

Recommended alignment procedure for π Shaper 6_6 / Focal- π Shaper 9

The described below procedure presents an example of alignment of beam shapers π Shaper and Focal- π Shaper (F- π Shaper) with using the standard π Shaper Mount and auxiliary tools: “Aligner” and “1 meter Lens” (for Focal- π Shaper only).

Important: Usually by installing a beam shaper in certain equipment it is recommended to align the optical system of that equipment without the beam shaper and then to install the beam shaper and align it by checking the measured input and output intensity profiles

The basic approach implies several stages:

- to provide a proper alignment of the Aligner with using a camera-based beam profiler,
- to install a beam shaper and correct its alignment by checking the output beam profile at the beam shaper exit,
- in case of F- π Shaper to install the 1 meter lens and correct the alignment by checking the resulting beam profile in zone of focal plane.

The below considered example was carried out

- with using laser of $\lambda = 532$ nm,
- the beam was expanded with using a zoom beam-expander $2^x - 10^x$,
- initial laser beam is elliptic, aspect ratio 1:0.9,
- camera-based beam profiler was used, see figure on right.

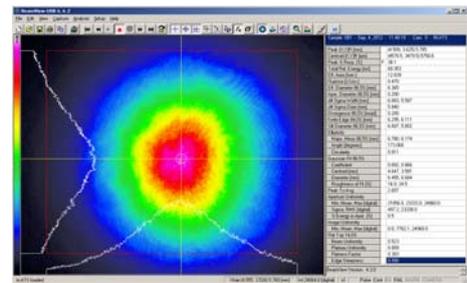
The below description presents stepwise procedure that is illustrated with photos and screenshots from beam profiler. There are provided also comments and recommended actions.



Initial beam

The beam after the zoom beam expander, at the Beam Shaper entrance:

- $1/e^2$ diameter ~ 6.4 mm,
- Ellipticity characterized by aspect ratio 1:0.9, larger vertical section.



Aligner

Aligner presents a tube with mounting thread M27x1 in its central part, this thread is identical to one used at most of π Shaper / Focal- π Shaper systems.

The tube ends are precisely machined with respect to the thread and are used for mounting with tough tolerance replaceable apertures:

- at entrance – aperture of 2 mm diameter,
- at exit - apertures of diameters
 - 3 mm,
 - 2 mm,
 - 1 mm.

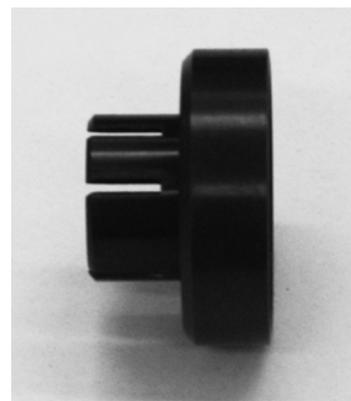


1 meter Lens (used with Focal- π Shaper only)

This is a convex-plano lens with focal length ~ 1000 mm mounted in a special holder compatible with exit mechanics of the Focal- π Shaper. The lens is used for purposes of alignment only.

Since the operational principle of the Focal- π Shaper implies using a diffraction limited lens after it that 1 meter lens is a convenient tool replacing a normal lens (for example F- Θ lens) on alignment stage and providing relatively big laser spots (typically several hundreds of microns) that can be caught by state-of-the-art camera-based beam profilers. Thus the same beam profile measuring instrument can be used to catch the intensity distributions before and after the Focal- π Shaper as well as in zone of focal plane.

After aligning the Focal- π Shaper with respect to the laser that 1 meter lens has to be replaced back to the normal lens.

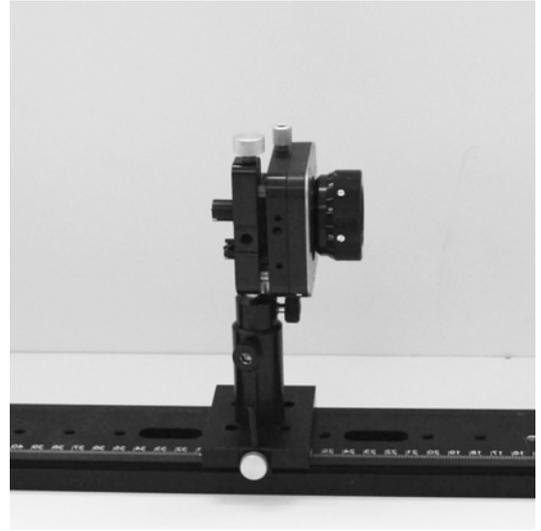


π Shaper Mount

This is a 5- or 4-axis Mount providing alignment in 2 lateral shift X/Y and 2 tilts around X/Y.

This device is usually recommended to be applied while delivery of π Shaper or Focal- π Shaper.

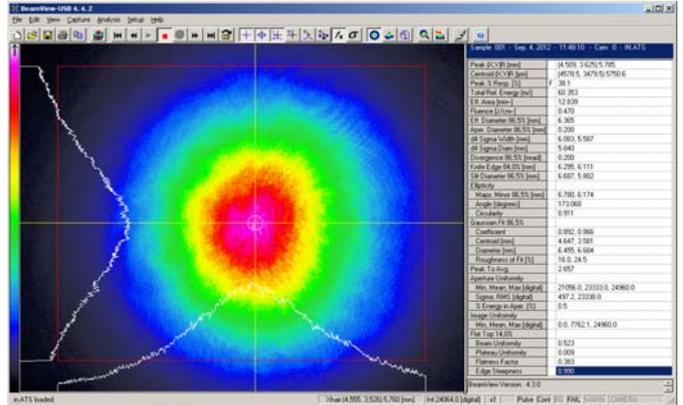
It is possible also to use other opto-mechanical devices providing similar functionality of alignment.



Alignment procedure for the Aligner

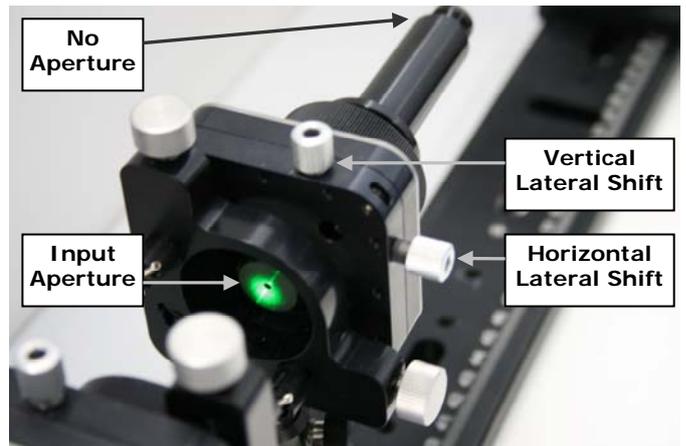
Action:

- to install the Laser and the Beam Expander,
- to install the camera-based beam profiler,
- to put the crosshair of beam profiler in center of the laser spot, this will ease further procedure.



Action: to install the Aligner in the π Shaper Mount :

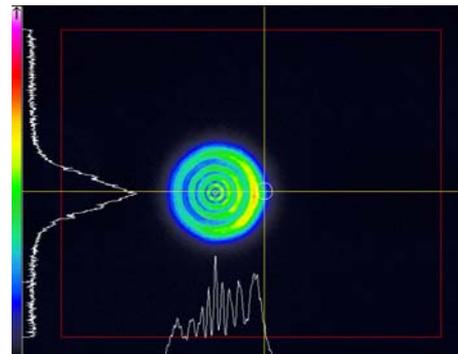
- entrance aperture of 2 mm diameter,
- **NO** aperture at the exit.



Apertures, mm	
In	Out
2	-

Comment:

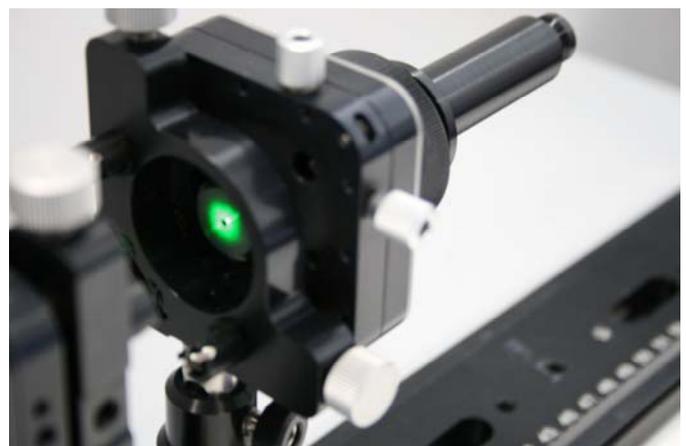
The Aligner is misaligned in horizontal direction



Action: to do lateral shifting in horizontal direction with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.

Important: Use lateral shifts (X/Y) only when ONLY entrance aperture is installed!

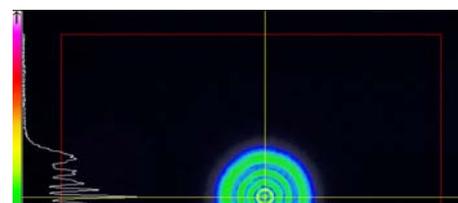
The knobs of lateral shifts are marked in above photo; the resulting spot is shown in right photo and next screenshot.



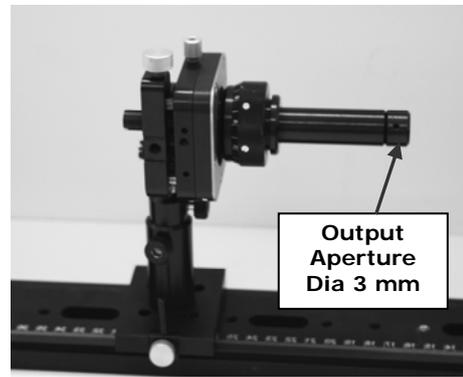
Apertures, mm	
In	Out
2	-

Comments:

The entrance aperture of the Aligner is aligned in vertical and horizontal directions. Diffraction pattern is symmetric. The center of rings coincides with the crosshair.

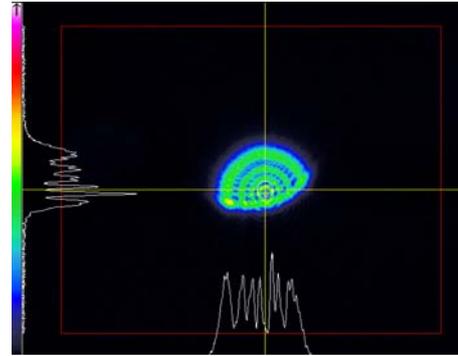


Action: to install the Output Aperture of 3 mm diameter.



Apertures, mm	
In	Out
2	3

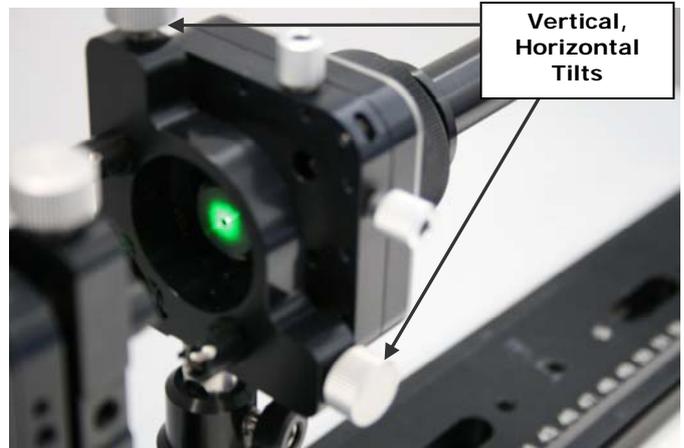
Comment:
There exists angular misalignment in vertical direction



Action: to do tilt in vertical direction with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.

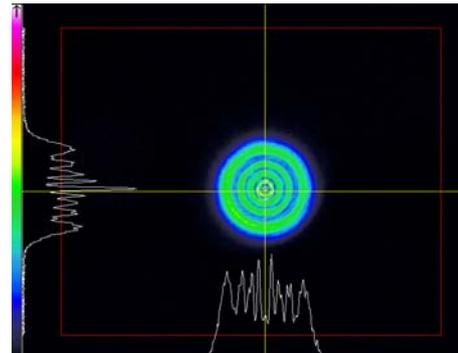
Important: Use primarily the tilts around X/Y, lateral shifts to be used AFTER tilts to correct the alignment.

The knobs of tilts around X/Y are marked in the right photo.

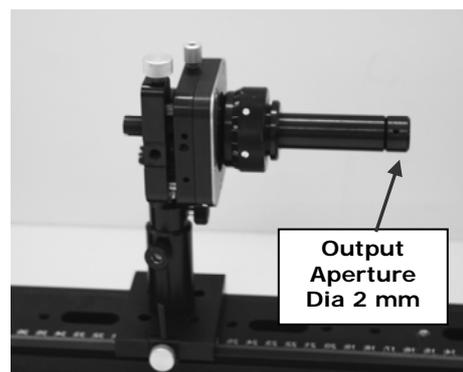


Apertures, mm	
In	Out
2	3

Comments:
Full beam after input 2mm aperture passes through the output 3 mm aperture.
Diffraction pattern is symmetric.
The center of rings coincides with the crosshair.

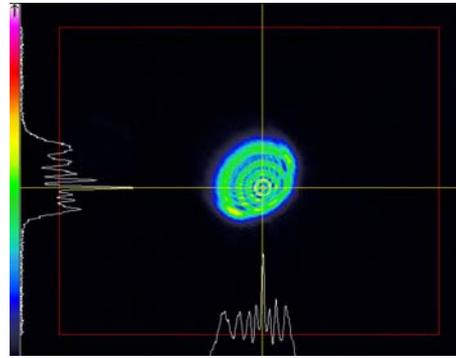


Action: to install the Output Aperture of 2 mm diameter.



Apertures, mm	
In	Out
2	2

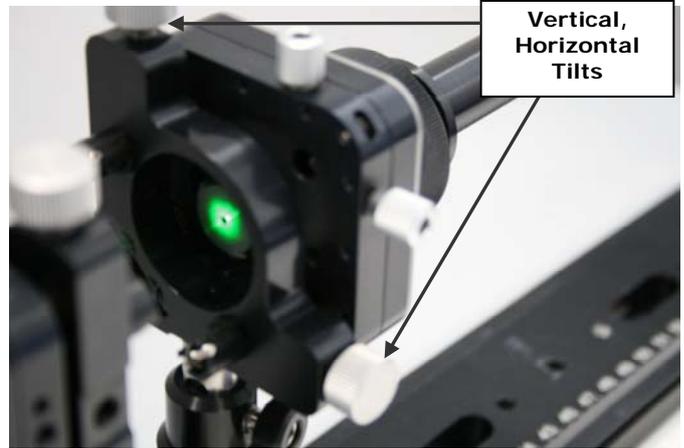
Comment:
There exists angular misalignment in horizontal and vertical directions.



Action: to do tilt in horizontal and vertical directions with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.

Important: Use primarily the tilts around X/Y, lateral shifts to be used AFTER tilts to correct the alignment.

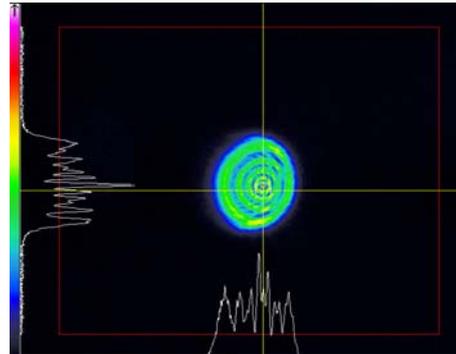
The knobs of tilts around X/Y are marked in the right photo.



Apertures, mm	
In	Out
2	2

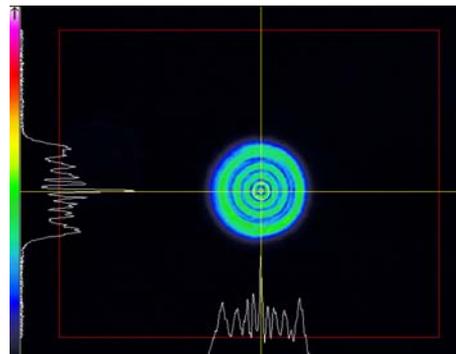
Comments:
Angular misalignment is almost eliminated in vertical direction but still strong in horizontal direction.

Action: to do tilt in horizontal direction with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.

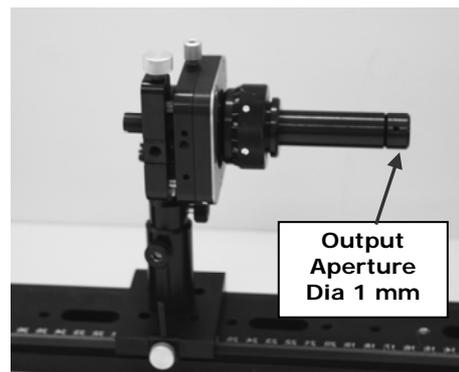


Apertures, mm	
In	Out
2	2

Comments:
The beam after input 2mm aperture passes through the output 2 mm aperture.
Diffraction pattern is symmetric.
The center of rings coincides with the crosshair.



Action: to install the Output Aperture of 1 mm diameter.

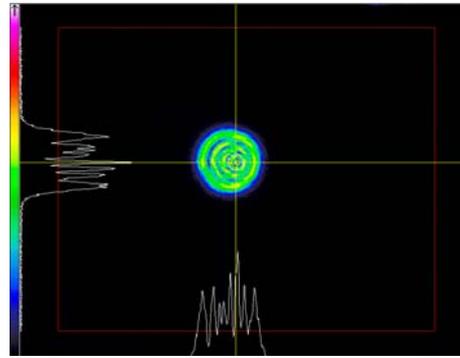


Apertures, mm	
In	Out
2	1

Comment:

There exists angular misalignment in horizontal direction.

Action: to do tilt in horizontal direction with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.



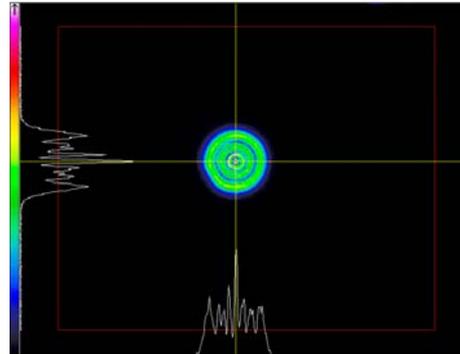
Apertures, mm	
In	Out
2	1

Comments:

The Aligner is aligned.

Diffraction pattern is symmetric.

The center of rings coincides with the crosshair.



Alignment procedure for the π Shaper 6_6

Finishing the aligning procedure of the *Aligner* means the Mount is close to the optimum position and the π Shaper 6_6 (hereinafter π Shaper) can be installed. Because of production tolerances there might be necessary to tune the π Shaper position.

Important:

According to the principle of operation the π Shaper :

- converts **Gaussian to Collimated Flattop beam**,
- input beam
 - Collimated for *telescopic* version of π Shaper,
 - Divergent for *collimator* version of π Shaper,
 - to have Gaussian or similar irradiance profile (peak irradiance in center, downing towards periphery),
 - to be TEM₀₀ or multimode,
 - to have pre-determined beam size (see specifications for particular models)
- Output beam
 - is collimated,
 - has Flattop irradiance profile



Fig. C.1

Action: to install the π Shaper and camera-based beam profiler.

Important:

The output intensity profile has to be close to Flattop!
There might be some imperfections in alignment and profile homogeneity
When proper alignment the pattern should have circular symmetry

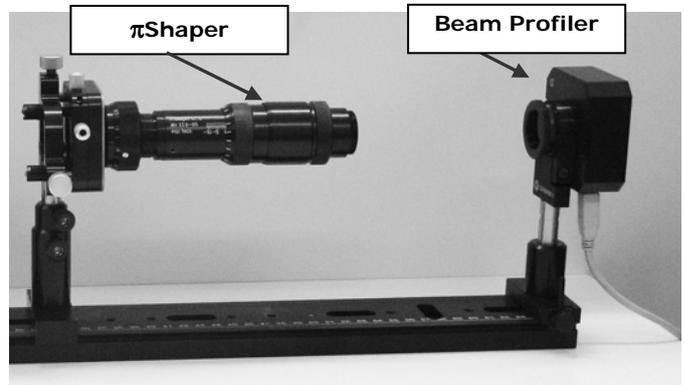


Fig. C.2

Typical view of beam profile pattern

Comments:

- there exists certain misalignment in horizontal direction – sharp bright ring on left side and smooth profile on right.

To improve alignment it is necessary to make lateral shifts and tilts in corresponding directions.

Before doing this, please, study the further chapter where behaviour of output profile while π Shaper misalignment is considered.

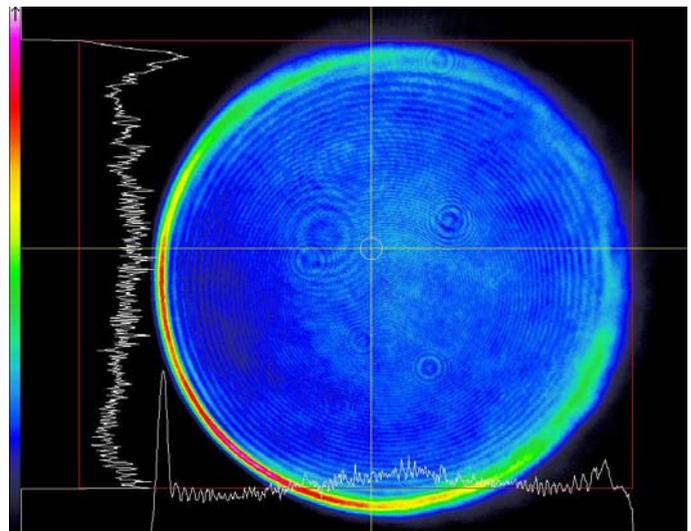


Fig. C.3

Misalignments of π Shaper

Proper alignment is important for any beam shaping optics; let's evaluate influence of misalignments in case of refractive field mapping beam shapers. The Fig. C.4 presents results of mathematical simulations as well as measurements of real profiles for the π Shaper 6_6 in three cases: perfectly aligned, lateral shift of a beam, angular tilt of the beam shaper.

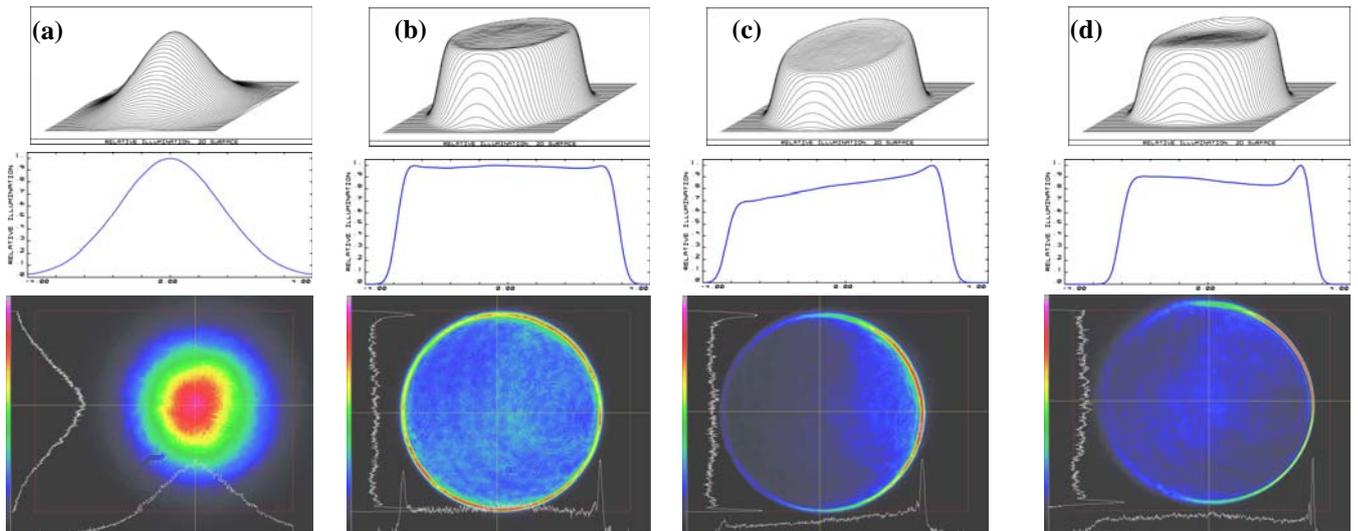


Fig. C.4 To evaluation of sensitivity of misalignments, theoretical and experimental intensity profiles for π Shaper 6_6:
 a) Input TEM_{00} beam, b) Output by perfect alignment c) Output by lateral shift at 0.5 mm, d) Output by tilt at 1° .

A small, up to about $\pm 20\%$ of diameter, lateral shift of a beam with respect to the beam shaper, or vice versa, doesn't lead to aberration but allows to get an interesting beam shaping effect – the output profile is skewed in direction of the lateral shift, this is illustrated in Fig. C.4c. The intensity profile itself stays flat but is tilted in the direction of the shift, and a remarkable feature is that the beam itself stays collimated and low divergent.

As an optical system designed to work with axial beams the π Shaper operates in relatively narrow angular field, the data in Fig. C.4d demonstrates the intensity profile behaviour by the beam shaper tilt at 1° . The intensity profile stays stable but there is visible degradation of quality on left and right sides of the spot due to aberrations, first of all coma. It should be noted that discussed here 1° tilt of the π Shaper 6_6 means about 2 mm (!) lateral shift of one of its ends, no doubts this misalignment can be easily compensated by ordinary opto-mechanical mounts.

These data show that the misalignments have influence on the π Shaper operation but sensitivity to these misalignments isn't tremendous, even with essential lateral shift (up to 0,5 mm!) and tilt (up to 1° !) the resulting profiles are close to flattop. In other words, the tolerance of positioning of a beam shaper is rather not tough and misalignments can be compensated by ordinary opto-mechanical mounts. Since the influence of a tilt on wave aberration of output beam is quite pronounced it is advisable to pay more attention to angular alignment while adjustment of beam shapers.

Correction of profile shown in Fig. C.3

Action: - to use horizontal tilt to achieve symmetric view of profile in horizontal direction,
 - when necessary to use X/Y lateral shifts to improve output profile,
 - it is also recommended to check symmetry of profile at distance about 1 meter, where a pattern with concentric diffraction rings appears.

Finally the profile should look like in Fig. C.5 bottom.

Comments:

- irradiance profile is uniform in central part
- there exists a bright rim, which can appear because of several reasons:
 - deviation of input beam profile from Gaussian in form of extended "wings",
 - too large input beam,
 - convergence of output beam.
- It is recommended to check above mentioned effects and correct conditions.

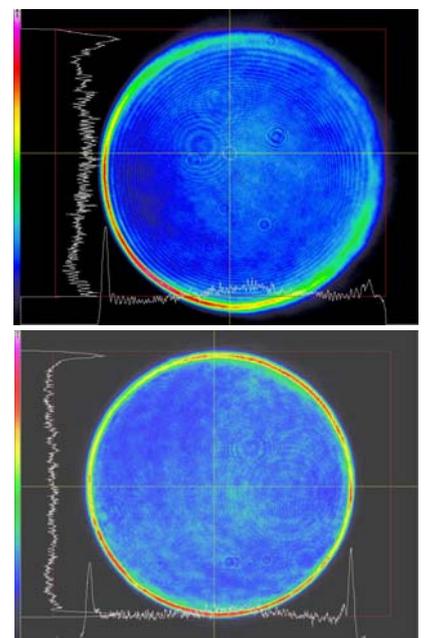
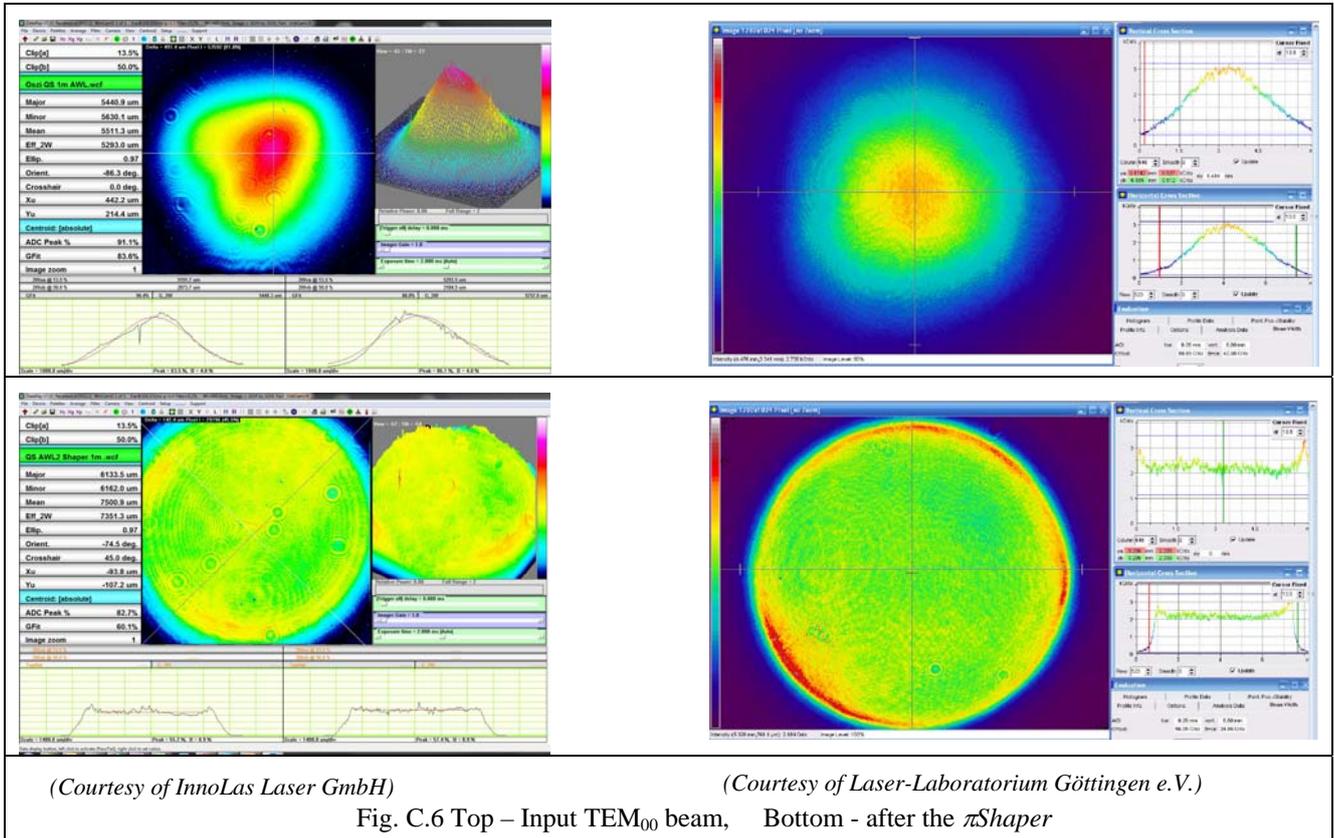


Fig. C.5

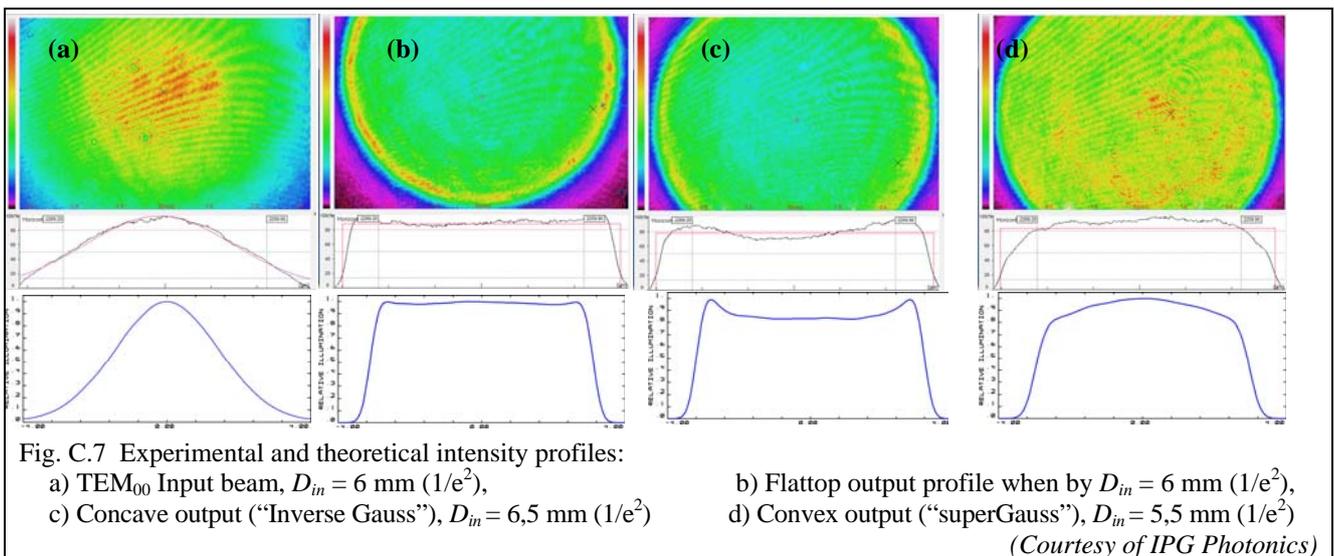
Examples of proper alignment of π Shaper



Variable Profiles by Variable Input Beam Size

The feature of the field mapping beam shapers that *output beam profile depends on the input beam size*, Fig. C.1, can be used as a powerful and convenient tool to vary the resulting intensity distribution by simple changing of laser beam diameter with using an ordinary zoom beam expander ahead of the π Shaper.

This approach is demonstrated in Fig. C.7 where results of theoretical calculations as well as measured in real experiments beam profiles for TEM₀₀ laser are shown.



The data relate to the π Shaper 6_6 which design presumes that a perfect Gaussian beam with $1/e^2$ diameter 6 mm to be converted to a beam with uniform intensity (flattop) with FWHM diameter 6.2 mm. When the input beam has a proper size, Fig. C.7a, the resulting beam profile is flattop, Fig. C.7b. Increasing of input beam diameter leads to downing of intensity in the centre, Fig. C.7c, sometimes this distribution is called as “inverse-Gauss”; input beam size reduction allows getting a convex profile that approximately can be described by super-Gauss functions, Fig. C.7d.

The considered intensity profiles correspond to about 10% beam size change; the larger are changes the more pronounced is variation in intensity profile.

An interesting feature of the field mapping beam shapers is in stability of the output beam size – variation of input beam diameter results in variation of intensity profile while the output beam diameter stays almost invariable. This is very important in practice and brings element of stability while searching for optimum conditions for a particular laser application.

Other useful data concerning the π Shaper behaviour as well as their using in practice can be found in papers:

1. Laskin, A., Laskin, V. Controllable Beam Intensity Profile for the Tasks of Laser Material Processing, in ICALEO 2012 Proceedings, Anaheim, CA, USA, Paper 707.
2. Laskin, A. V., Imaging techniques with refractive beam shaping optics. In Laser Beam Shaping XIII , Forbes, A.; Lizotte, T. E., eds., vol. 8490, 2012 DOI: 10.1117/12.930284.
3. Laskin, A., Laskin, V., "Refractive beam shapers for material processing with high power single mode and multimode lasers" in *Laser Resonators, Microresonators, and Beam Control XV*, Proceedings of SPIE Vol. 8600 (SPIE, Bellingham, WA 2013) 8600-38.
4. Laskin, A., Laskin, V., "Collimating beam shaper for holography and interferometry " in *Practical Holography XXVII: Materials and Applications*, Proceedings of SPIE Vol. 8644 (SPIE, Bellingham, WA 2013) 8644-5.
5. Laskin, A., Achromatic refractive beam shaping optics for broad spectrum laser applications. In Laser Beam Shaping X, Forbes, A.; Lizotte, T. E., eds., vol. 7430, 2009 743003.
6. Laskin, A., Laskin, V. Creating Flattop Square Laser Spots in Microprocessing Systems with Scanning Optics, in ICALEO 2012 Proceedings, Anaheim, CA, USA, Paper M305.
7. Laskin, A., Laskin, V. Beam Shaping Optics to Improve Holographic and Interferometric Nanomanufacturing Techniques, in ICALEO 2012 Proceedings, Anaheim, CA, USA, Paper N405.
8. Laskin, A., Laskin, V., "Applying field mapping refractive beam shapers in laser technologies for solar energy" in *Laser Material Processing for Solar Energy*, Proceedings of SPIE Vol.8473 (SPIE, Bellingham, WA 2012) 8473-23.
9. Laskin, A.; Laskin, V., Beam shaping in high-power laser systems with using refractive beam shapers. In Laser Sources and Applications , Graf, T.; Mackenzie, J. I.; Jelinkova, H.; Powell, J., eds., vol. 8433, 2012 DOI: 10.1117/12.920002.
10. Laskin, A., Williams, G., McWilliam, R., Laskin, V., "Applying field mapping refractive beam shapers to improve holographic techniques" in *Practical Holography XXVI: Materials and Applications*, Proceedings of SPIE Vol. 8281 (SPIE, Bellingham, WA 2012) 82810K.
11. Laskin, A.; Laskin, V., Applying of refractive beam shapers of circular symmetry to generate non-circular shapes of homogenized laser beams. In Laser Resonators and Beam Control XIII,, Kudryashov, A. V.; Paxton, A. H.; Ilchenko, V. S., eds., vol. 7913, 2011 DOI: 10.1117/12.881719.
12. Laskin, A.; Laskin, V., Applying field mapping refractive beam shapers to improve irradiation of photo-cathode of FEL. In X-Ray Free-Electron Lasers: Beam Diagnostics, Beamline Instrumentation, and Applications, Moeller, S. P.; Yabashi, M.; Hau-Riege, S. P., eds., vol. 8504, 2012 DOI: 10.1117/12.930274.
13. Laskin, A.; Laskin, V., Refractive beam shaping optics to improve operation of spatial light modulators. In Acquisition, Tracking, Pointing, and Laser System Technologies XXVI , Thompson, W. E.; McManamon, P. F., eds., vol. 8395, 2012 DOI: 10.1117/12.920521.
14. Laskin, A.; Drachenberg, D.; Mokhov, S.; Venus, G.; Glebov, L.; Laskin, V., Beam combining with using beam shaping. In Acquisition, Tracking, Pointing, and Laser System Technologies XXVI , Dubinskii, M., ed., vol. 8381, 2012 DOI: 10.1117/12.920515.

Alignment procedure for the Focal- π Shaper

Aligning of the Aligner means the Mount is close to the optimum position and the Focal- π Shaper can be installed. Because of production tolerances there might be necessary to tune the position of the Focal- π Shaper.

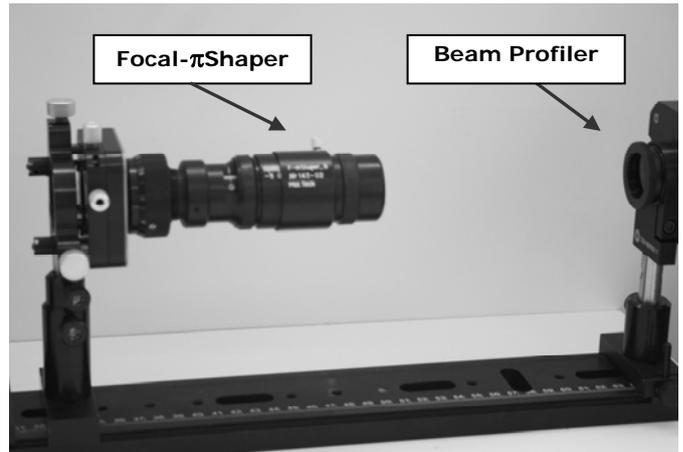
Action: to install the Focal- π Shaper and camera-based beam profiler.

Typical view of beam profile pattern is shown in next figure.

Important:

The output intensity profile *SHOULDN'T BE* Flattop!
It should have central laser spot and several rings, so similar to Airy disk distribution.

When proper alignment the centre of those rings to be in coincidence with the peak of central laser spot.



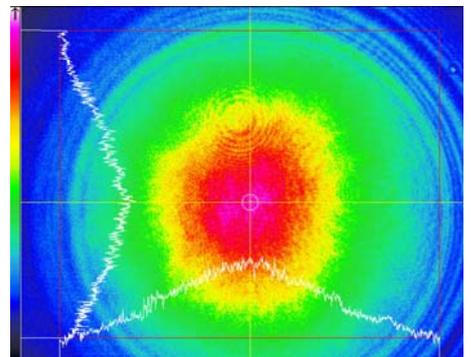
Comments:

- there exists certain misalignment in vertical and horizontal directions – the rings should be “raised” and shifted left.

Action: to do *lateral shifting* in vertical and horizontal directions with checking the spot with camera to provide symmetric diffraction pattern being centred with the crosshair.

Important: Use lateral shifts (X/Y) only!

It is recommended also to locate the beam profiler at longer distance.



Important: When small input beam size the rings can be not good seen, then it is recommended either to enlarge temporarily the input beam size for alignment purposes, or another way – scanning full range of lateral shifts on Mount in both directions to make the rings visible.

The right figure shows typical view of beam profile after F- π Shaper at 0.9 m distance.

Comments:

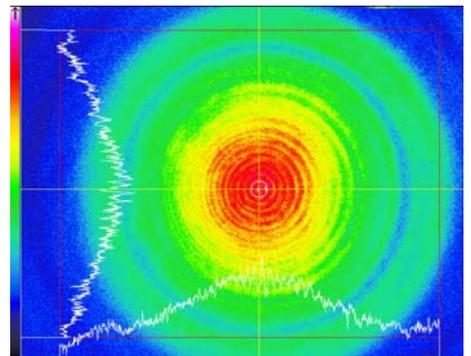
- the image demonstrates good symmetry.

Next step is analyzing the pattern near the focal plane of a lens.

For alignment purpose it is convenient to apply 1 meter lens:

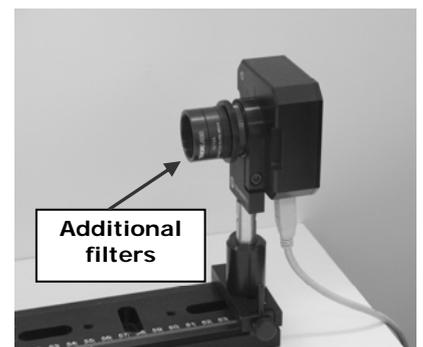
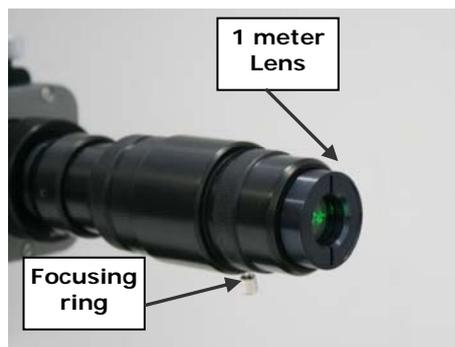
- negligible aberrations,
- relatively large spots, several hundreds of microns, that can be caught by the popular camera based beam profilers.

By finishing the alignment that 1 meter lens should be replaced by a working focusing lens.



Actions:

- to install the 1 meter lens at the Focal- π Shaper exit,
- to install additional neutral filters on the beam profiler, typically +2D, to prevent damaging of camera due to increased irradiance,
- to put the beam profiler after the F- π Shaper at distance approx. 1 meter,



- by rotating the focusing ring (see on right) to find the position of the beam waist, this will be a starting point for further adjustments,
- by rotating the focusing ring to shift the waist far from 1 meter lens, in order to analyze the profiles BEFORE the waist,
- to reach the profile looking as a donut, see the next picture.

Important: To move the waist far from the lens it is necessary to rotate focusing ring in direction of negative values on the scale engraved on the F- π Shaper case,
The rule: Negative values correspond to negative optical power, hence to shifting the profiles FROM the lens.

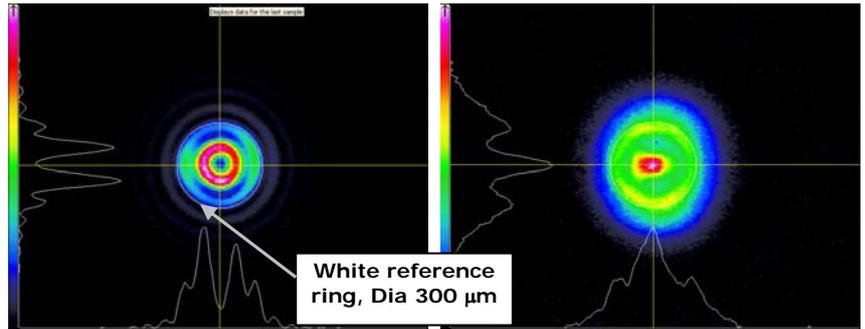
The right figure shows examples of profile.
 Spot diameter is about 300 μm .

Comments:

- there exists certain misalignment in horizontal direction.

Action:

- to do tilt in vertical direction with checking the spot with camera to provide symmetric diffraction pattern.



Important: It is convenient to use a reference ring like white ring of 300 μm diameter on the above and below pictures.

Important: Use primarily the tilts around X/Y, lateral shifts to be used AFTER tilts to correct the alignment.

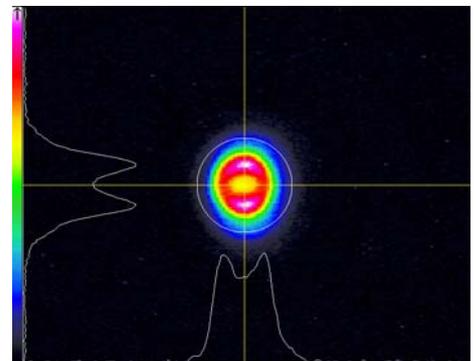
Important: As a rule by aligning it is necessary to “move” the spot in direction of maximum intensity, in case of above pictures – to the left.

The right figure shows typical view of beam profile for the aligned F- π Shaper.

Comments:

- the image demonstrates good symmetry,
- the profile in vertical direction has deeper intensity in the centre due to ellipticity of initial laser beam.

To reach the flattop intensity it is necessary to adjust input beam diameter.
 The optimum beam diameter depends on a profile of initial TEM₀₀ laser beam, typically for the Focal- π Shaper 9 the optimum $1/e^2$ diameter to be 4-4.5 mm.



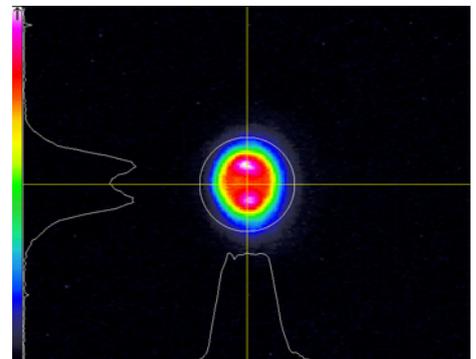
Action:

- to tune the input beam diameter by external zoom beam expander .

Example of resulting spot is shown in right figure.

Comments:

- the profile is flattop in horizontal direction,
- the image demonstrates good symmetry,
- the profile in vertical direction has deeper intensity in the centre due to ellipticity of initial laser beam.



Important: It is recommended to use a zoom beam expander ahead of the Focal- π Shaper in order to simplify the final procedure of adjusting the input beam diameter.

Important: The fine tuning of beam size internally can be done by rotating the magnification ring of the Focal- π Shaper; it is necessary to keep in mind that the range of size variation is limited by +/-15% only and by rotating the magnification ring there happens shift of the waist of resulting beam and it is necessary to compensate that shift by rotating the focusing ring.

After finishing the alignment of the Focal- π Shaper with respect to the laser it is necessary to remove the 1 meter lens and use a working focusing lens.

Important: The sequence of profiles created by focusing of a beam after the Focal- π Shaper will be repeated with the working lens as well, but the spot *size* will be changed *proportionally* to change focal length, while *distances along the optical axis* are changed in *square proportion*.

Other useful data concerning the π Shaper behaviour as well as their using in practice can be found in papers:

15. Laskin, A., Laskin, V. (2010) Refractive field mapping beam shaping optics: important features for a right choice, in ICALEO 2010 Proceedings, Anaheim, CA, USA, Paper M1301.
16. Laskin, A., Laskin, V. Creating Flattop Square Laser Spots in Microprocessing Systems with Scanning Optics, in ICALEO 2012 Proceedings, Anaheim, CA, USA, Paper M305.
17. Laskin, A., Laskin, V. (2011) Applying of Refractive Spatial Beam Shapers with Scanning Optics, in ICALEO 2011 Proceedings, Orlando, FL, USA, Paper M604.