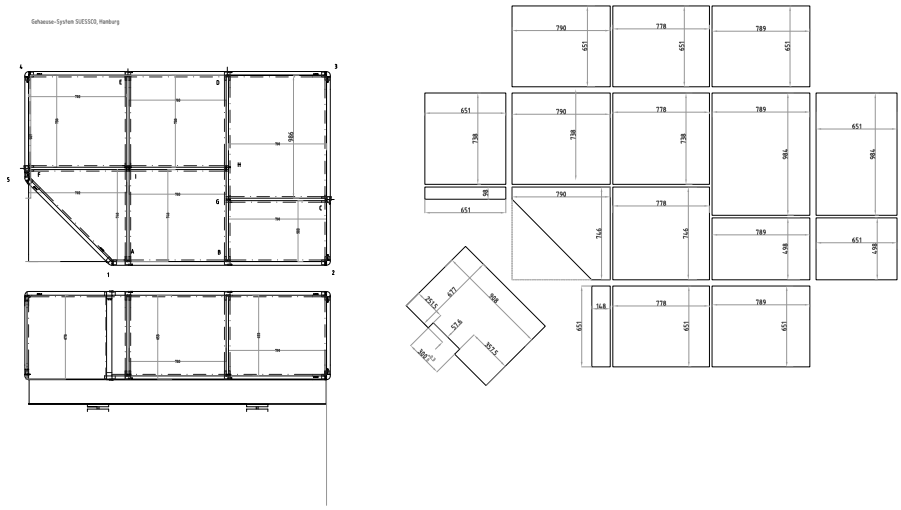


Figure 8.63: BESO-STOPADJUST-1

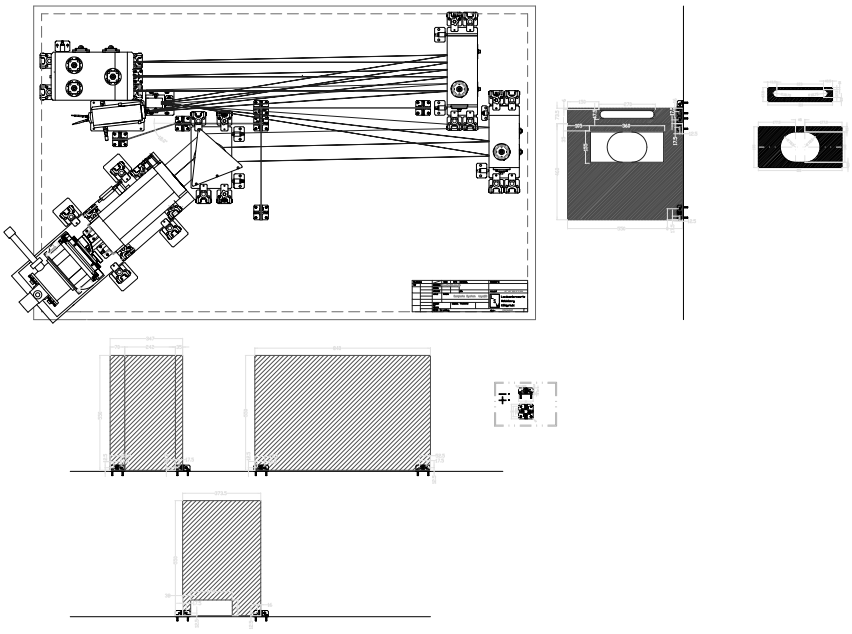


Figure 8.64: BESO-STRAYLIGHTSTOPS

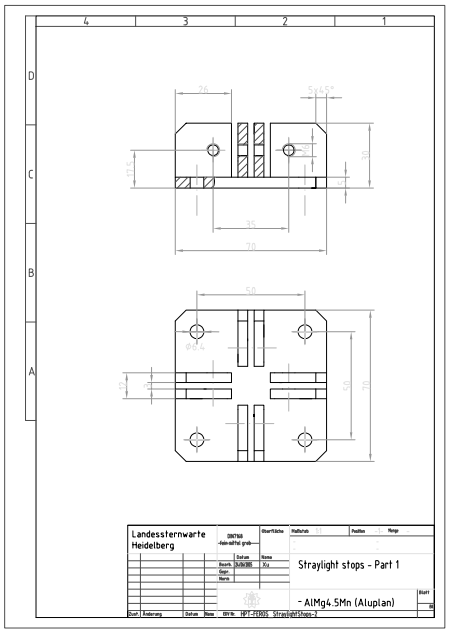


Figure 8.65: BESO-STRAYLIGHTSTOPS-1

8.13 Tools

The instrument toolbox provides all tools necessary to install and maintain the instrument. Some special tools have been manufactured for BESO. - The AC stand (fig. 8.66) holds the Autocolimator at the level of the optical axis of the instrument and is adjustable in tip and tilt.
- The AC can be mounted on the FEU using a special plate. An adapter is availble to mount the laser on the FEU.
- The small adjustment mirror (fig. 8.67) helps to adjust the Fiber Exit Unit head. Placed on top of the Fiber Exit Unit, the mirror surface is at the focus position that would be inside the image slicer.
- The large adjustment mirrors (fig. 8.67) help to aligne the instrument.
- Three small adjustment screws (fig. 8.69) can be used to position the CCD inside the dewar.
- A white teflon cylinder and a small teflon rod define the distance from the diaphragm in the FEU to the fiber ends and the first lens of the F/N system.



Figure 8.66: Autocollimator stand that hold the autocollimator on center of beam level above the optical bench.

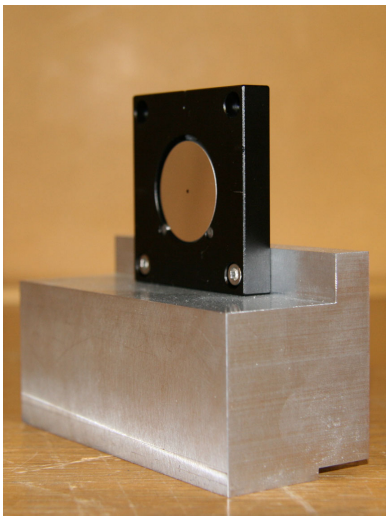


Figure 8.67: Mirror to adjust the autocollimator when put in place of the Fiber-Exit-Unit head.

8.14 Fiber Head

The fiber head is mounted to the telescope and holds the glass fibers guiding the light to the telescope, the microlenses and the diaphragm. The diaphragm can be adjusted for each fiber seperately. The diaphragm is also used as mirror to reflect light into the fiber viewer camera on the telescope platform.



Figure 8.68: Mirror-Stand for instrument alignment. (2x)

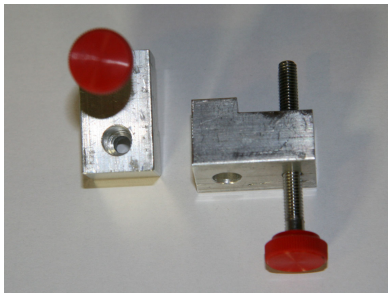


Figure 8.69: CCD-Positioner for alignment inside the dewar. (3x)

8.15 Calibration Unit

The Calibration Unit consists of three Lamps which are built into a small housing that is limited by the surrounding telescope structure. All lamps are images by transfer optics to the telescope focus. A movable mirror switches between light from the flatfield (tungsten) lamps or the wavelength calibration (arc) lamp.
The last mirror that brings the f/8 light beam to the telescope focus is retractable. It moves out of the telescope beam during observation.
The tungsten lamps and the mirror motors are controlled by relay board, that switches the electric current.

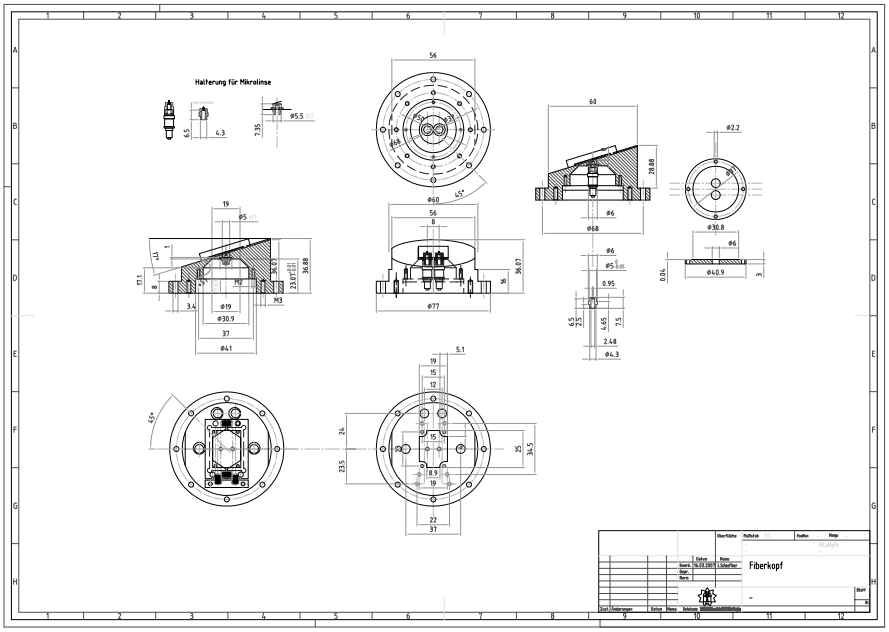


Figure 8.70: BESO-FIBERHEAD-1

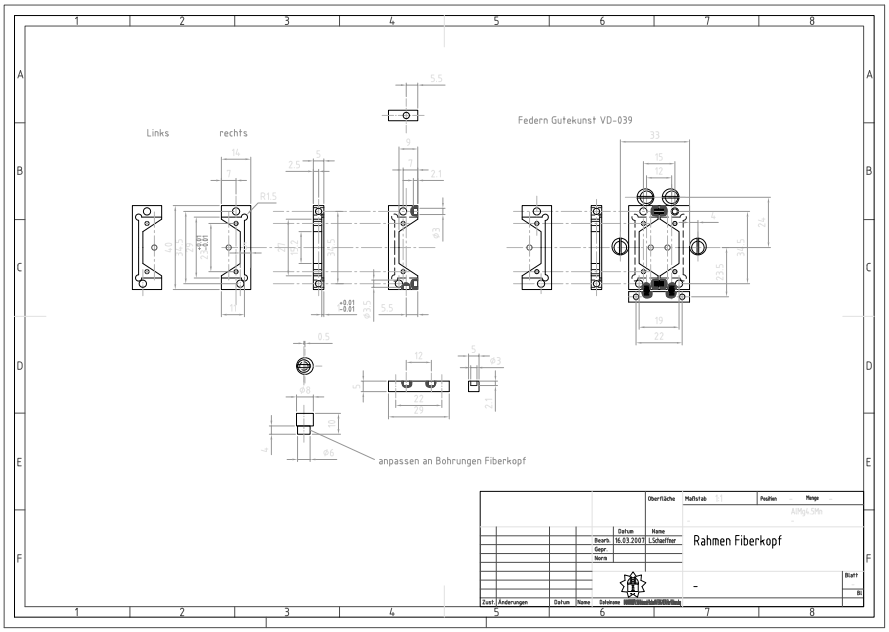


Figure 8.71: BESO-FIBERHEAD-2

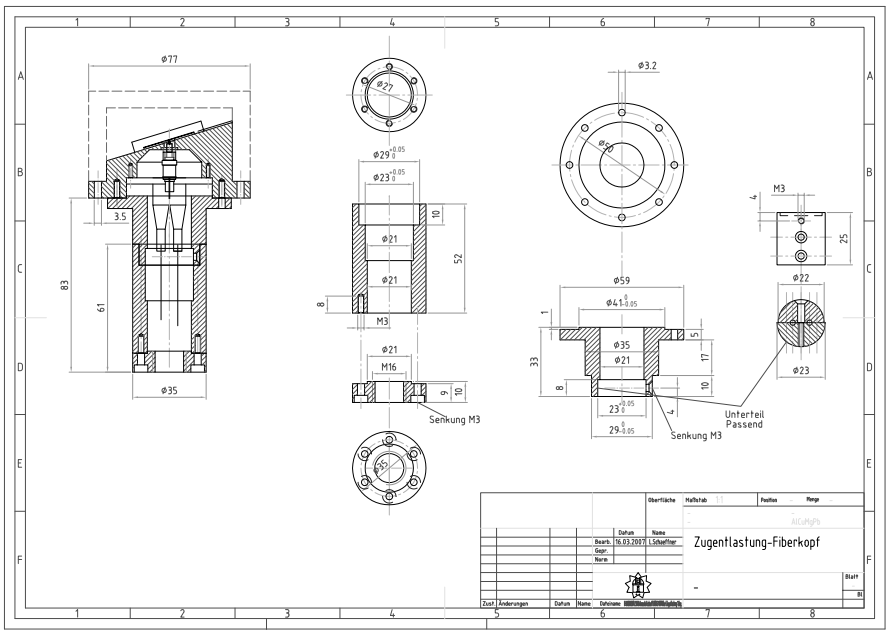


Figure 8.72: BESO-FIBERHEAD-3

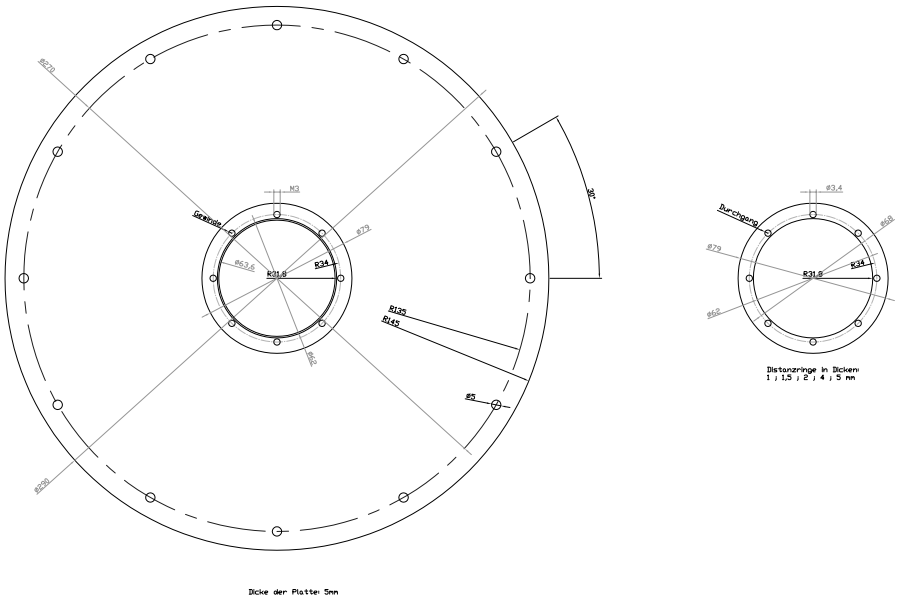


Figure 8.73: BESO-FIBERHEAD-ADAPTER

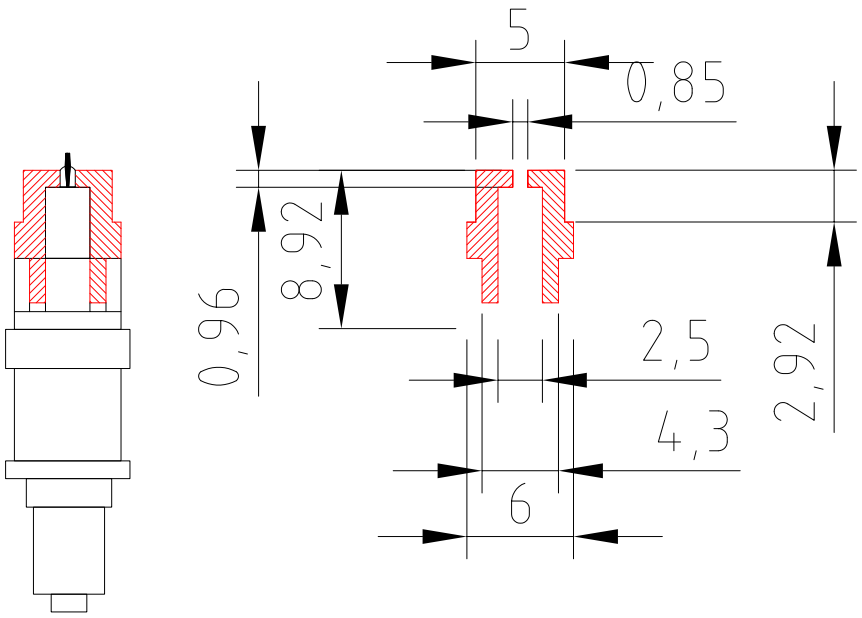


Figure 8.74: BESO-FIBERHEAD-LENS

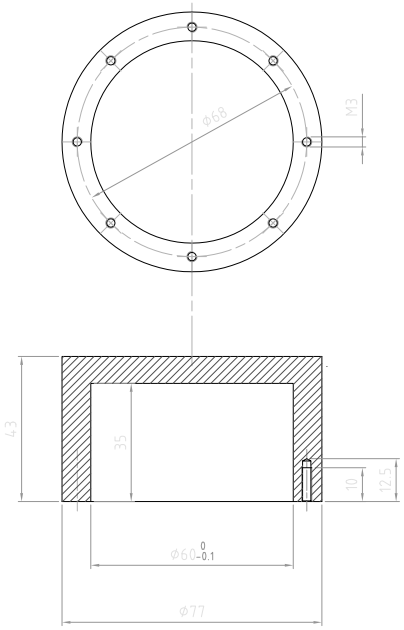


Figure 8.75: BESO-FIBERHEAD-COVER

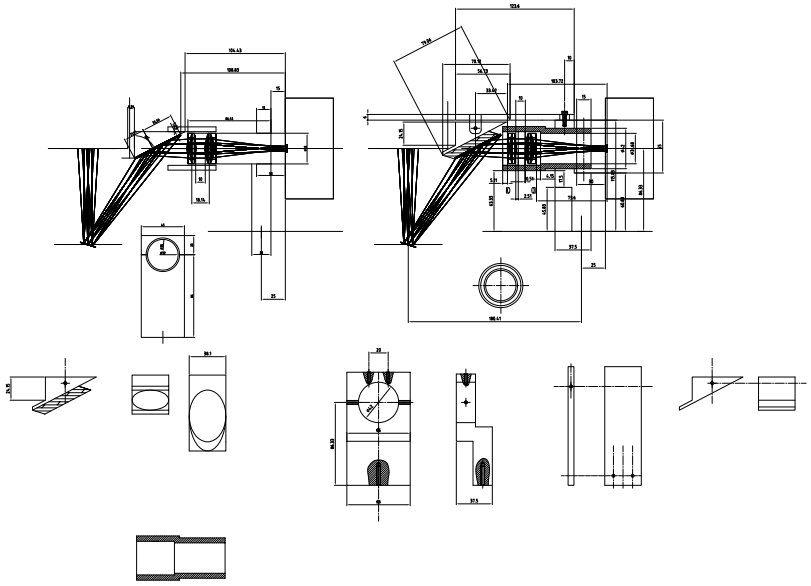


Figure 8.76: BESO-FIBERHEAD-VIEWER



Figure 8.77: BESO-FCU

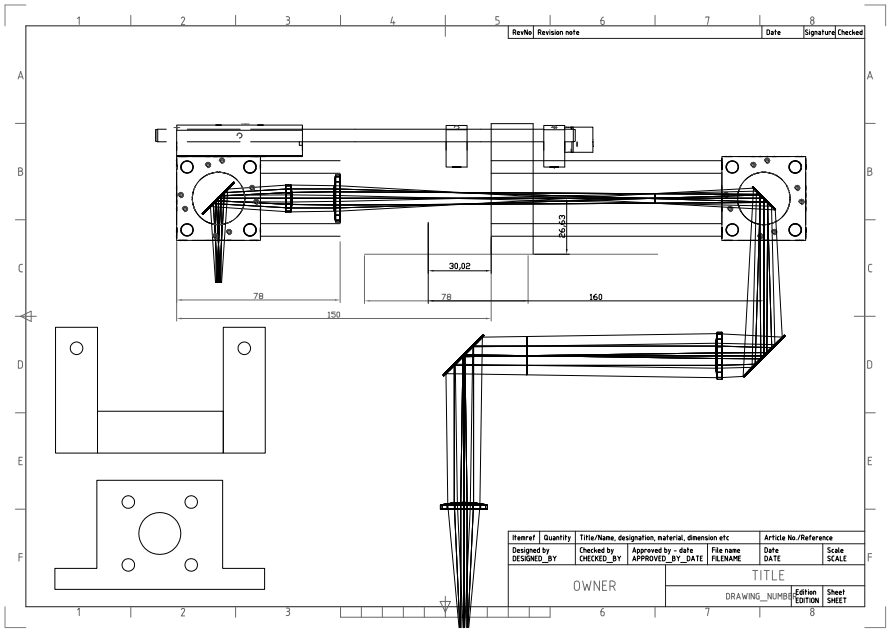


Figure 8.78: BESO-FCU-1

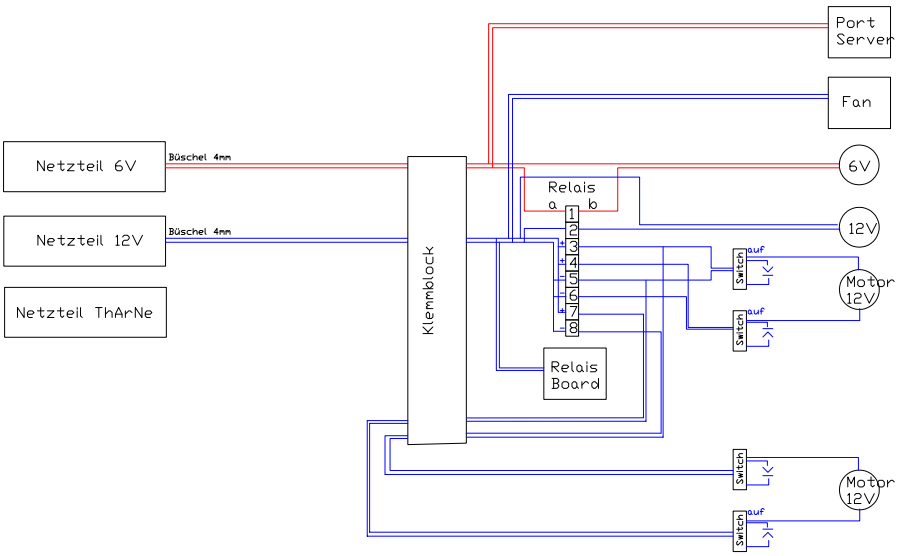


Figure 8.79: BESO-FCU-ELECTRIC

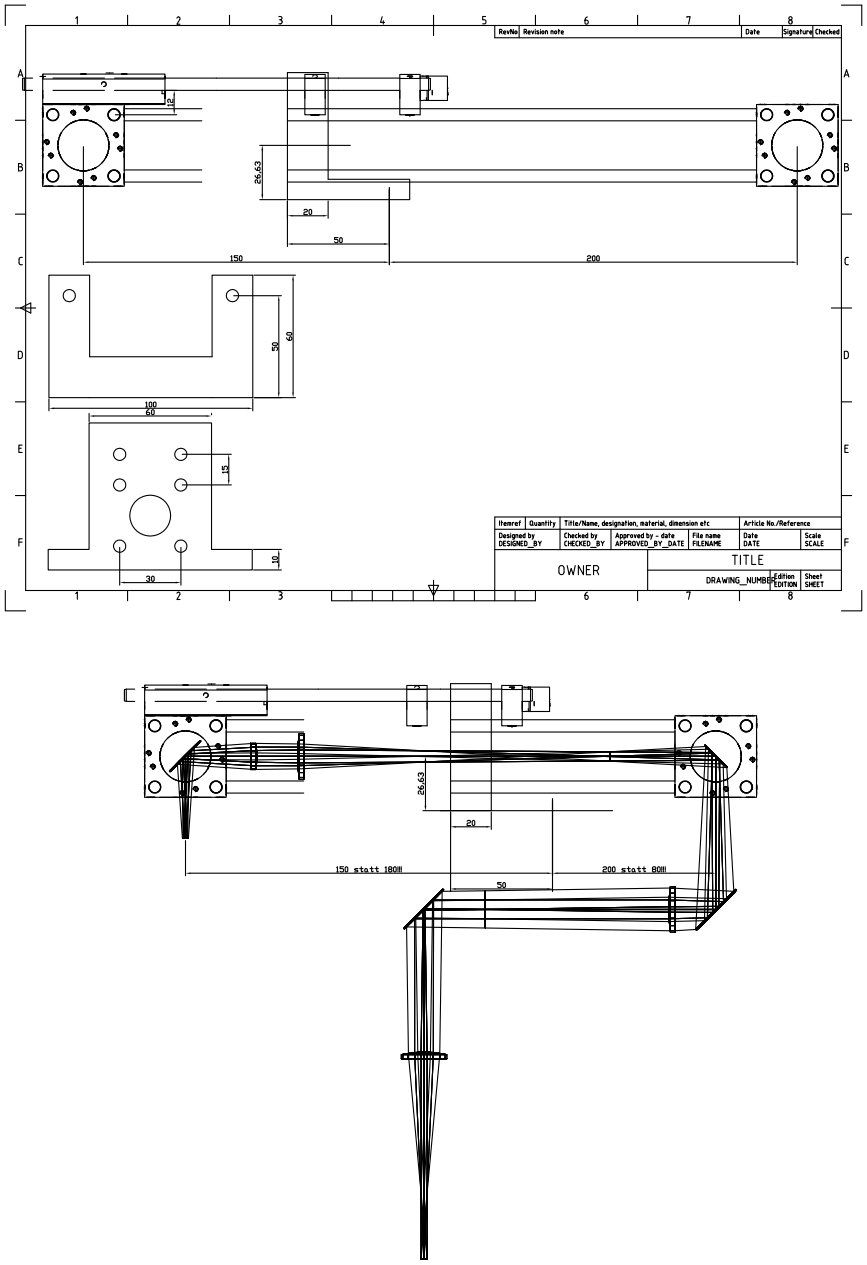


Figure 8.80: BESO-FCU-TRANSFEROPTICS

Chapter 9

Imaging System

The imaging system consists of a cryogenic system with a closed-cycle cooler and a dewar that holds the detector. Temperature-regulation, exposure-control and readout is done by a electronic system, that is mounted to the dewar.

9.1 CCD

The detector is a grade 1 device from e2v technologies. It is has 4096 x 2048 pixels, of 15 μm each. The detector is cooled and stabilised at operating temperature to reduce the dark-current while keeping the quantum-efficiency high. This operating temperature is a tradeoff between low dark-current and high quantum-efficiency as both decline with temperature.

9.2 Cryo-System

The 'Cryo-Tiger' closed-cycle cooler manufactured by Infrared Labs cools the dewar to -150 °C from room temperature. The CCD is heated and stabilised against the cold plate by an electric heater.
The system needs approx. 4 hours to cool down from room temperature and approx. 2 hours to warm up.
The cryo-system can be heated above room temperature to speed up the release of vapor adsorbed on the surfaces and the charcoal getter.

9.3 Electronics

The electronics from Astronomical Research Cameras generates the clock patterns to drive the CCD, performs the 16 bit AD-conversion, transmits the data to the instrument workstation via fiber-optic link and switches the shutter and the electric heater.

9.4 Shutter

The shutter shipped with the imaging system consists of an iris mechanism that is operated by a solenoid. The shutter is opened with a short electric pulse and kept open with a constant current.
The electronics in the imaging system that drives the shutter is designed so that the shutter just opens but heats up by the constant current. This behaviour could not be changed because it is hard wired in the system.
To avoid heating the shutter and inducing turbulence in the optical path, the solenoid has been thermally decoupled from the shutter. To avoid overheating the solenoid in long term exposures a passive cooler has been attached to the solenoid, that is outside of the instrument enclosure.

Chapter 10

Instrument Alignment

10.1 Fiber Exit Unit Head

- Center FN-system and image-slicer in XY.
- Use teflon cylinder and rod to adjust distance to first FN-lens.
- Mount fibers into fiberhead.
- Use teflon cylinder to adjust distance of fiber-end to diaphragm.
- Bring image-slicer into focus.
- Adjust image-slicer with microscope so that both fiber images are correctly sliced and focused.

10.2 Detector

- Mount autocollimator on breadboard on XY-stage.
- Glue flat mirror to back side of flat dewar window. (Flange level)
- Align autocollimator for focus and tip/tilt.
- Move autocollimator 5mm towards CCD.
- Remove dewar window.
- Adjust CCD with tools, so that it appears correctly in autocollimator (focus, tip, tilt).
- Clamp CCD mount, remove tools.
- Mount cold shield.
- Mount field lens.

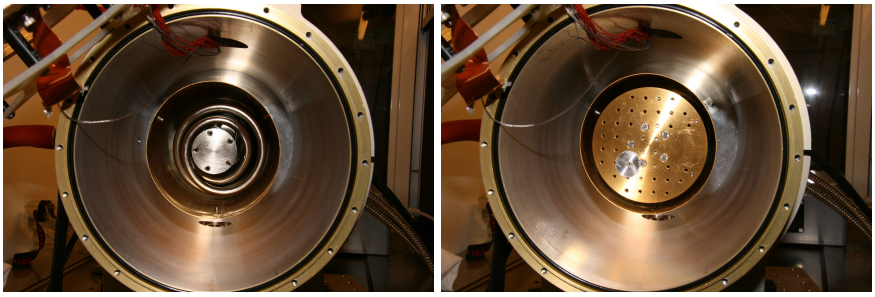


Figure 10.1: Dewar empty (left) and with cold plate (right).

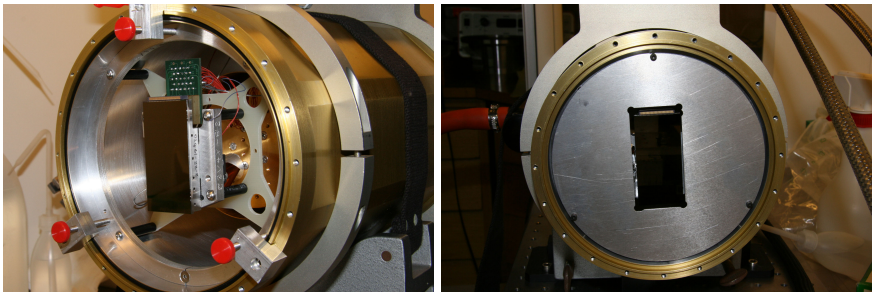


Figure 10.2: CCD support structure (left) and mounted cold shield (right).

10.3 Instrument

10.3.1 FEU

- Check for nominal beam level.
- Adjust top to be parall to table top.

10.3.2 Fibers - FEU

- Insert fibers to the FEU head.
- Adjust fiber-end position with teflon cyclinder.
- Adjust fibers in FEU head so that they have the right separation for the image-slicer.
- Test beam level in several distances (without slicer) to adjust F/N system.
- Adjust slicer so that slices are equally bright.

10.3.3 FEU - Main Collimator

- Adjust with laser and small mirror to mech. acc. - Check with AC.

10.3.4 FEU - Folding Mirror

- Adjust with AC to be upright.
- Adjust side-angle to hit transfer-col in center.

10.3.5 FEU - Transfer Collimator

- Adjust with laser and small mirror to mech. acc.
- Check with AC and 2nd small mirror.

Alternative procedure:
- AC+Lens between Transfer-Col + Fold-Mirror (Adjust to intermed. focus).
- Mark intermediate focus with thin mirror (Focus and collimation).
- Move AC between Fold-Mirror and Main-Col.
- Adjust with Marker-Mirror for focus and collimation.
- Remove Marker-Mirror and place aux-mirror before prism.
- Adjust Trans-col for focus.

10.3.6 Echelle

- Remove 1st small mirror and adjust echelle to nom. beam positions.

10.3.7 Prism

- Mount prism to nominal position.
- Check order separation.

10.3.8 Detector + Camera

- Use centering tool.
- Focus camera with Hartman mask or MIDAS.
- Adjust Echelle angle (1° at screw is about 1px on detector).
- Adjust breadboard angle so that center order is in right position.
- Check that order-number is 39.

10.4 Telescope Adapter

10.5 Calibration Unit

Chapter 11

Safety

During setup, maintenance and operation of the instrument the following aspects should be regarded to ensure safety for the personnel.

11.1 Handling of heavy and sensitive parts

The optical bench consists of one heavy (600 kg) and large (2500 x 1500 x 200 mm) tabletop. Further heavy items are the echelle grating and the collimator mirrors in their support structure (50 kg each). The optical parts should always be protected against rapid changes in temperature.

11.2 Clibration lamps: High voltage, radioactive elements, UV rays

The calibration arc-lamp contains a long-lived Thorium element. No protection against radiation is required. When replacing, ensure that the glass-body of the lamp stays intact. The lamp uses high voltage when in operation.
The tungsten lamps become very hot during operation. Be careful when replacing! Avoid fingerprints on the glass body. The tungsten lamps used for calibration are made with UV transparent glass and are not suitable for general lighting.

11.3 Earthquakes

All heavy parts are clamped to the optical bench. The vibration-control system of the bench is clamped to the table-top also. Therefore no moving or dropping items are expected during earthquakes.

Chapter 12

Appendix

Attached to this manual, that covers the regular use and maintanance of the science instrument, you find a collection of documents that may help in case of a failure, not covered by this manual.
- Southern spectrophotometric standards **?**
- Pfeiffer Vacuum, TPG 261 Single Gauge Manual (german)
- Pfeiffer Vacuum, IKR 251 Cold Cathode Gauge (german)
- Infrared Labs, Dewar Deescription
- Polycold Systems, Compressor Shipping Bolts Notice
- Polycold Systems, External Dryer Installation Instructions
- Polycold Systems, Cryotiger Operating Manual
- Polycold Systems, Cryotiger Technical Manual
- Astronomical Research Cameras, Voodoo Software Manual
- Astronomical Research Cameras, ARC 45 Video Processor Board Manual
- Astronomical Research Cameras, ARC 22 Fiber Optic Timing Board Manual
- Astronomical Research Cameras, ARC 30 Utility Board Command Manual

Attached you also find a list that shows the spareparts stored with the instrument. When installing a sparepart a replacement must be ordered and the item count should be updated. The installation of some spareparts (e.g. image slicer or fiberset) - though available - require extensive recalibration of the instrument. Specifications and quotations of all optical and mechanical parts are stored in a seperate folder in Bochum.