Lasers in Manufacturing Conference 2017

# Twin hexapod operated beam expander and dual pyrocam measurement for laser beam path optimization

M. Jamalieh[a,b], M. Bohrer[a,b], B. Weinberger[a,*]

[a]Dr. Bohrer Lasertec GmbH, Ludwig-Boltzmann-Strasse 2, Neusiedl am See A-7100, Austria
[b]Technical University of Vienna, Karlsplatz 13, Vienna 1040, Austria

**Abstract**

Beam path optimization is a procedure in which beam parameters in terms of diameter and divergence are adjusted to produce a beam that fits inside the intended beam delivery optics with a minimal obtained divergence along a defined path length. In flatbed engraving and cutting machines working distances up to 6 m or even more are expected, therefore a well collimated beam (i.e. propagates parallel) along this path distance is required for presentable clean cutting or engraving results. The commercially available beam expanders used in beam path optimization are limited in adjustability and usually not customized to certain laser devices. Lasers are manufactured with different parameters and customized beam expanders would be the best solution. $CO_2$ lasers are being used in this research. A laser beam adjustment process will be researched using two robot translation stages (Hexapods) acting as two lens holders in addition to a camera based laser beam profiler 'Pyrocam' (capable of detecting 10600 nm wavelength), all mounted inline on an extendible test bench (up to 12 m). The bench is one of its kind and used constantly for laser device testing and evaluation. The optimization process uses algorithms to automatically drive the bench's movable elements constantly until the desired beam path parameters yield satisfactory results. The infrared camera is used to monitor the adjusted (distorted) beam in comparison to a reference and during that the system analyses the beam parameters (diameter and divergence). The robots will be periodically changing the position of the lenses to observe how lens tilting and shifting affects the beam parameters.
After checking laser systems with beam expanders, significant deviation in beam size up to approx. 89% over 6 m was calculated. With our method deviations in beam collimation and size will be dramatically improved across the engraving distances resulting in a constant engraving quality.

Keywords: CO2 laser; beam expander; hexapod; Pyrocam; cutting; engraving.

* Corresponding author.
*E-mail address:* bernhard.weinberger@drbohrer.com

## 1. Introduction

Lasers produce coherent photons with a relatively collimated beam (i.e. beam propagates with very small diameter change measured in millimetres along a defined distance, e.g. 6 meters). The process of perfecting the beam diameter along the required beam propagation path is challenging especially for high precision laser engraving and cutting applications.

The machines which use lasers (specifically RF excited $CO_2$ lasers) to process materials come in different sizes depending on the user request and the nature of the intended application. For machines with large working areas (known as large-format) a well collimated $CO_2$ laser beam source is highly recommended, for example in high precision screen printing processes for applications like printing of anti-counterfeit papers or high-end consumer products (e.g. special beverage cans, bottle labels).

Intensive challenging research is being done to characterize the collimation of $CO_2$ lasers beam along a chosen path.

The goal of this paper is to introduce an early stage laser beam optimization setup consisting of a laser source, a motorized long inline extendible working bench up to 10 meter in total, a stage system of two mini robots (a twin hexapod system) which can move each stage within 6 degrees of freedom and a computer that will command the bench movements and orient the hexapods using a designed algorithm in addition to a special camera based $CO_2$ laser beam profilers. Each robot holds a lens and moves it in a predefined set of movements while the bench scans the camera along a 6 meter path. Pictures of the laser beam along its desired path (e.g. 6 meters) are processed in real time then saved and used as feedback to reposition the lenses. At the end of this process optimal spatial positions are determined and suggested to be used as a beam expander with the chosen laser beam source.

## 2. Background

The rising need for precision, processing time and a homogenous beam over a working distance led us to take beam expander system optimization into the next level. Manually operated hard work which is being done since years at Dr. Bohrer Lasertec on $CO_2$ laser beam expander systems is now taking a different path and a step forward using a twin hexapod operated beam expander and a dual Pyrocam measurement setup. When it comes to laser applications such as engraving and cutting laser beam quality and stability plays an important role.

Some of the parameters used in determining laser beam quality and stability are:

- Beam width
- Beam pointing stability
- The profile of a beam (e.g. for Gaussian beams)
- Power stability
- $M^2$ beam quality factor (discussed in section 3.3.)

### *2.1. Why do we need a beam expander*

A laser beam is considered relatively collimated in comparison to conventional photonic sources such as light bulbs which emit light in all directions. A laser beam is well collimated due to the resonating cavity characteristics (where laser light is being created, amplified and emitted from the laser device). However, there is still a degree of imperfection and laser beams exhibit a different degree of beam divergence depending on many factors.

In laser engraving and cutting machines a relatively collimated beam is needed otherwise the beam will be not homogeneous along the working distance of the machine, for example beam width at different positions will be different resulting errors in the engraving and cutting process.

*2.2. Beam expander components*

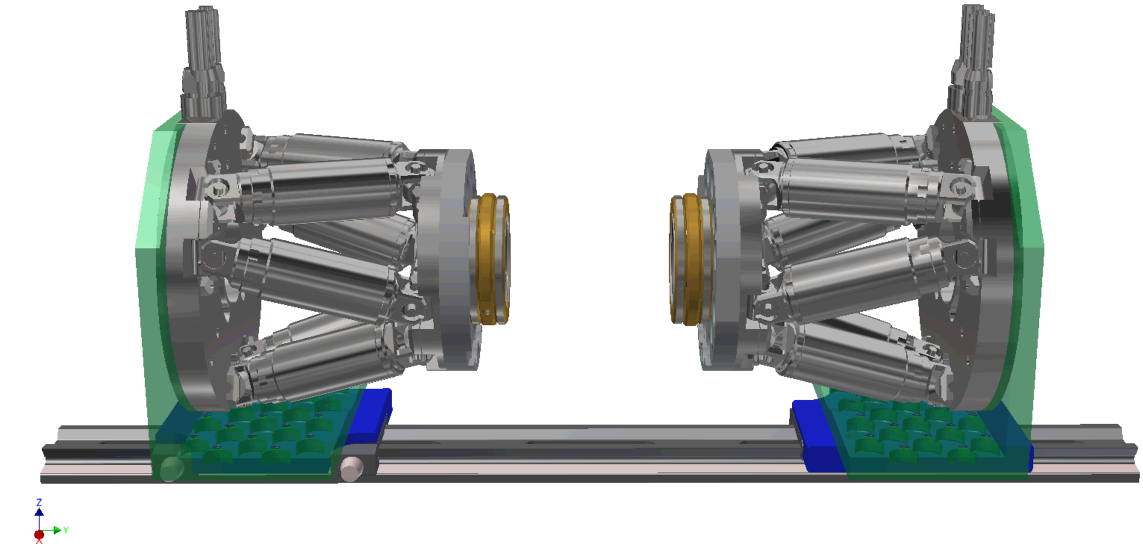
Beam expanders could be an inherent part of a laser engraver or cutter, it is job is to make sure a laser beam is as near as possible to propagate parallel from the output of the beam expander until the laser beam hits the material to be processed.

Beam expanders in their simple form consist of two lenses, one at the beam entrance and the other on the beam exit. The beam entrance lens is a divergent lens and the beam exit lens is a convergent lens, both have specific focal lengths that will make them fit together. The distance between the two lenses is adjusted to obtain a parallel propagating beam on the output of the beam expander

for

**3.** I

Bea




A process like this usually requires two personnel, some hours of installation, alignments and adjustments to produce satisfactory results. For safety reasons it is required that two personnel operate such a laser experiment.

*3.1. Comparison between different beam expanders*

Comparison between three commercially available beam expanders have been done and additionally a beam expander developed at Dr. Bohrer Lasertec for specific $CO_2$ laser sources for engraving machines. The telescopes were adjusted to get the minimal deviation of beam size along 1 to 6 meters of the beam path also the distance of the telescope from the laser aperture (faceplate) is crucial. For adjusting a telescope the distance between the beam entrance optic and the beam exit optic is varied until the beam is parallel and through this process the beam will be changing its shape constantly while the operator adjusts the beam. A telescope should not introduce significant beam deformations or produce additional laser interferences on the image plane such as circular fringes or horizontal and vertical interference lines.

Table 1. Results of laser beam optimization process using three commercially available beam expanders and two others developed by Dr. Bohrer Lasertec

| Beam expander magnification factor | Input aperture in mm | Output aperture in mm | Distance from laser aperture in mm | Temp after 15 min in °C | Deviation in beam size along 6 m in % |
|---|---|---|---|---|---|
| 2x | 20 | 28 | 35 | 38 | 88.6 |
| 3x | 20 | 28 | 35 | 38 | 77.4 |
| 4x | 20 | 28 | 35 | 39 | 33.0 |
| 2.54x | 35 | 35 | 730 | 37 | 77.4 |
| 3.8x | 35 | 35 | 200 | 32 | 37.3 |
| 3.8x | 35 | 35 | 250 | 33 | 24.9 |

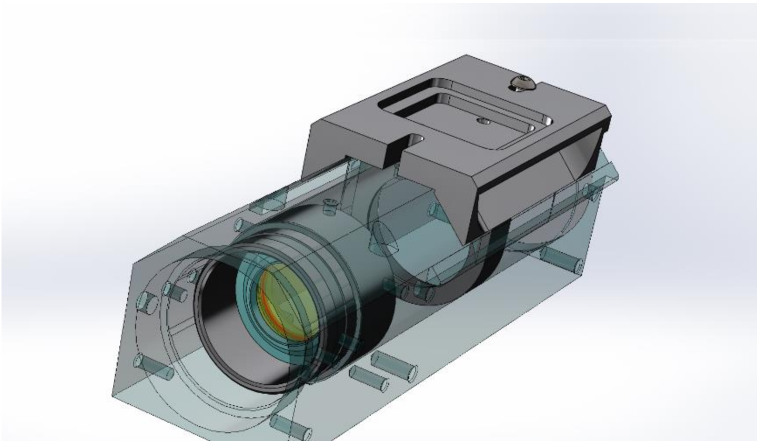


Fig.1. Shows the telescope designed and operated at Dr. Bohrer Lasertec. With its aluminium housing, easy optic exchange mounts and the sliding adjustment mechanism allows easier handling and installation as well as the possibility to mount long focal length optics

### *3.2. Challenges using beam expanders*

The following challenges were encountered often during the experiments and we put more focus to understand them:

- The size of the beam expander is crucial, small beam expanders are practical and compact but not easy to adjust due to short focal lengths, the bigger beam expanders look bulkier but more easy to adjust and fine tune due to the large focal lengths of its input and output lenses.
- Aperture size is important for lasers with large beam diameter and a big lenses are always an advantage.
- Temperatures might be an issue in non-water cooled beam expanders as might put a stress on the optics and eventually lead to damage.

From table 1. We conclude that a larger beam expander in length and optic diameters will result a relatively good beam collimation showing only 24.9 % of beam size change along the tested distance of 6 meters as well as lower temperatures.

### *3.3. Beam expander effect on beam quality factor M²*

The beam quality factor $M^2$ is a unitless number that determines the focusability of a laser beam (i.e. the ability of a laser beam to be focused to the smallest point it could). A laser beam with $M^2$ of 1.00 is considered to be perfect, however, most $CO_2$ lasers show factors between 1.00 and 1.50.

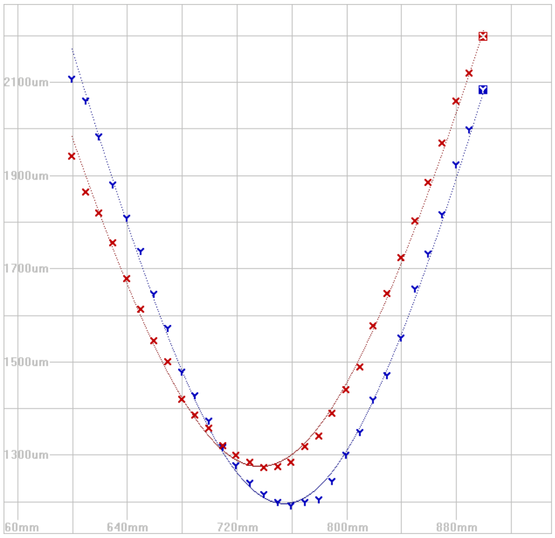
During the intensive experiments it was found that introducing beam expanders in the system effects the beam quality factor $M^2$. Therefore a comparison have been conducted and $M^2$ was measured and before and after using a telescope. The following table shows the results of this comparison.

Table 2. Results show the effect of using or not using a beam expander. A laser source was chosen from a well-known laser manufacturer which showed almost perfect beam quality during previous tests

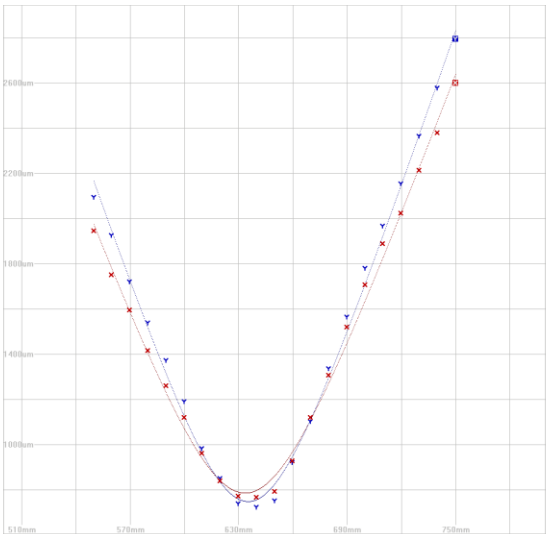
| Evaluated parameter | Without beam expander | With beam expander | Unit |
|---|---|---|---|
| Divergence | 2.60 | 1.30 | mrad |
| $M^2$ | 1.05 | 1.29 | unitless |
| Astigmatism | 0.14 | 0.08 | unitless |
| Asymmetry | 1.09 | 1.09 | unitless |

The beam expander magnification used with this laser was 1.875x which suited the chosen laser perfectly for an intended application. As well as a long focal length (650 mm) convergent lens was used as a part of the $M^2$ test. After using the beam expander the laser beam quality test showed obviously lower divergence value meaning that the beam became more collimated.

Figure 2 shows beam width diagrams as a part of beam quality factor measurement, an introduced lens with a relatively long focal length (to minimize errors) will form a laser beam caustic and a software provided with the Pyrocam measures the laser beam width after the introduced lens at defined positions. From the measured laser beam widths the laser beam quality factor is calculated along with other important factors such as Divergence, Astigmatism and Asymmetry.




(a) Without beam expander




(b) With beam expander

Fig.2. (a) shows two overlapping curves of the beam width on both x and y axes along the caustic range; (b) shows in the same manner the mentioned beam width curves but after introducing a beam expander

## 4. Automatized setup

To achieve maximum possible precision and stability with faster optimization process time, new devices are introduced into the system. The camera takes a reference image and a beam adjusted image respectively. In addition to the camera two hexapods act as the beam expander lens holders. The hexapod robots are used to hold a Zinc Selenide lens (ZnSe) each and they periodically move them in a set of predefined translation and rotation movements controlled by an algorithm.

The motorized extendible stage with all the mounted devices is considered one of its kind and plays an important role in research and production.

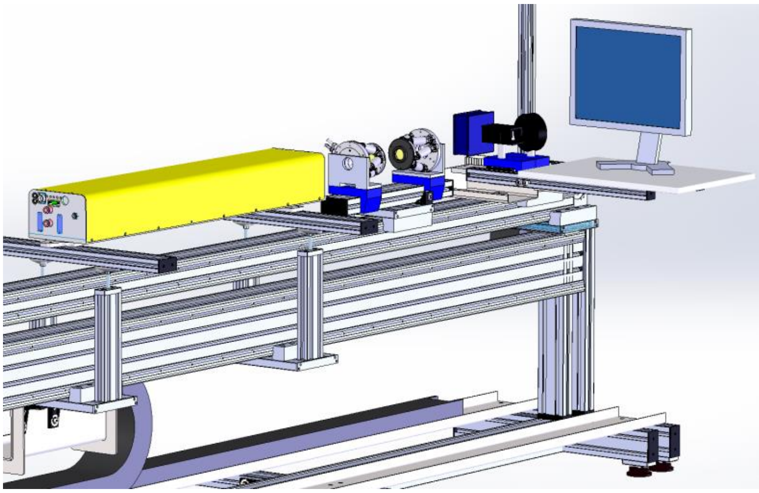


Fig. 3. Shows a CAD illustration of the extendible test bench (retracted for better view). A laser is mounted (yellow) and in front of it the two hexapods are facing each other and forming the beam expander, after that a Pyrocam and a laser power meter will capture and measure the laser beam. All objects are mounted on a sliding stages

### *4.1. The twin Hexapod system*

Two hexapods have been ordered from Physik Instrumente (PI) in order to achieve the principle of the twin hexapod operated beam expander. Each of the hexapods are capable of translating its stage with 6 degrees of freedom (3 rotational and 3 translational movements) with a minimal incremental motion down to 0.1 µm and Min. incremental rotation down to 3 µrad [2].

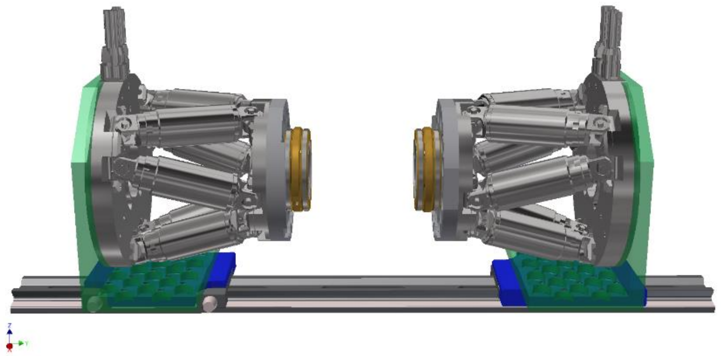


Fig. 4. Shows a CAD representation of the hexapods mounted on a rail and the two beam expander optics

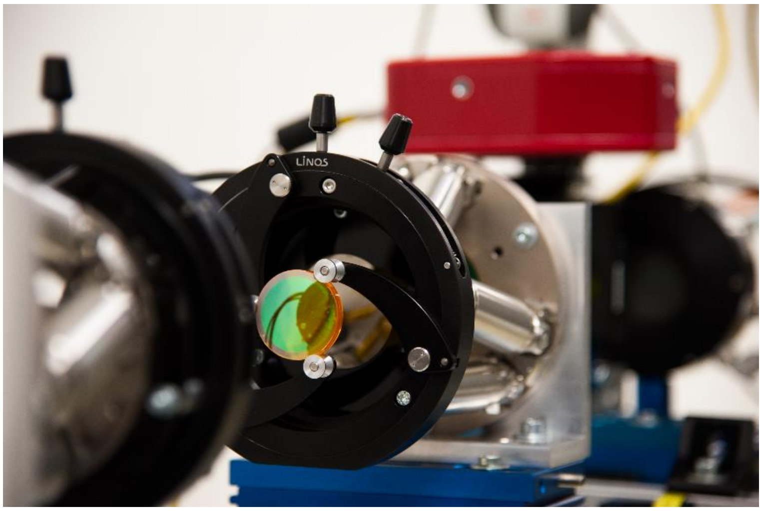



Fig. 5. Shows the two hexapods facing each other with the ZnSe lenses mounted on them, along with the Pyrocam and a laser power meter in the back

The two hexapods are mounted inline facing each other. The first hexapod is holding the divergent lens (the entrance of the beam expander), the second hexapod will hold the convergent lens (the output of the beam expander). The hexapods are capable of very precise and small displacements on each degree of freedom in the nanometre range.

In this manner the system is capable of changing the distance between the two lenses as well as performing tilts and off centre shifts (de-aligning the lenses). This system is indeed a perfect solution for developing a beam expander.

*4.2. The camera based laser beam profiler*

Pyrocam is considered to be the high-end way to observe and visually see a laser beam especially in high power lasers. The Pyrocam camera is capable of accurately capturing and analysing wavelengths from 1.06-

3000 µm with its Pyro-Electric array. It features a solid state high-resolution array with a wide dynamic range, fast data capture rates, and operates in CW or Pulsed modes which makes it an ideal candidate for $CO_2$ lasers [3].
For years the Pyrocam III was and still being used on a daily basis at Dr. Bohrer Lasertec to observe laser beams and analyse them. And for the beam expander optimization experiments two Pyrocam IV were ordered. The first Pyrocam is intended to be used as a real time reference profiler in the same time the second one will see the beam after being adjusted.

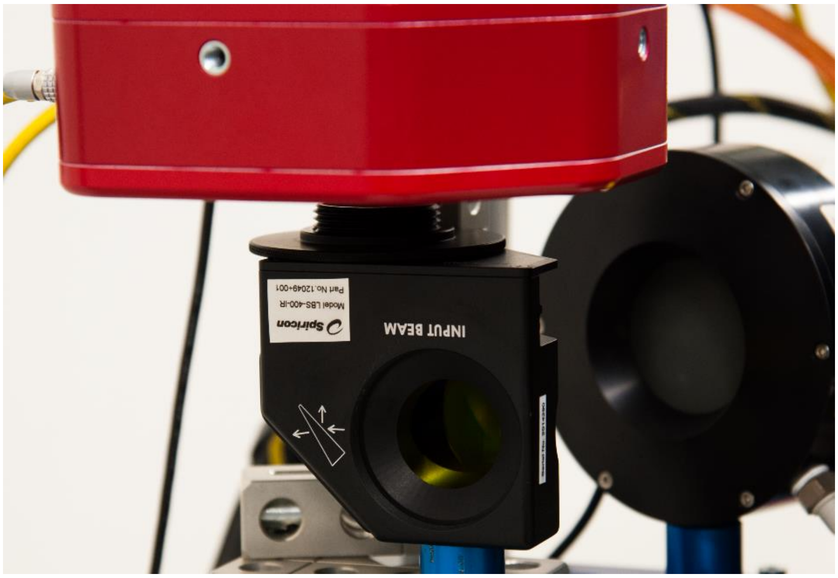



Fig. 6. Shows the Pyrocam IV (red object) mounted on top of its ZnSe laser beam power splitter wedge system. After that a laser beam power meter (black object) is mounted to monitor the power and dump the rest of the beam

**5. Outlook**

Diligent efforts are put into this project and the development will continue to excel optical benches for high power lasers. After finishing all necessary R&D steps and verifying test results of the inline twin hexapod operated beam expander the second Pyrocam (for reference image) will be taken into operation therefore a setup change is to be performed in order to fit the camera. This system will be the foundation to study deformations an additional optic would introduce into the laser beam such as beam splitters, Calcium Fluoride power attenuators in a quality never done before.

**6. Conclusion**

On this unique optical bench for high power lasers we could already demonstrate how to optimize the beam path for various flatbed systems, an R&D work already integrated in hundreds of big laser systems. The combination of the two high-end devices (Hexapod and Pyrocam) will enable us to investigate $CO_2$ lasers in depth. Many $CO_2$ laser manufacturers and users are eager to know how their lasers would perform under certain conditions when external optics are involved especially for their laser source optimization purposes and also industries who are interested in installing specific lasers with their engraving or cutting machines.

Whereas laser systems showed a diameter difference of 88.9 % between first and last position (1 to 6 m), we could optimize 88.9 % to 24.9 % and intensity has the square of diameter in its formula thus resulting in an improvement of laser beam intensity over the working distance of a machine.

The following path optimization facts have been concluded regarding beam expanders.

Beam expanders perform better in beam collimation when:

- They have larger input and output optics
- Optics can withstand high temperatures
- Optics with longer focal lengths for accurate adjustment
- Beam expanders effects the laser beam quality factor

## Acknowledgments

The authors are grateful to II-VI for optics (M. Benzing, O. Schulz, M. Hennecke), SMC for the precision chillers (A. Pichler), Spiricon/Newport for the power detectors and the Pyrocams (J. Reingruber, C. Dini, O. Glatz). Special thanks to Physik Instrumente (PI) GmbH for the Hexapods and making this project possible. Synrad for lasers (C. Webster, P. Martin, J. Bethel, R. Wheeler). Iradion for lasers (P. Brak). Trotec (A. Penz, G. Ernst, A. Jauker, F. Gruber) for their exceeding support. And as always to Univ.-Prof. Dr. D. Schuöcker - still as senior advisor, where one of the authors started as his first employee in 1985 at the newly founded institute for high power laser technology. Many thanks to the Laser Team. Pictures made by the authors. This project has been funded by the European Regional Development Fund (ERDF), by the Austrian Federation, by the AustrianWirtschaftsservice GmbH (AWS, I. Paska, R. Ernst) and by the Federal State of Burgenland, managed by Wirtschaft Burgenland GmbH (WiBuG, G. Ostermayer, C. Kugler, S. Hajek).

## References

[1] Beam Expander product information page on II-IV Infrared, Website page link accessed on (2017-05-07): http://www.iiviinfrared.com/CO2-Laser-Optics/beam-expanders.html

[2] PI Hexapod model H-811.D2 datasheet p. 2, available on PI website page link accessed on (2017-05-07): https://www.physikinstrumente.com/en/products/parallel-kinematic-hexapods/hexapods-with-motor-screw-drives/h-811d2-6-axis-miniature-hexapod-700884/

[3] G.E. Slobodzian, Director of Engineering, Retired, Ophir-Spiricon, Apples to Apples: Which Camera Technologies Work Best for Beam Profiling Applications, Part 1, website article link accessed on (2017-05-07): http://www.ophiropt.com/laser--measurement/knowledge-center/article/8064.