Flat Top Beam Shaper 6_6 / 7_7

Laser Beam Shaping Optics

Manual

March 15, 2019

Specification Flat Top Beam Shaper 6_6 / 7_7

Table 1

Common for all Flat Top Beam Shaper 6_6 and *7_7* models:	
Type	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 ~6-7 mm - High edge steepness
Other features	- Achromatic for design wavelengths - Compact design suitable for scientific and industrial applications - Long working distance
Overall dimensions	- Diameter 39 mm - Length <143 mm
Weight	< 250 g
Mounting	External Thread M 27x1, at Input and Output

Flat Top Beam Shaper features

Model	Input 1/e² Diameter, mm	Output FWHM Diameter, mm	Optimum spectrum*, nm	Applications based on
#34-259	7 - 7.1	7	10000 - 11000	CO_2 lasers
#12-242	6.4 - 6.5	6.4	1940 - 2160	mid-IR Lasers
#12-241	5.9 - 6.0	6.0	1800 - 2050	near IR Lasers
#37-700	6.4 - 6.5	6.2	1500 - 1600	near IR Lasers
#34-258	6.4 - 6.5	6.1	1020 - 1100	Nd:YAG, Fiber and other near IR lasers
#36-649	5.9 - 6.0	6.0	700 - 900	Ti:Sapphire, Diode Lasers, other near IR lasers
#12-644	5.9 - 6.0	6.0	405 – 680 achromatic	He-Ne, He-Cd and other lasers of visible spectrum
#34-257	6.3 - 6.4	5.8	520 - 550	2^{nd} Harmonics of Nd:YAG and similar lasers
#34-256	6.3 - 6.4	5.6	330 - 380	3^{rd} Harmonics of Nd:YAG and similar lasers
#34-255	6.3 - 6.4	5.2	250 - 275	4^{th} Harmonics of Nd:YAG and similar lasers

* - according to coatings applied

Description

The Flat Top Beam Shaping systems 6_6 use optical components to convert single (TEM_{00}) or multimode input beams with Gaussian intensity profiles to flattop beams with uniform intensity distributions.

The Flat Top Beam Shapers are telescopic systems with two optical components. It is implied that the wave fronts at the input and output are flat. The transformation of the irradiance profile from Gaussian to uniform is achieved in a controlled manner, by accurately introducing wave aberration with the first component and then compensation in the second, Fig.1, top.

Thus, the resulting collimated output beam has a uniform irradiance and a flat wave front, characterized by low divergence – similar to that of the input beam. In other words, the field mappers transform the irradiance distribution *without deterioration of the beam consistency and without increasing the beam divergence*.

The main features of refractive field mappers are:

- refractive optical systems transforming Gaussian to flat-top (uniform) irradiance distribution
- transformation through controlled phase front manipulation – 1st component introduces spherical aberration required to re-distribute the energy, then 2nd component compensates the aberration
- output beam is free of aberrations, phase profile is maintained flat, hence, low output divergence
- TEM_{00} and multimode beams applied
- collimated output beam
- beam profile is stable over large distance
- implementations as telescopic or collimating optical systems; achromatic optical design - beam shaping for several lasers simultaneously
- Galilean design, no internal focusing

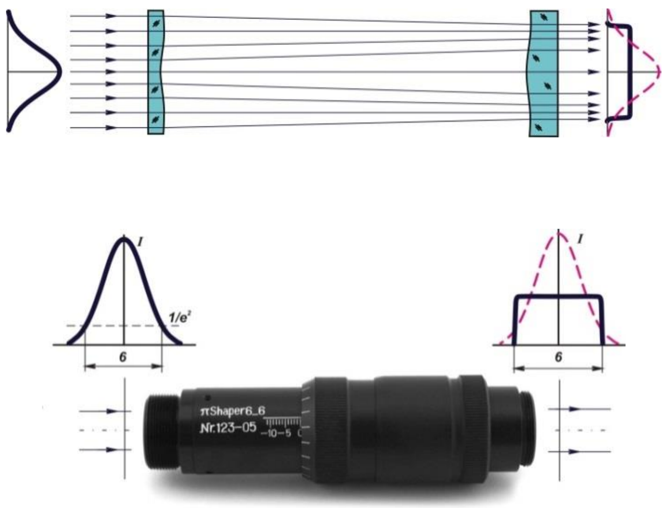
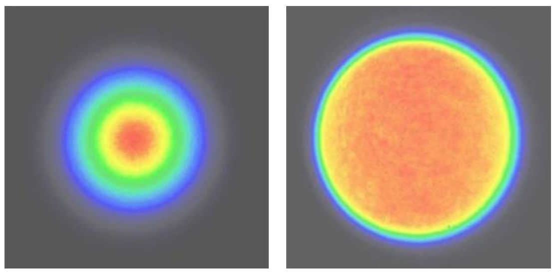


Figure 1. Refractive field mapping beam shaper Flat Top Beam Shaper.



Angular magnification of the telescopic system is about 0.65. Thus, from the point of view of paraxial optics, the diameter of the output beam is increased by factor 1/0.65 while the field angle is reduced by a factor 0.65.

The Flat Top Beam Shaper optical system consists of 2 components with different clear apertures (CA):

- Input: CA=~10 by Flat Top Beam Shaper 6_6 and CA= 12 by Flat Top Beam Shaper 7_7,
- Output: CA= ~8 by Flat Top Beam Shaper 6_6 and CA= 10 by Flat Top Beam Shaper_7_7.

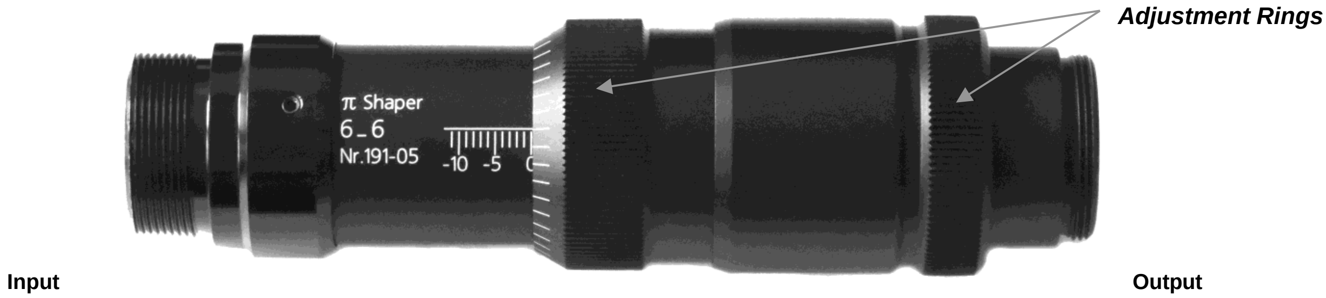


Figure 3. Flat Top Beam Shaper side view.

Input beam

The optical design of the Flat Top Beam Shaper presumes the input TEM_{00} or multimode beam is **collimated** and has $1/e^2$ intensity diameter 2ω=~6 mm for Flat Top Beam Shaper 6_6 and 7mm for Flat Top Beam Shaper 7_7 (ω is a beam waist). The exact data for particular models are given in the Table 1.

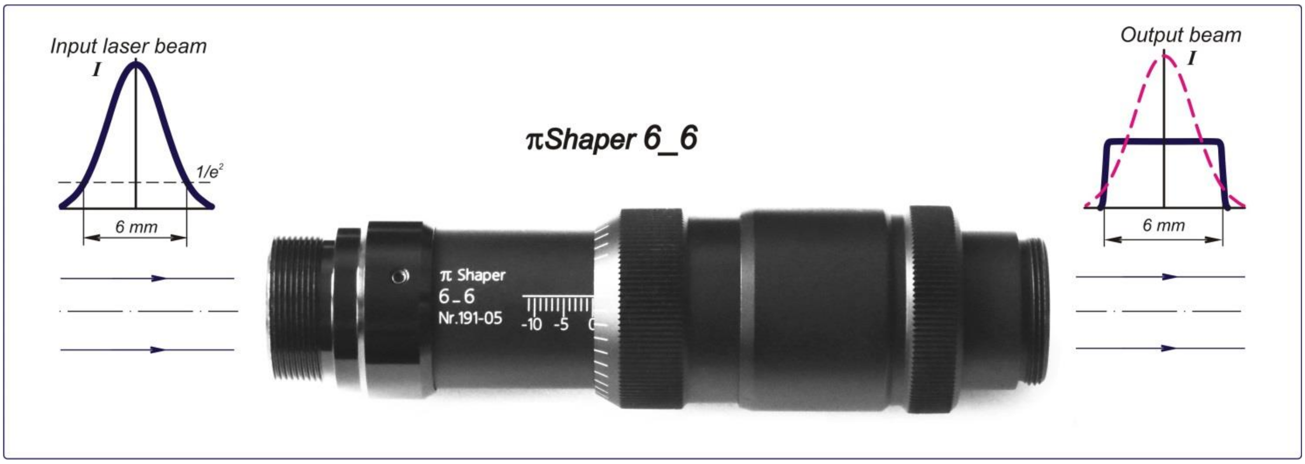


Figure 4. Flat Top Beam Shaper operation.

Clear apertures of the input optical components are ~1.5 times bigger than optimum 2ω. Hence, theoretically 99% of the Gaussian beam is passing through the optics.

One of components of the Flat Top Beam Shaper, at the output side, is movable; this feature is used to compensate for the input beam divergence and the full range of compensation is ±4mrad, which is an order of magnitude larger than that of typical laser beams of ~6mm $1/e^2$ diameter and wavelength <2μm (see details in chapter "Features of mechanical design").

Output beam

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

Wavefront error (wave aberration) is below ±λ/10.

That uniform profile is kept stable over a distance about 200mm. After 200mm, due to diffraction, the intensity profile is transformed to a non-uniform one similar to the Airy disk distribution in the far field.

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

Comparison of the output intensity profiles is presented in the Appendix in the chapter titled "Behavior of Flat Top Beam Shaper 6_6_VIS when changing the diameter of input beam." Typically, the tolerance for an input beam diameter is ±5%.

Variation of the input beam intensity distribution results in variation of the Flat Top Beam Shaper output intensity profile.

To provide a uniform output intensity distribution, it is necessary to adapt the size of the input beam. Examples of such adaptations are presented in the Appendix in the chapter titled "Behavior of Flat Top Beam Shaper 6_6_VIS when changing the shape of input beam."

The effect of the output beam profile variation, as it relates to the input beam size, can be used to compensate for the deviation of the input beam profile from a perfect Gaussian profile.

Spectral properties

Optical components of the Flat Top Beam Shaper are made from fused silica, optical glasses, or ZnSe. These materials are characterized by low dispersion and the optical design is developed in such a way that the system can work within a specific waveband.

The achromatic Flat Top Beam Shaper can be used simultaneously with lasers of different wavelengths.

AR-coatings of each version of the Flat Top Beam Shaper are optimized for the corresponding spectrums:

Table 2

Flat Top Beam Shaper 6_6 model	**AR-coating**	**Optimum* spectrum, nm**	**Working band, nm (acceptable performance)**	**Material of lenses**
#34-259	V-type @10.6 µm	10000 - 11000	10000 - 11000	ZnSe
#12-242	V-type @2.05 µm	1940 - 2160	1900 - 2200	Fused Silica
#12-241	V-type @1940 nm	1800 - 2050	1700 - 2100	Fused Silica
#37-700	V-type @1550 nm	1500 - 1600	1450 - 1650	Fused Silica
#34-258	V-type @1064 nm	1020 - 1100	980 - 1160	Fused Silica
#36-649	V-type @800 nm	700 - 900	680 - 950	Fused Silica
#12-644	Broad-band	405 – 680 achromatic	400 – 700	Optical glasses
#34-257	V-type @532 nm	520 - 550	510 - 570	Fused Silica
#34-256	V-type @350 nm	330 - 380	320 - 390	Fused Silica
#34-255	V-type @266 nm	250 - 275	245 - 280	Fused Silica

When working within optimum bands, total losses do not exceed 5%.

Applying the Flat Top Beam Shaper at a wavelength outside of the optimum spectral waveband increases losses.

Features of Mechanical design

All Flat Top Beam Shaper models have M27x1 Mounting Threads at both ends**.**

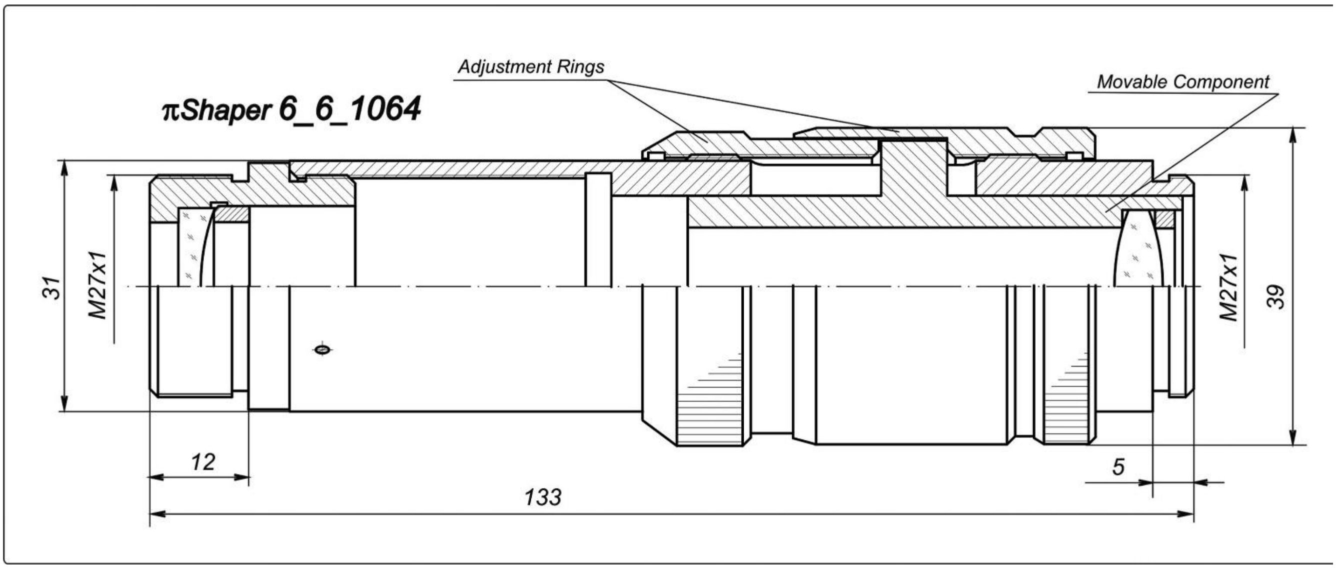


Figure 5. Flat Top Beam Shaper basic mechanical design.

One of the components of the Flat Top Beam Shaper, at output side, is movable. This feature is used to adapt the unit to the real conditions of operation to compensate for properties such as the working wavelength, divergence of the input beam, etc. The range of motion is +/-10 mm and the component is moved by turning two adjustment wheels. These wheels are also used for fixation of the movable component, see the picture. The Flat Top Beam Shaper has 1mm step ruler on the case and strokes on one of adjustment wheels, these signs can be used as reference of position of the movable component.

Thus, a general suggestion while working with a Flat Top Beam Shaper is to start to work from the original position. By turning the adjustment wheel (internal thread of 0.5 mm pitch is used), it is possible to move the component. This adjustment tool could be used either to compensate for the divergence of the source laser beam or to provide a certain optical power to the Flat Top Beam Shaper 6_6.

Please, note, the possibility of moving the output component is provided for correction purposes only - in terms of divergence the compensation is provided for a range maximum +/-4 mrad!

Alignment

The Flat Top Beam Shaper is an optical device with a narrow field of view, and is therefore sensitive to errors in positioning with respect to the input beam. Theoretical calculations characterizing the sensitivity of the Flat Top Beam Shaper to misalignments and tilting, as well as experimental examples, are described below in the Appendix in a separate chapter titled "Behavior of Flat Top Beam Shaper 6_6_1064 when misalignments."

To properly convert the beam profile, it is necessary to consider adjusting to the Flat Top Beam Shaper unit in the optical system. Possible adjustments include:

- Lateral translation in X/Y axes, i.e. perpendicular to optical axis, and
- Tilting around X/ Y axes.

The opto-mechanical design for the complete optical system with the Flat Top Beam Shaper should contain a 4-axis mount for alignment; examples of such tools are presented in Fig.6 and 7.

Tilt/tip range	±4°
XY translation range	±2 mm
Locking of position	By locking screws
Thread for optics mounting	M27x1 internal
Mounting holes	5 holes M6
Weight	0.2 kg

Figure 6. Flat Top Beam Shaper 4-axis mount (#34-312): Industrial, with position locking

Figure 7. Flat Top Beam Shaper mounted in 4-axis industrial mounmt.

Uniform intensity and a symmetric view of the beam at the Flat Top Beam Shaper output are the criteria for proper alignment.

It is strongly recommended to apply an instrument beam profiling system (eg. camera-based).

Tolerances for the Flat Top Beam Shaper systems are:

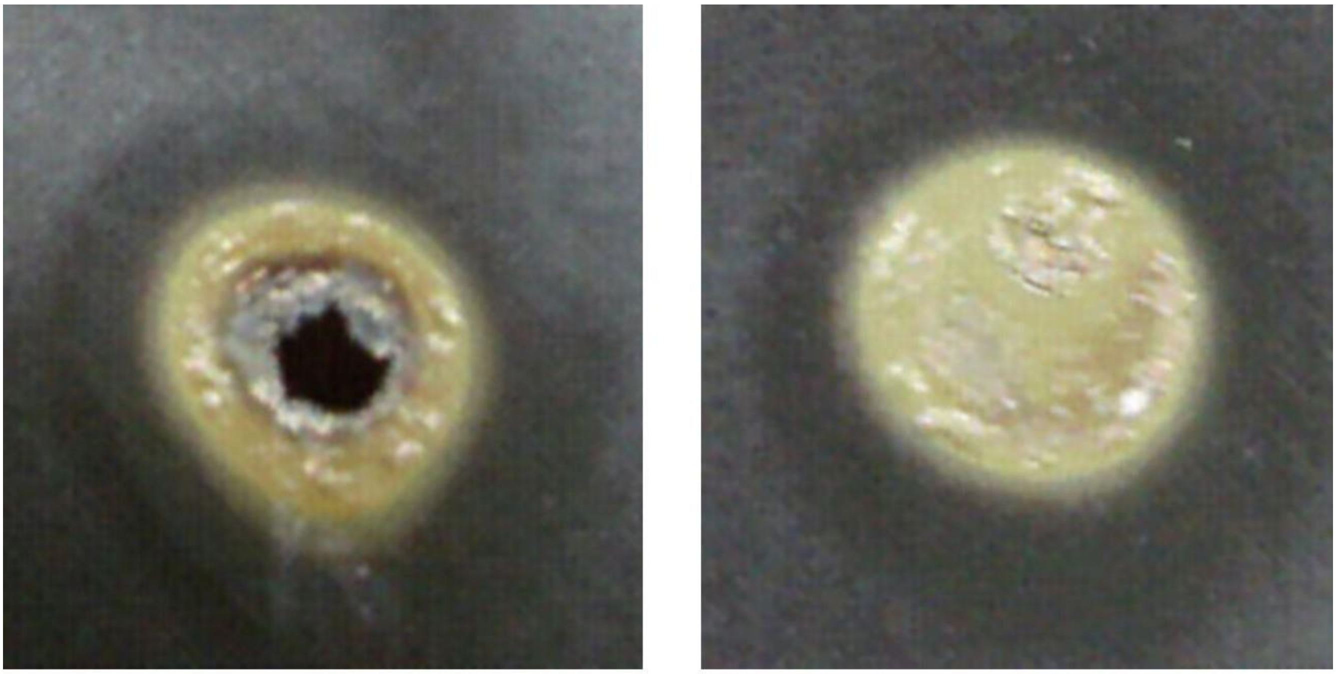
- Lateral misalignment ±0.1 mm;
- Tilt ±0.1°.

Since the system is sensitive to misalignments, it is recommended, after turning the component, to check the alignment.

An example of the Beam Intensity Profile Transformation of a TEM_{00} laser beam with proper adjustment of a Flat Top Beam Shaper is shown in Fig.2.

Example of the Flat Top Beam Shaper 6_6_1064 operation

An illustration of the Flat Top Beam Shaper's influence during material processing, is presented at left picture. Here one can see a comparison of a laser engraving in a material with a pure TEM_{00} laser as well as with the same laser but with a Flat Top Beam Shaper after it.



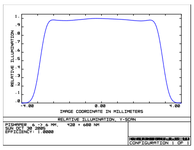
a) Direct engraving by TEM_{00} laser **b) Engraving by TEM_{00} laser with πShape**

Figure 8. Examples of material processing (a) without and (b) with a Flat Top Beam Shaper (*Courtesy of EO Technics*).

The difference is evident - irregular shape of the depression with a ragged unwished hole in the middle in case of direct engraving with the TEM_{00} laser. A good shaped round depression with a controlled depth when applying the Flat Top Beam Shaper.

Appendix

Behavior of the Flat Top Beam Shaper 6_6_VIS when changing the diameter of an input beam.

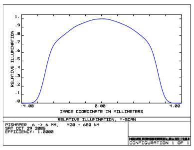


(a)

Intensity profile at the Flat Top Beam Shaper 6_6_VIS output by input laser beam of **6 mm** diameter (1/e^2).

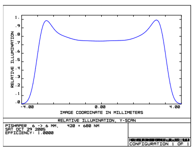
According to design the non-uniformity of the output beam intensity distribution is within ±2% range.

Variation of diameter of source laser beam.



(b)

Intensity profile at the Flat Top Beam Shaper 6_6_VIS output by input laser beam of **5 mm** diameter (1/e^2).



(c)

Intensity profile at the Flat Top Beam Shaper 6_6_VIS output by input laser beam of **7 mm** diameter (1/e^2).

Figure 9. Output profiles by variable 1/e^2 diameter of input Gaussian beam.

The fact that *output beam profile depends on the input beam size*, Fig. 9, can be used as a powerful and convenient tool to vary the resulting intensity distribution by simple changing the input laser beam diameter with a variable beam expander placed before the Flat Top Beam Shaper.

This approach is demonstrated in Fig. 9 where the results of theoretical calculations, as well as measured results from real experiments beam profiles for a TEM_{00} laser, are shown. The data related to the Flat Top Beam Shaper 6_6 which design presumes a perfect Gaussian beam with a 6 mm 1/e^2 diameter is converted to a beam with uniform intensity (flattop) with FWHM diameter 6.2 mm. When the input beam has a proper size the resulting beam profile is flattop, Fig.9(a). An increased input beam diameter leads to a reduction of intensity in the center, Fig.9(c); this distribution is sometimes called "inverse-Gauss." By reducing the input beam size the profile can be approximately described by super-Gauss functions, Fig.3(b).

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

Experimental data of operation of a Flat Top Beam Shaper 6_6_1064 are presented in Fig. 10, next page.

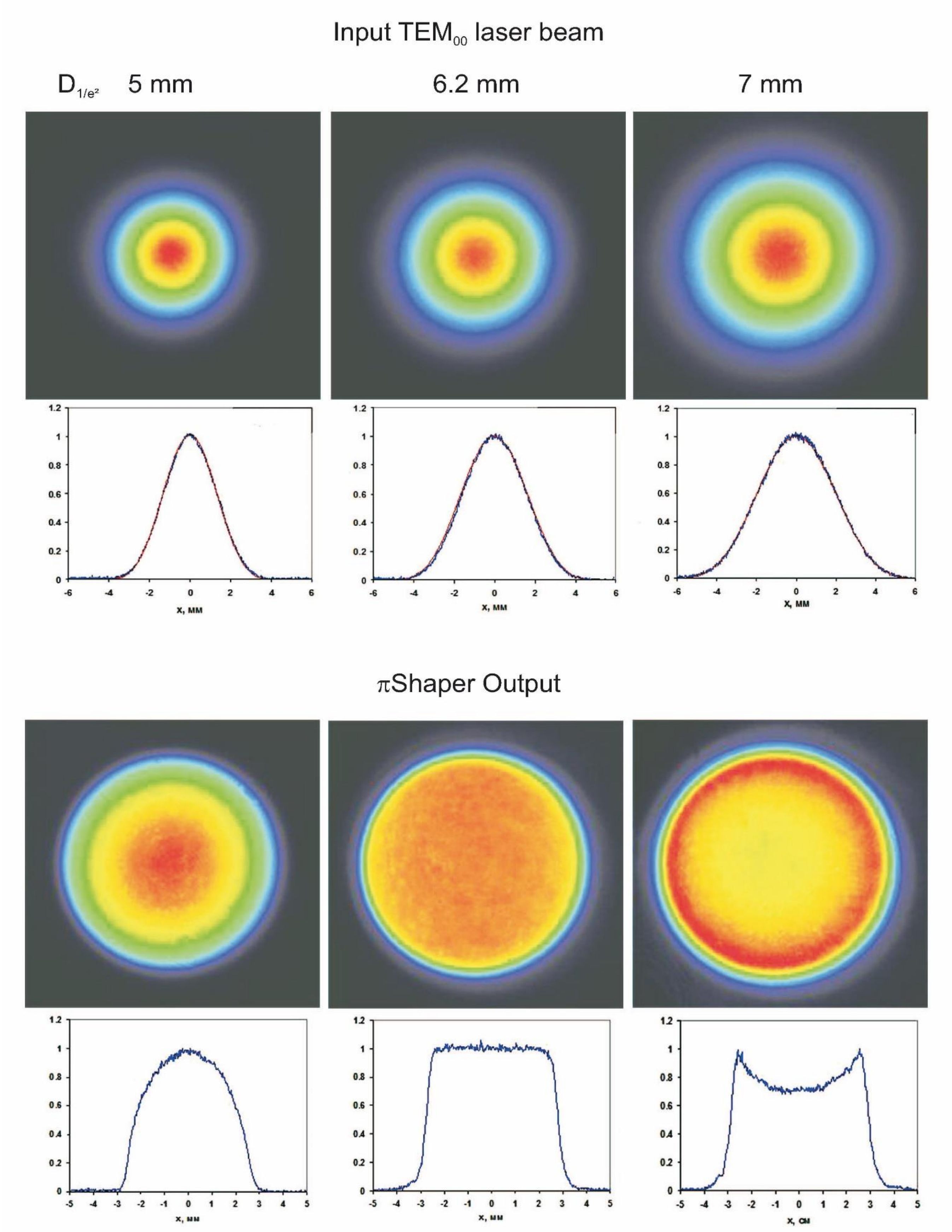


Figure 10. Flat Top Beam Shaper operation by variable diameter of perfect Gaussian input beam.

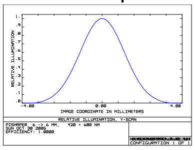
Behavior of Flat Top Beam Shaper 6_6_VIS when changing the shape of input beam

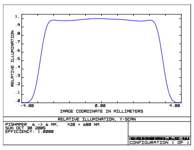
Left Column – data for input beam:

- Diameter 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 Flat Top Beam Shaper.

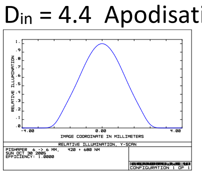
Right Column – data for output beam (Full Width at Half Intensity)

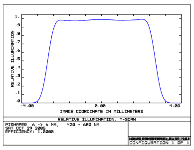
D_{in} = 6.0 Apodisation: Type Gaussian, Factor = 1 — D_{out} = 6.0



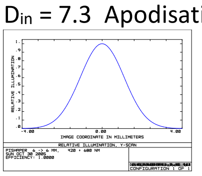


D_{in} = 4.4 Apodisation: Type Gaussian, Factor = 0.5 — D_{out} = 5.4





D_{in} = 7.3 Apodisation: Type Gaussian, Factor = 1.5 — D_{out} =6.4



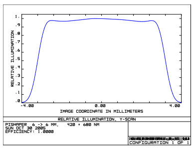


Figure 11. Flat Top Beam Shaper operation by variable profile (intensity distribution) of input beam.

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

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

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 over e point at the edge of the entrance pupil (which means the intensity has fallen to the 1 over e squared point, about 13% of the peak). The Apodisation factor can be any number greater than or equal to 0.0.

Misalignment Behavior of Flat Top Beam Shaper 6_6_1064

Proper alignment is important for any beam shaping optics. Let's evaluate the influence of misalignments in the case of refractive field mapping beam shapers. Fig. 12 presents results of mathematical simulations as well as measurements of real profiles for the Flat Top Beam Shaper 6_6 in three cases: perfectly aligned, lateral shift of a beam, angular tilt of the beam shaper.

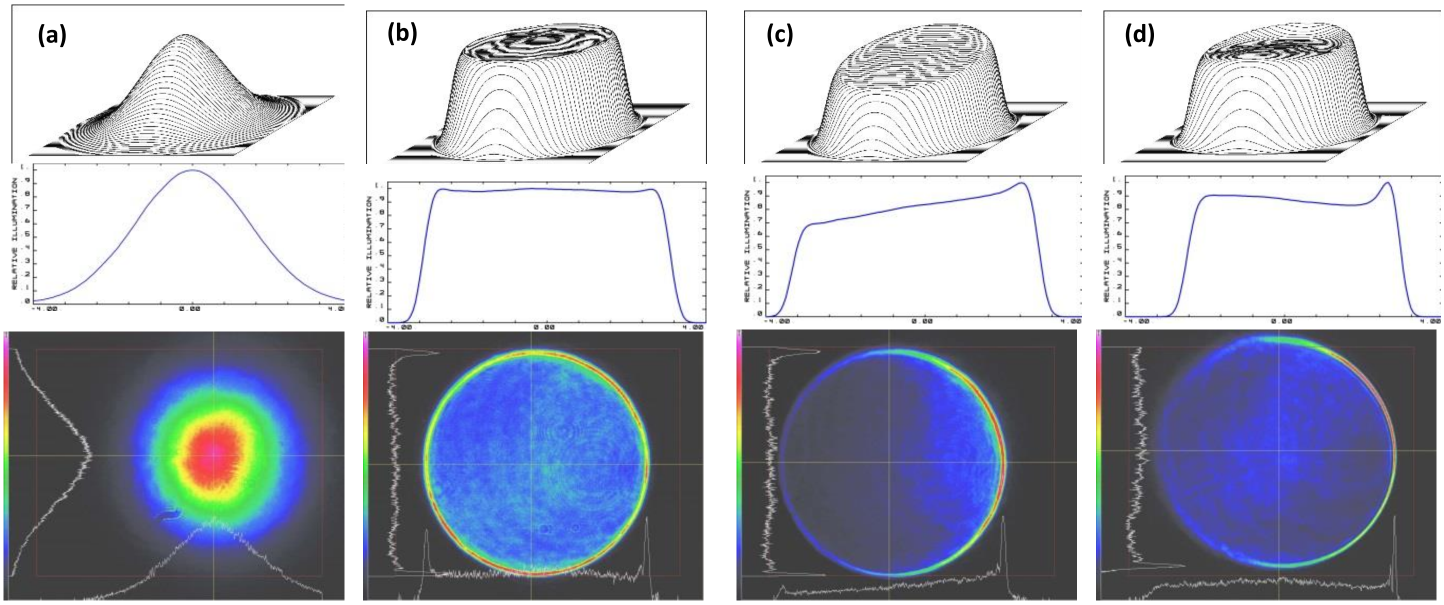


Figure 12 To evaluation of sensitivity of misalignments, theoretical and experimental intensity profiles for Flat Top Beam Shaper 6_6_1064 @ 1064nm:
a) Input TEM_{00} beam, b) Output by perfect alignment c) Output by lateral shift at 0.5 mm, d) Output by tilt at 1^o.

Aberration correction of the Flat Top Beam Shaper systems is provided for a diameter at least 1.6 times larger than $1/e^2$ diameter of a laser beam. Therefore, a small (up to about +/-20% of diameter) lateral shift of a beam with respect to the beam shaper, or vice versa, doesn't lead to aberration, but allows for an interesting beam shaping effect. The output profile is skewed in the direction of the lateral shift, which is illustrated in Fig. 12c. 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 with low divergence. This skewed profile can be used in applications where a steady increasing or decreasing of intensity is required, for example to compensate attenuation of acoustic waves in acousto-optical devices.

As an optical system designed to work with axial beams, the Flat Top Beam Shaper operates in a relatively narrow angular field. The data in Fig. 12d demonstrates the intensity profile behaviour by the beam shaper tilt at 1^o. The intensity profile stays stable but there is visible degradation of quality on the left and right sides of the spot due to aberrations, primarily coma. It should be noted that discussed here 1^o tilt of the Flat Top Beam means about 2 mm of lateral shift of one of its ends. This misalignment can be easily compensated for by ordinary opto-mechanical mounts.

These data show that the misalignments have an influence on the Flat Top Beam 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^o), the resulting profiles are close to flattop. In other words, the tolerance for positioning a beam shaper is somewhat forgiving and misalignments can be compensated for by ordinary opto-mechanical mounts. Since the influence of a tilt on wave aberration of an output beam is quite pronounced, it is advisable to pay more attention to angular alignment while adjustment of beam shapers.

Within 0.1^o tolerance of angle alignment or 0.1 mm of lateral shift, Flat Top Beam Shaper 6_6 is almost insensitive to errors of alignment.