πShaper 12_12

Laser Beam Shaping Optics

Manual

January 30, 2020

1. *Specification*

Table 1

Common for all *πShaper 12_12* models:	
Type	Field mapping beam shaper as a telescope of Galilean type, without internal focus
Input beam	- Collimated - TEM_{00} or multimode with Gaussian or similar intensity profile
Output beam	- Collimated - Flat-top, uniformity within 5% - Diameter ~12 mm, see exact data below - High edge steepness
Other features	- Compact design suitable for scientific and industrial applications - High resistance for high peak power pulse lasers - Conserving flatness of the beam wavefront - Long working distance - Water cooling, option for CW (or average) power > 400 W
Weight	< 600 g
Mounting	- Input: outer thread M27x1 - Output: outer thread M33x1; Adaptor M33x1 -> M27x1 (outer)

***πShaper 12_12* features**

Model*	**Input 1/e² Ø, mm**	**Output FWHM Ø, mm**	**Spectral band, nm**	**Dimensions Ø/Length, mm**	**Design wave-lengths, nm**	**Applications based on**
_10.6	12.0 - 12.2	12.0	10000-11000	49 / 271	10600	CO_2 lasers
_9.4	12.0 - 12.2	12.0	9000-10000	49 / 271	9400	CO_2 lasers
_5.1	12.0 - 12.2	12.0	5000-5500	49 / 271	5100	CO, quantum cascade lasers
_1064	12.8 - 13.0	12.4	1020 - 1100	49 / 271	1064	Nd:YAG, Fiber lasers, NIR Lasers
_1064_HP	12.0 - 12.1	12.0	1020 - 1100	42 / 358	1064	High-peak power Nd:YAG, Fiber lasers
_1064_HP_W	12.0 - 12.1	12.0	1020 - 1100	49 / 360	1064	High-peak power USP lasers, water cooled
_1064_C	58 mrad (full) divergent	12.0	1020 - 1100	42 / 285	1064	Nd:YAG, Fiber lasers, NIR Lasers
_TiS_HP	12.0 - 12.1	12.0	700 - 900	42 / 358	800	Ti:Sapphire lasers, NIR Lasers
_532	12.8 - 13.0	11.8	515 - 550	49 / 271	532	2nd Harmonics Nd:YAG, similar lasers
_532_HP	12.0 - 12.1	11.8	515 - 550	42 / 358	532	2nd Harmonics of Nd:YAG, high-peak power lasers
_355_HP	12.0 - 12.1	11.3	330 - 380	42 / 358	355	3rd Harmonics of Nd:YAG, high-peak power lasers
_325	12.7 - 12.9	11.4	305 - 345	49 / 271	325	He-Cd, UV lasers
_266	12.6 - 12.8	10.6	250 - 270	42 / 285	266	4th Harmonics of Nd:YAG UV lasers
_266_HP	12.0 - 12.1	10.6	250 - 270	42 / 358	266	4th Harmonics of Nd:YAG, high-peak power lasers
_266_C	60 mrad (full) divergent	12.0	250 - 270	42 / 285	266	4th Harmonics of Nd:YAG UV lasers

* - Basic models are Telescopes of Galilean type (without internal focus),
Models with index **_HP** are versions for high peak power lasers,
Models with index **_C** are Collimators without internal focus.

2. Description

The ***πShaper_12_12*** series of beam shaping systems represent optical components for converting input single mode beams (TEM_{00}) or multimode beams, the intensity profile of which is similar to Gaussian, into flattop beams with a uniform intensity distribution. Due to many of the same properties, the generic name ***πShaper*** is used for all models below. If necessary, differences between models will be noted additionally.

The *πShapers* are field mapping beam shapers implemented as telescopic systems with two optical components, Fig.1. It is implied that wavefronts at the input and output are flat; the transformation of the intensity profile from Gaussian to uniform is realized in a controlled manner, by the accurate introduction of wave aberrations by the 1st component and further compensation by the 2nd component.

Thus, the resulting collimated output beam has a uniform intensity and a flat wavefront; it is characterized by low divergence – almost the same as that of the input beam. In other words, the field mapping beam shapers *πShaper* transform the intensity distribution *without violating the integrity of the beam and without increasing its divergence*.

In short, the main features of the refractive field mappers are:

- refractive optical systems transforming Gaussian to flat-top (uniform) distribution;
- transformation through controlled phase front manipulation – the 1st component introduces the spherical aberration necessary for energy redistribution, and the 2nd component compensates for the aberration;
- the output beam is free from aberrations, the phase profile is maintained flat, hence, low output divergence;
- TEM_{00} and multimode beams applied;
- collimated output beam;
- the beam profile remains stable over large distance;
- implementations in the form of telescopic or collimating optical systems;
- Galilean design, no internal focusing.

The operation of various versions of *πShaper*s is presented in Fig.2, examples of beam shaping – in Fig.3, 4.

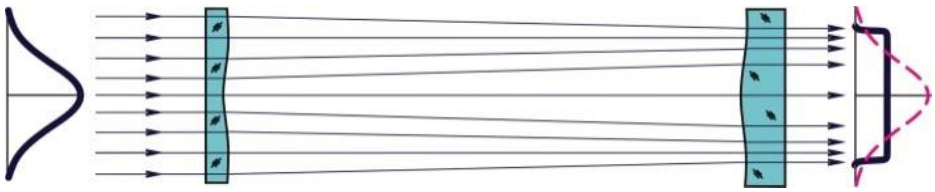


Figure 1. The principle of operation of the refractive field mapping beam shaper.

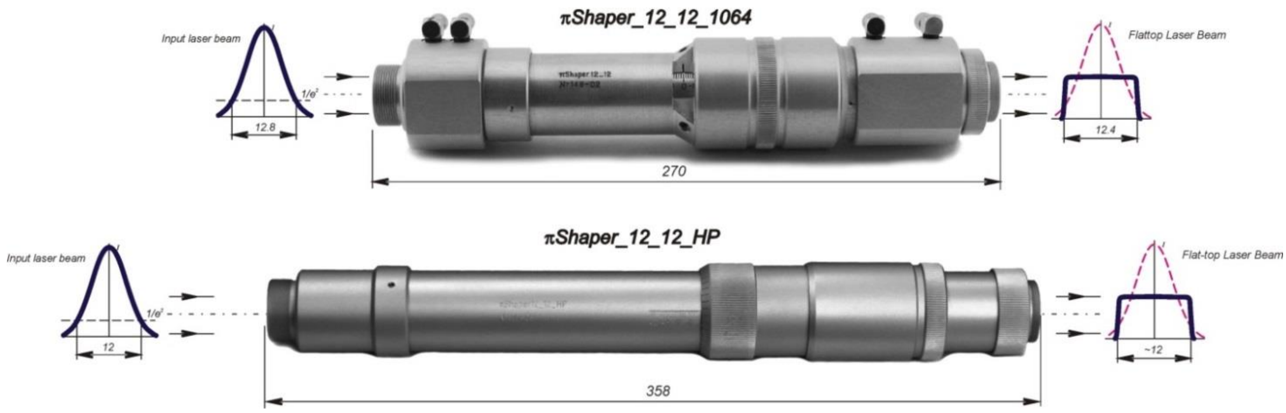


Figure 2. The refractive beam shapers *πShaper.*

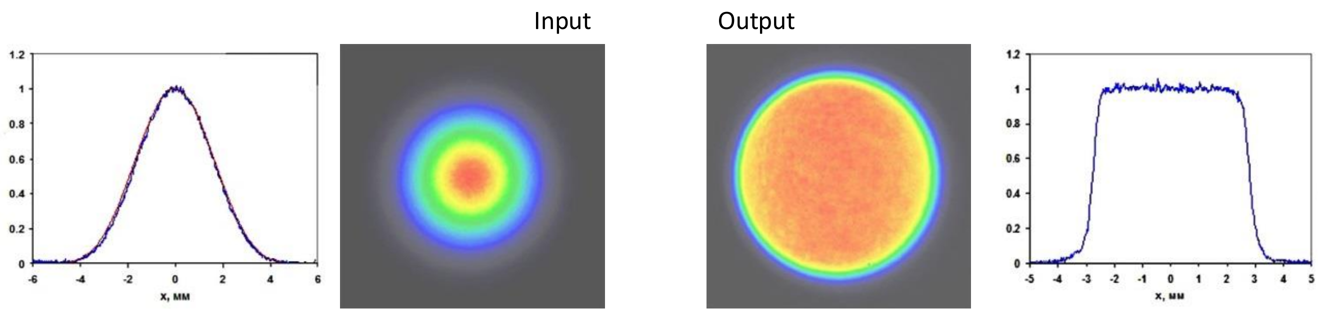


Figure 3. Beam shaping of the ***TEM₀₀*** laser, the measured intensity profiles:
on the left – Input TEM_{00} beam, on the right - after the *πShaper* (example for the *πShaper 6_6* is shown)

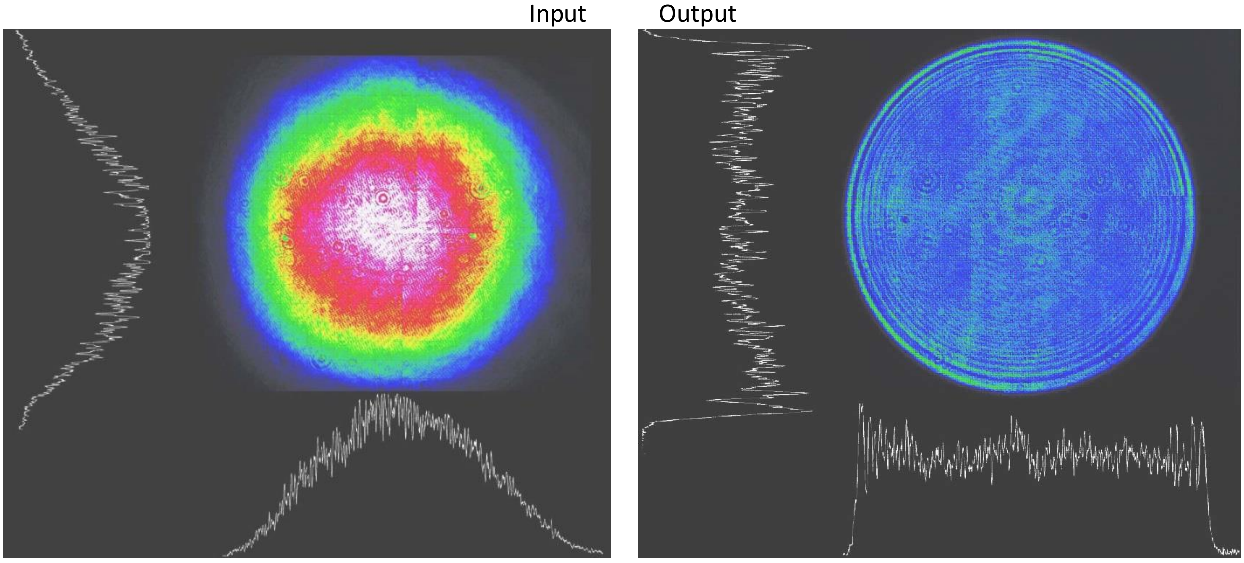


Figure 4. Beam shaping of the high peak power ***multimode*** laser with the *πShaper 12_12_1064_HP*,
the measured intensity profiles: left – Input, parabolic, 1064 nm, 6 ns pulse width, 2.7 J pulse energy, 1/e² Ø 10 mm,
right – at the *πShaper* output, FWHM . Ø 12 mm

Courtesy of Georgia Institute of Technology

The Angular Magnification of the telescopic system is about 0.78, therefore, from the point of view of paraxial optics, the diameter of the output beam is increased by factor 1/0.78, and the field of view angle is reduced by factor 0.78.

The optical system of the *πShaper* consists of 2 components with the following clear apertures (CA):

Table 2

	Clear aperture (CA), mm		Comments
	Input	Output	
πShaper _12_12_HP	17.8	16	Input protection aperture Ø15.8 mm
πShaper _12_12_HP_W	17.8	16	Input protection aperture Ø15.8 mm, water cooled
πShaper _12_12	19	15	water cooled
πShaper _12_12_10.6 / 9.4 / 5.1	21	16.6	water cooled, CO_2 , CO lasers

The input and output sides of the *πShaper* are shown in Fig. 5; the adjustment rings are always located closer to the exit.

Figure 5. Side views of the *πShaper*: top – water cooled models, bottom - _HP models.

3. *Input beam*

The optical design of the *πShaper* assumes that the input beam is TEM_{00} or multimode with the Gaussian-like or parabolic Intensity profile, see examples in Fig.3 and 4. The input beam is to be **collimated** and have an $1/e^2$ intensity diameter 2ω = ~12 mm (ω is the beam waist), the exact data for particular models are given in Table 1.

The optimum size of the input beam depends on its intensity profile. For example, in the case of multimode high peak power pulse lasers, as shown in Fig. 4 (1064 nm, 6 ns, 2.7 J pulse), the optimal $1/e^2$ diameter of the input beam is typically 10-11 mm. It is strongly recommended to measure the intensity distributions of lasers using a beam profiler in order to determine the optimum diameter of the input beam. When working with multimode high peak power pulse lasers, it is highly recommended to provide in the optical setup the ability to adjust the diameter of the input beam with control of the output beam profile.

Notes: Variation of the input beam size results in a variation of output profile!
Deviation of the input beam profile from the Gaussian function also results in a variation of the output profile!

To evaluate the intensity distribution, it is strongly recommended to use dedicated instruments,
for example, camera-based beam profilers!

According to the data in Table 2, the Clear Apertures of the input optical components are more than 1.5 times larger than the optimum 2ω, therefore, theoretically 99% of the Gaussian beam passes through the optics.

One of the *πShaper* components, on the output side, is movable; this feature is provided to compensate for the divergence or convergence of the input beam, the full compensation range is ±1.3 mrad, which is an order of magnitude greater than the natural divergence of laser beams of ~12mm $1/e^2$ diameter and wavelength <2µm, see the chapter "Features of mechanical design".

4. *Output beam*

In accordance with the principle of operation, the output beam is collimated and has a uniform intensity profile, the theoretical deviation from uniformity is less than 2%.

The wavefront error (wave aberration) is less than ±λ/10.

Depending on the structure of the input beam, a uniform output profile remains stable at a distance of about 600 – 800 mm. With further propagation in space, owing to diffraction effects, the intensity profile of a flat-top beam of a single phase front (TEM_{00} input) is transformed into a non-uniform beam with the Airy disk distribution in the far field. The behavior of multimode beams is more complex and strongly depends on the properties of the input beam. Typically, it is transformed in the far field back into a Gaussian-like or parabolic profile.

See detailed descriptions, as well as methods for overcoming diffraction effects using imaging in the article

"Imaging techniques with refractive beam shaping optics"
http://www.pishaper.com/pdfs/spie2012_imaging_tech_refract_beam_shaping_optics.pdf

Variation of the input beam size results in a variation of output intensity profile!

A comparison of the output intensity profiles is presented in the Appendix in the chapter "πShaper 12_12_1064 Variation in the output intensity profile with a variation of the diameter of the TEM_{00} Gaussian input beam".

Typically, the tolerance for input beam diameter is ±5%.

Variation of the input beam intensity distribution results in a variation of the πShaper output intensity profile!

To ensure a uniform distribution of the output intensity, it is necessary to adapt the size of input beam; examples of such adaptation are presented in the Appendix in the chapter "πShaper 12_12_1064 Providing a flat-top output profile with input beams which profiles deviate from the Gaussian function".

The effect of changing the profile of the output beam by changing the size of the input beam can be used to compensate for the deviation of the profile of the input beam from the ideal Gaussian!

Note: To evaluate the intensity distribution, it is strongly recommended to use dedicated instruments,
for example, camera-based beam profilers!

5. *Spectral properties*

The optical components of the *πShaper* are made of fused silica or ZnSe, these materials are characterized by low dispersion, and the optical design is optimized for operation in a specific working band.

The AR-coating of each *πShaper* model is optimized for the respective spectrum:

Table 3

πShaper 12_12 model*	AR-coating	Optimum* spectrum, nm	Working band, nm (acceptable performance)	Material of lenses
_10.6	V-type @10.6 µm	10000 - 11000	10000 - 11000	ZnSe
_9.4	V-type @9.4 µm	9000 - 10000	9000 - 10000	ZnSe
_5.1	V-type @5.1 µm	5000 - 5500	5000 - 5500	ZnSe
_1064	V-type @1064 nm	1020 - 1100	980 - 1160	Fused Silica
_1064_HP	V-type @1064 nm	1020 - 1100	980 - 1160	Fused Silica
_1064_HP_W	V-type @1064 nm	1020 - 1100	980 - 1160	Fused Silica
_1064_C	V-type @1064 nm	1020 - 1100	980 - 1160	Fused Silica
_TiS_HP	V-type @800 nm	700 - 900	680 - 950	Fused Silica
_532	V-type @532 nm	515 - 550	500 - 570	Fused Silica
_532_HP	V-type @532 nm	515 - 550	500 - 570	Fused Silica
_355_HP	V-type @355 nm	330 - 380	320 - 390	Fused Silica
_325	V-type @325 nm	305 - 345	300 - 360	Fused Silica
_266	V-type @266 nm	250 - 270	245 - 280	Fused Silica
_266_HP	V-type @266 nm	250 - 270	245 - 280	Fused Silica
_266_C	V-type @266 nm	250 - 270	245 - 280	Fused Silica
* - according to the AR-coatings				

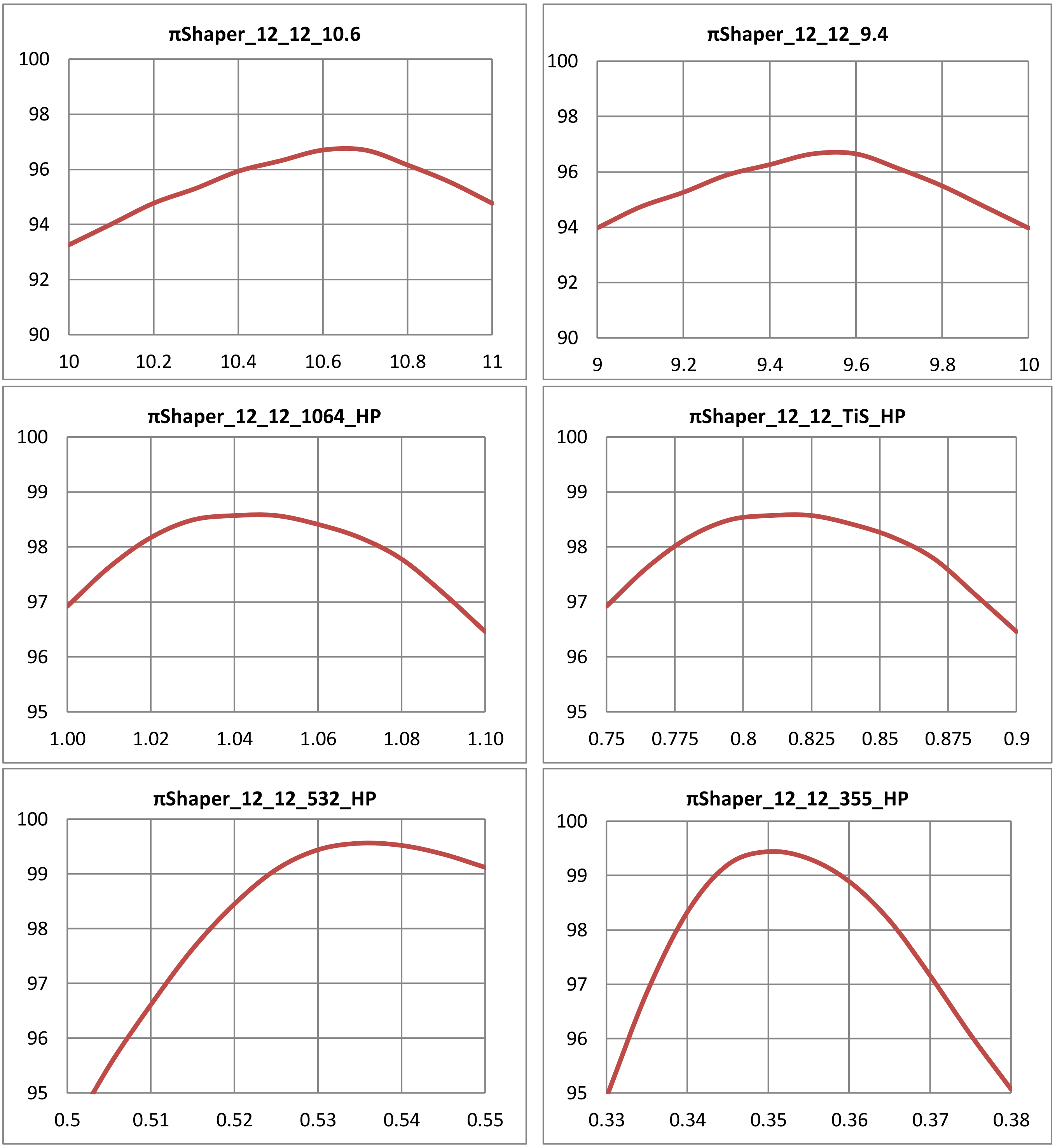
Spectral transmission graphs for the popular *πShaper* models are presented in Fig. 6. These data are based on measurements of reflection of the optical surfaces with AR-coatings. Devices manufactured in various production batches may have deviations from the presented graphs.

When operating in the optimum spectrum, the total losses do not exceed 6%.

Since *πShaper* devices are developed for use with lasers with high peak pulse energy or relatively high average or CW power, V-type AR-coatings with minima at the design wavelengths, Table 1, are applied.

The transmission spectral properties of *πShaper* models not mentioned in Fig.6 are similar to those of *_HP* models for the same design wavelengths; the transmission graph for the *πShaper* is similar to that for the *πShaper 12_12_HP*.

Using *πShaper* at a wavelength outside of the optimal spectral band will increase losses.



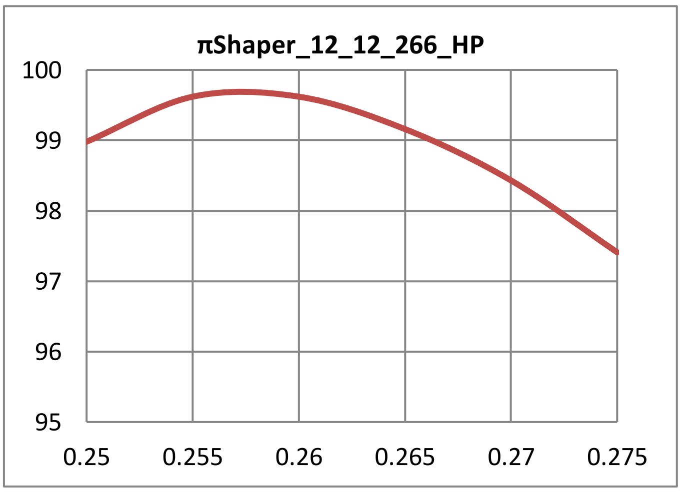


Figure 6. Spectral transmission, %, versus wavelength, μm for πShaper_12_12.
Other explanations in the text.

6. *Features of Mechanical design*

General drawings of two main *πShaper* implementations with overall dimensions are presented in Fig. 7.

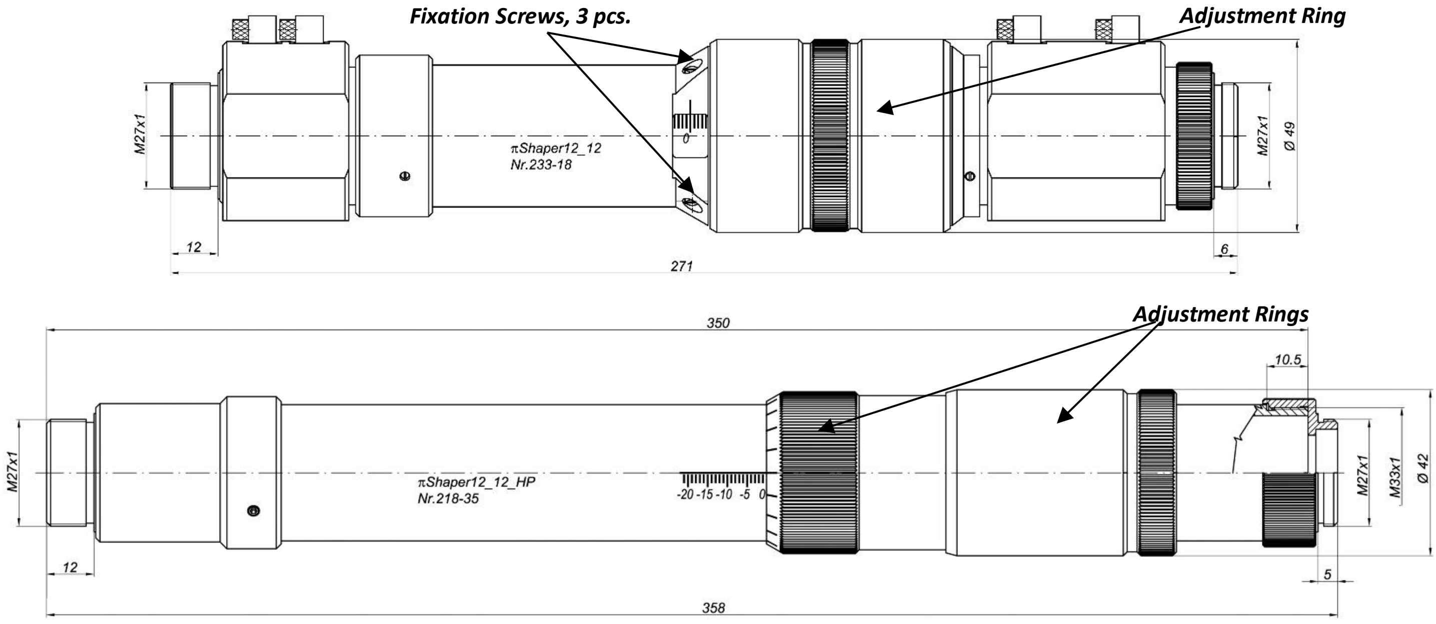


Figure 7. Basic mechanical designs of the *πShaper*: top – water cooled models, bottom - _HP models.

Mounting. All *πShaper* models have the same mounting design:

Input side:	-	Outer Thread M27 x 1
Output side:	-	Outer Thread M33 x 1
	-	Adaptor M33 x 1 -> M 27 x 1 (outer)

Thus, an M**27x1** mounting thread is provided at both ends of the *πShaper*.

It is assumed that the *πShaper* is mounted in the optical system by means of these threads, preferably using the 4-axis Mounts described in the next Chapter.

Other mounting methods should be discussed with the Supplier.

Movable Component. One of the *πShaper* components, on the output side, is movable. This feature is provided to adapt the beam shaper to actual conditions of operation, such as the working wavelength, or the divergence/convergence of the input beam.

Note: Movement of the πShaper Component is the ***last*** *step in the adjustment procedures;*
it should only be done, when the 4-axis alignment has been completed !

The movement in the range of ±20 mm (±10 mm in obsolete versions) is provided by rotating the Adjustment Rings, Fig.5 and 7:

- in the water cooled models
  - release of the 3 Fixation Screws,
  - rotation of the Adjustment Rings,
  - fixation of the chosen position of the Adjustment Ring using the Fixation Screws,
- in the *πShaper 12_12_HP* models
  - step-by-step rotating the two Adjustment Rings,
  - these Rings are used also for fixation of the movable component.

The adjustment rings are always located closer to the beam exit.

The criterion of the proper adjustment is the collimated output beam, i.e. providing the beam of lowest divergence.

Note: Movement of the πShaper Component is the ***last*** *step in the adjustment procedures;*
it should only be done, when the 4-axis alignment has been completed !

The *πShaper* is equipped with a Scale of 1 mm pitch, which is used to determine the position of the movable component. Original position of components with respect to each other is optimized for the design wavelength, Table 1.

Thus, the general suggestion when working with *πShaper* is as follows:

- start from the original position and
- perform the 4-axis alignment procedure, see the next Chapter and the recommendations presented in
  http://www.adloptica.com/manual/Alignment_pish66_f_pish9.pdf
  http://youtu.be/hinngpo4knY
  http://pishaper.com/pdfs/alignment.zip?Align=Download+Alignment+video,
  and provide a symmetric output beam,
- turn the Adjustment Ring(s) to compensate for the divergence or convergence of the input laser beam and to achieve a collimated output beam, i.e. the beam with the lowest divergence.

*Note: Movement of the πShaper Component is the **last** step in the adjustment procedures;*
it should only be done, when the 4-axis alignment has been completed !

Note: Moving the output component is provided for correction purposes only!
In terms of divergence, compensation is provided for a maximum range of ±1.3 mrad !

Features of water cooled πShaper versions.

1) Movable component:
   - the movement mechanism is equipped with only one Adjustment Ring,
   - relative position of the component is controlled using the Scale seen through the window in the device cabinet,
   - fixation of the chosen position of the Adjustment Ring using the 3 Fixation Screws.
2) Connection of pipes of the water cooling system should be done through the fittings, see Fig. 8.
3) Inner thread M23x0.75 at the *πShaper* entrance.
   This thread can be used to mount additional optical components, such as collimators or negative lenses, used to optimize the divergence of the input beam.
   It is recommended to discuss the appropriateness of using this option in a specific task with the Supplier.

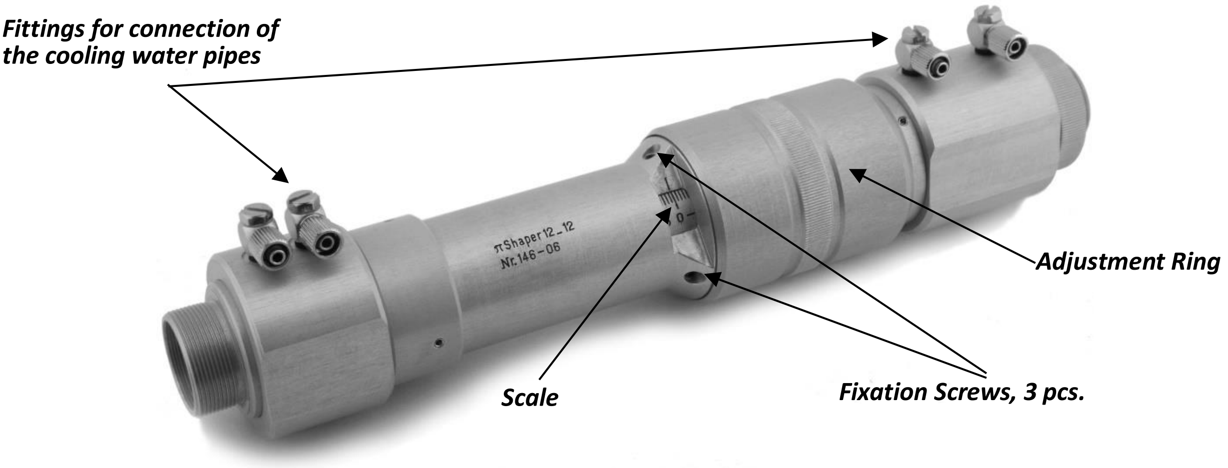


Figure 8. Water cooled *πShaper*.

7. Alignment

The *πShaper* is an optical device with a narrow field of view; therefore it is sensitive to errors of its positioning relative to the input beam. The results of theoretical calculations characterizing the sensitivity of *πShaper* to displacements and tilts, as well as experimental examples, are described below in the Appendix in a separate chapter "Behavior of ***πShaper_12_12_1064*** when misalignments" . To ensure the correct result of beam profile conversion, it is necessary to take care of the *πShaper* alignment in the optical system; the adjustments should be

- lateral translations along the X/Y axes, i.e. perpendicular to the optical axis, and
- tilts around the X/ Y axes.

The optomechanical design of the complete optical system with *πShaper* must contain a 4-axis mount for its alignment; examples of such tools are presented in Fig.9 and 10.

Tilt/tip	range	±4°
	sensitivity	3arcsec
X/Y translation	range	±2 mm
	sensitivity	1 µm
Thread for the πShaper mounting		M27x1 internal
Mounting Holes		Thread M6, 6 positions
Overall dimensions		66 x 66 x 34 mm
Weight		320 g

Figure 9. Mount M27, 4-axis, for the πShaper mounting, ***lockable***

The lockable 4-axis Mount M27, Fig. 9, provides firm alignment and fixation of the *πShaper*, it is recommended for use in industrial equipment, as well as in other applications where stable positioning of the optics is required. Examples of mounting the *πShaper* using the Mount M27 with a demonstration of design features are presented in Fig. 11.

Detailed design information about the Mount M27 is presented in http://pishaper.com/shaper_adjust.html#tabs-1

The 4-axis Mount presented in Fig. 10 is not equipped with locks; however, it has the knurled screws, which makes it very convenient for use in laboratory conditions or for quick setup of the πShaper for test purposes, see also

http://pishaper.com/shaper_adjust.html#tabs-2

Tilt/tip	ange	±2°
	sensitivity	3 arcsec
X/Y translation	range	±2 mm
	sensitivity	1 µm
Thread for the πShaper mounting		M27x1 internal
Mounting Hole		Thread M6, 2 positions
Overall dimensions		77 x 77 x 65 mm
Weight		200 g

Figure 10. 4-axis Mount, without locking, for laboratory use.

Figure 11. The *πShaper* mounted in the Mount M27:
(a) side view,
(b) the screws of the tilt around the X/Y axes, as well as the locking screws are shown,
(c) the screws of the X/Y latreral translation mechanism and locking screws are shown.

The *uniform intensity* distribution and the *symmetric view* of the beam at the *πShaper* output are the criteria for proper alignment.

Note: To evaluate the intensity distribution, it is strongly recommended to use dedicated instruments, for example, camera-based beam profilers!

Tolerances for the *πShaper* alignment:

- lateral displacement ±0,2 mm;
- angular tilt ±0,1°.

Examples of the beam profile transformation under the conditions of the correct *πShaper* alignment are presented in Figs.3, 4 and 14.

Recommendations to alignment procedure are presented in

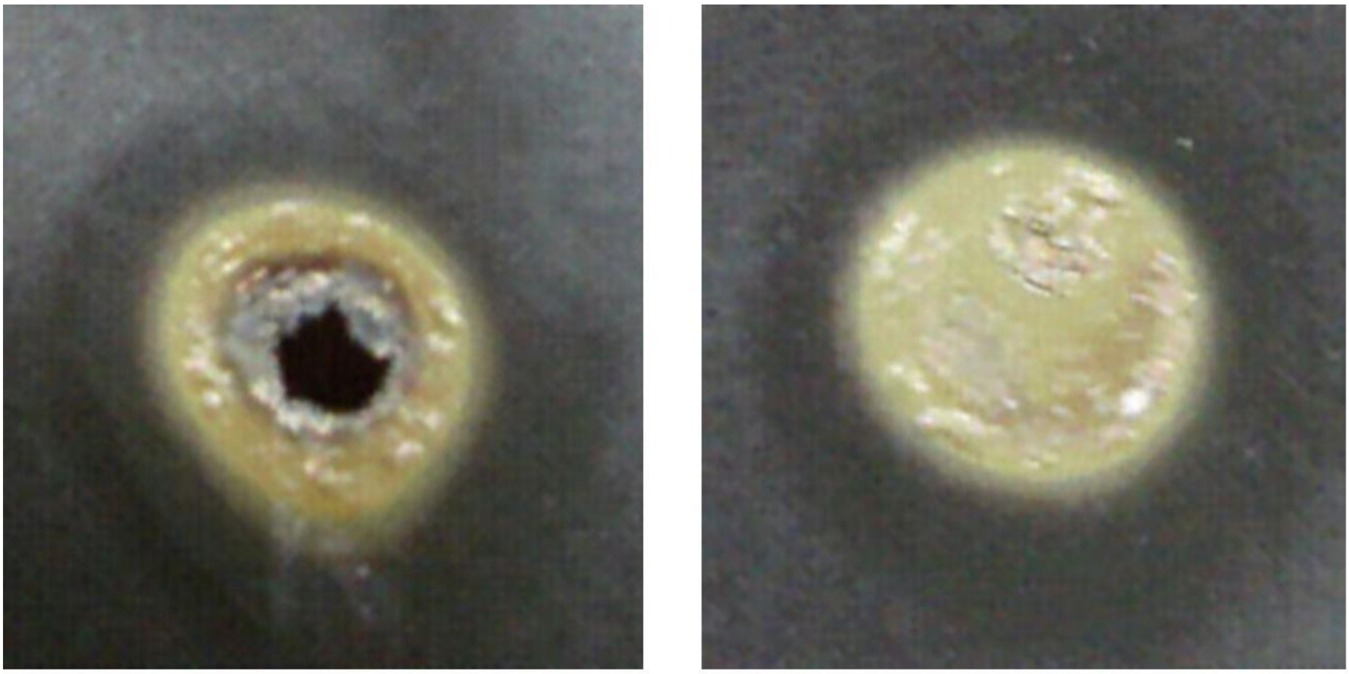
http://www.adloptica.com/manual/Alignment_pish66_f_pish9.pdf

http://youtu.be/hinngpo4knY

http://pishaper.com/pdfs/alignment.zip?Align=Download+Alignment+video

8. *Example of the πShaper_6_6_1064 operation*

An illustration of the *πShaper's* influence on the results of material processing with a laser is presented in the left picture. The comparison shows the engraving of a depression in a material with a pure TEM_{00} laser as well as with the same laser but using a *πShaper* with it.



a) Direct engraving by TEM_{00} laser **b) Engraving by TEM_{00} laser with πShaper**

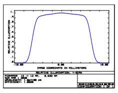
Figure 12. Examples of material processing (a) without and (b) with a *πShaper* (*Courtesy of EO Technics*).

The difference is evident— the result is an irregularly shaped depression with a ragged hole in the middle for the case of direct engraving with the TEM_{00} laser and a well-shaped round depression with a controlled depth when using the *πShaper*.

9. *Appendix*

<u>*πShaper* 12_12_1064</u>

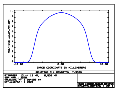
<u>Variation in the output intensity profile with a variation of the diameter of the TEM_{00} Gaussian input beam</u>



(a)

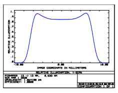
Input 1/e^2 diameter **<u>12.8 mm</u>**.

Variation of diameter of input laser beam



(b)

Input 1/e^2 diameter **<u>11 mm</u>**.



(c)

Input 1/e^2 diameter **<u>15 mm</u>**.

Figure 13. Output profiles by variable 1/e^2 diameter of input Gaussian beam.

The feature of the field mapping beam shapers that *output the beam profile depends on the input beam size*, Fig. 13, can be used as a powerful and convenient tool to vary the resulting intensity distribution by simple changing of the laser beam diameter with an ordinary zoom beam expander in front of the ***πShaper***.

This approach is demonstrated in Fig.13 where results of theoretical calculations are shown. The data relate to the ***πShaper 12_12*** of which the design presumes that a perfect Gaussian beam with 1/e^2 diameter 12.8 mm is to be converted to a beam with uniform intensity (flattop) with FWHM diameter 12.4 mm. When the input beam has a proper size, the resulting beam profile is flattop, Fig.13(a). Increasing the input beam diameter leads to the decrease in intensity in the centre, Fig.13(c); sometimes this distribution is called as "inverse-Gauss." Input beam size reduction allows for a convex profile that approximately can be described by super-Gauss functions, Fig.13(b).

An interesting feature of the field mapping beam shapers is the stability of the output beam size–the variation of the input beam diameter results in a variable intensity profile while the output beam diameter stays almost invariable. This is very important in practice and brings an element of stability while searching for the optimal conditions for a particular laser application.
Experimental data of operating the ***πShaper 6_6_1064***, realizing the same beam shaping principle, are presented in Fig. 14, next page.

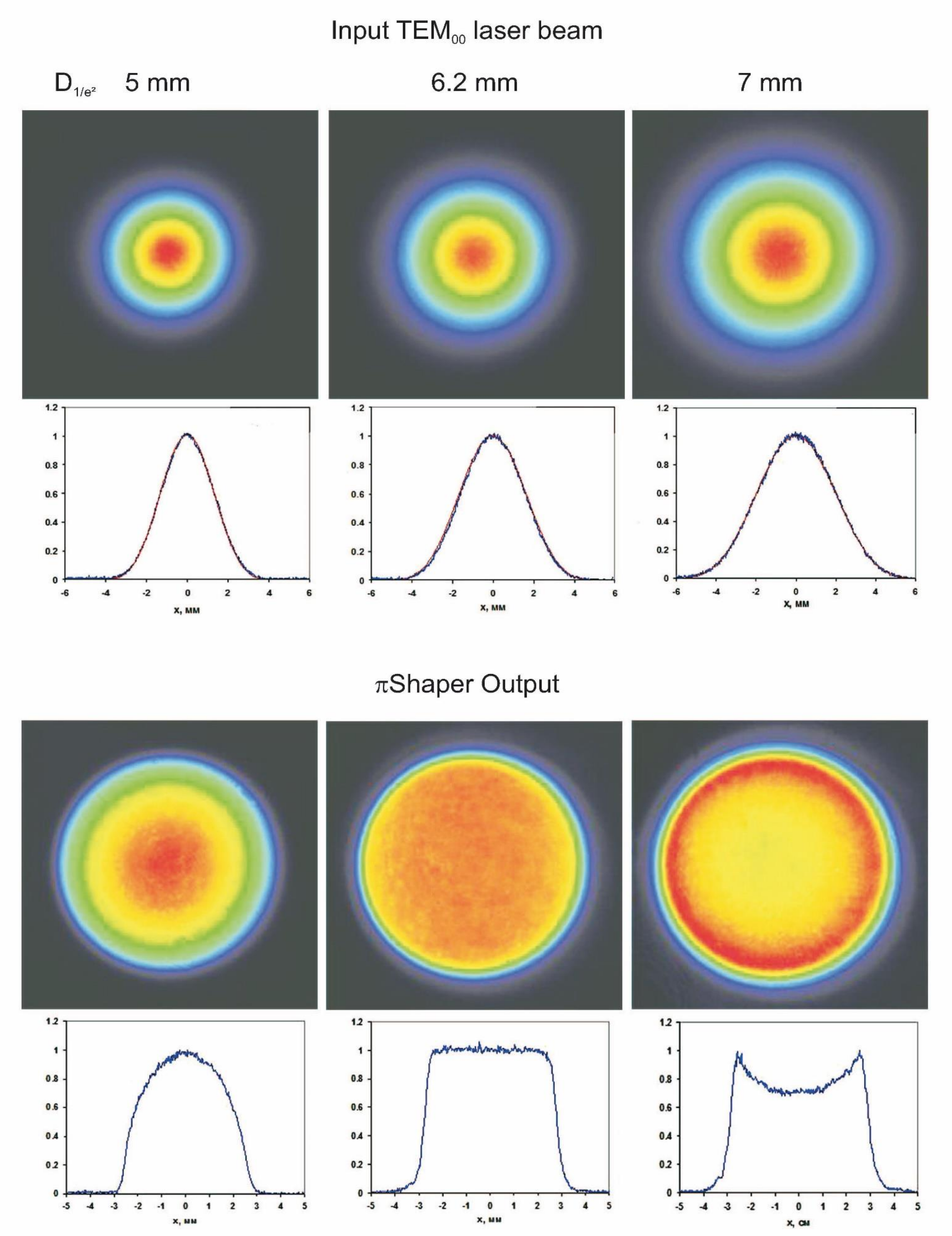


Figure 14. *πShaper* operation by variable diameter of perfect Gaussian input beam.

***πShaper* 12_12_1064**

Providing a flat-top output profile with input beams which profiles deviate from the Gaussian function

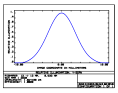
Left Column – data for input beam:

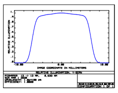
- Diameter D_{in} for $1/e^2$ intensity level,
- Gaussian Apodisation of Factor=1 corresponds to TEM_{00} beam of $M^2=1$,
- Diameter is adjusted to get uniform intensity profile at output of ***πShaper***.

Right Column –data for output beam profile and D_{out} diameter at the Full Width at Half Maximum (FWHM) Intensity.

D_{in} = 12.8 mm *Gaussian*, Apodisation Factor 1

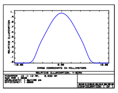
D_{out} = 12.4 mm

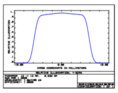




D_{in} = 11 mm *Parabolic, short "wings"*, Apodisation Factor 0.7

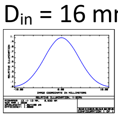
D_{out} = 11.6 mm





D_{in} = 16 mm *Extended "wings"*, Apodisation Factor 1.5

D_{out} = 12.8 mm



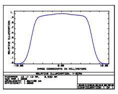


Figure 15. *πShaper* operation by variable profile (intensity distribution) of input beam.

Apodisation Type

By default, the pupil is always illuminated uniformly. However, there are times when the pupil should have a non-uniform illumination. For this purpose, ZEMAX supports pupil Apodisation, which is a variation of amplitude over the pupil. Three types of pupil Apodisation are supported:

uniform, Gaussian, and tangential. Uniform means rays are distributed uniformly over the entrance pupil, simulating uniform illumination. Gaussian Apodisation imparts an amplitude variation over the pupil that is Gaussian in form. The Apodisation factor refers to the rate of decrease of the beam amplitude as a function of radial pupil coordinate. The beam amplitude is normalized to unity at the center of the pupil. The amplitude at other points in the entrance pupil is given by

$$A(\rho) = \exp(- G\rho^2),$$

where G is the Apodisation factor and ρ is the normalized pupil coordinate. If the Apodisation factor is zero, then the pupil illumination is uniform. If the Apodisation factor is 1.0, then the beam amplitude has fallen to the 1/e point at the edge of the entrance pupil (which means the intensity has fallen to the $1/e^2$ point, about 13% of the peak). The Apodisation factor can be any number greater than or equal to 0.0.

Behavior of *πShaper 12_12_1064* when misalignments

Dependence of the πShaper 12_12_1064 intensity profile on the tilt or the respective lateral displacement (decentering).

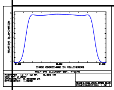
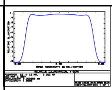
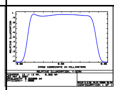
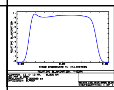
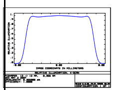
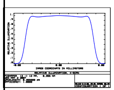
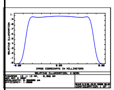
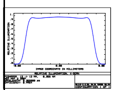
0°	0,1° (0,0017 rad, 0,4 mm)	0,3° (0,0051 rad, 1,2 mm)	0,5° (0,0085 rad, 2,0mm)
			
			

Figure 16.

To the evaluation of the sensitivity of misalignments, theoretical intensity profiles for *πShaper 12_12_1064* @ 1064nm.

Conditions:

- data in columns – for the respective tilt misalignments around the *πShaper* input component, value of the respective lateral displacement of the optics output is given in parentheses for reference,
- upper row – the plane of the tilt (Y),
- lower row – the plane orthogonal to the tilt(X).

πShaper 12_12_1064 performance is practically unchanged with angular tilt misalignments of up to ±0.1° or lateral displacements of up to ±0.2 mm. Larger alignment errors can lead to a serious change in the output intensity distribution.

The sensitivity of *πShaper 12_12* to misalignments is similar to the sensitivity of the *πShaper 6_6*, which is described in the next chapter.

Optimum alignment of the *πShaper 12_12* can be provided using the 4-axis Mounts described in the Chapter 7.

Behavior of *πShaper 6_6_1064* when misalignments

Correct alignment is important for any beam shaping optics; let's evaluate the effect of misalignments in the case of the refractive field mapping beam shapers. Fig. 17 presents results of mathematical simulation, as well as measurements of real profiles for the *πShaper 6_6* in three cases: perfectly aligned, lateral beam displacement, angular tilt of the beam shaper.

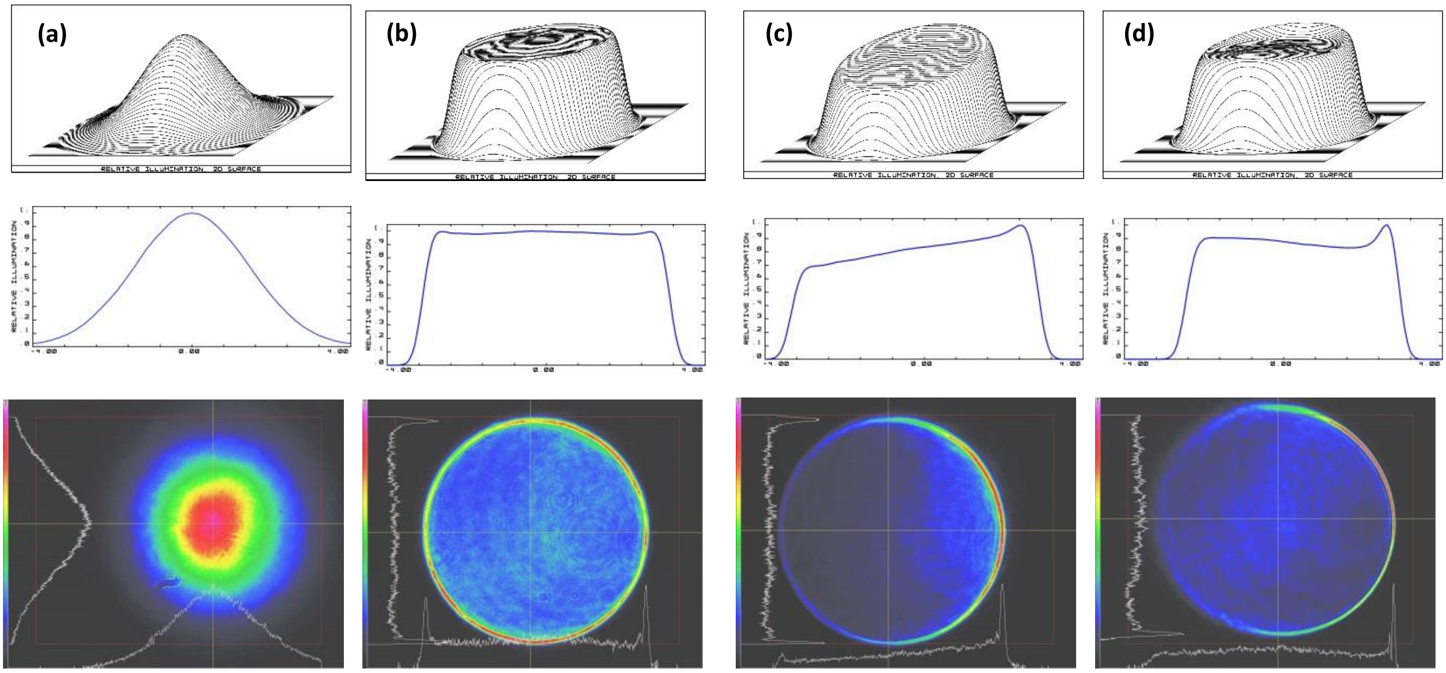


Figure 17 To the evaluation of the sensitivity of misalignments, theoretical and experimental intensity profiles for ***πShaper 6_6_1064*** @ 1064nm: a) Input TEM_{00} beam, b) Output by perfect alignment c) Output by lateral shift at 0.5 mm, d) Output by tilt at 1°.

The aberration correction of *πShaper* systems is provided for the clear aperture (CA) diameter of at least 1.6 times larger than the $1/e^2$ diameter of a laser beam. Therefore, a small, up to ±20% of the diameter, lateral displacement of the beam with respect to the beam shaper or vice versa doesn't lead to aberration, but allows obtaining an interesting beam shaping effect – the output profile is skewed in the direction of the lateral displacement, this is shown in Fig. 17c. The intensity profile itself remains flat, but tilts in the direction of the displacement; and a remarkable feature is that the beam itself remains collimated and with small divergence. This inclined profile can be used in applications where a steady increase or decrease of intensity is required, for example, to compensate for the attenuation of an acoustic wave in acousto-optical devices.

As an optical system designed to work with axial beams, the *πShaper* operates in a relatively narrow angular field; the data in Fig. 17d demonstrate the behaviour of the intensity profile when the beam shaper is tilted at 1°. The intensity profile remains stable, but there is noticeable deterioration in quality on the left and right sides of the spot due to aberrations, first of all coma. It should be noted that the tilt of 1° means for the considered *πShaper 6_6* the lateral displacement of one of its ends by about 2 mm! No doubts, this displacement can be easily compensated by conventional opto-mechanical mounts, for example by the 4-axis Mounts described in the Chapter 7.

These data show that misalignments affect the *πShaper* operation, but the sensitivity to these misalignments is not high: even with significant lateral displacement (up to 0.5 mm!) and tilt (up to 1°!) the resulting profiles are close to flat-top. In other words, the tolerance of positioning of a beam shaper is rather not tough, and misalignments can be compensated by conventional opto-mechanical 4-axis mounts. Since the influence of a tilt on the wave aberration of the output beam is quite pronounced, it is recommended to pay more attention to the angular alignment when setting up the beam shapers.

πShaper 6_6 performance is practically unchanged with angular tilt misalignments of up to ± 0.1 ° or lateral displacements of up to ± 0.1 mm.