Prototyping Active Alignment of a Beam Expander

JULIA THORPE[1] AND ISAAC WOODARD[1]

[1] Knight Campus Graduate Internship Program, University of Oregon, 1252 University of Oregon, Eugene OR 97403

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The manual alignment of optical components can be difficult and time consuming to optimize. Here, an apparatus is prototyped to optimize the configuration of a Keplerian beam expander by automating positioning of lenses with Python based on data obtained from a Thorlabs BC106N-VIS beam profiler. The lenses are mounted on piezoelectric stages to adjust their alignment on the micrometer scale in three dimensions. The beam profiler is used to detect aberrations and measure collimation in the expanded beam. It was found the apparatus is viable for optimizing the transverse alignment of the beam expander. Due to time constraints, z-axis alignment and automation were not tested.

1. Introduction

An ideal beam expander produces a beam that has a consistent Gaussian profile and is collimated out to infinity. A telescope composed of two lenses can be used as a beam expander, with the distance between the two lenses given by the sum of their focal lengths. It is worth noting the magnification, M, is given by the ratio of the focal lengths of the lenses,

$$M = -f_B/f_A, \tag{1}$$

with f_A and f_B being the focal lengths of the lenses closest to and furthest from the light source, respectively.

Poor transverse alignment of the lenses leads to aberrations in the expanded beam. These aberrations can be described as coma or distortion aberrations and are a result of the beam not being centered on the optical axis of the lens [1]. The result of these aberrations is the deformation of the beam into an ellipse. Meanwhile, incorrect distancing of the two lenses will cause the expanded beam to either diverge or converge. Due to spherical aberration, the effective focal length of a lens can vary from its theoretical value [2].

A camera & motor system known as a beam profiler can be used to detect aberrations in a beam and check if it is collimated by taking images at different distances from the beam expander. Such systems can be purchased or custom-made as in the system used by Bonnett et al. [3].

By mounting the lenses of the beam expander on piezoelectric translation stages, the alignment can be optimized on the micrometer scale. Piezo stages are devices that allow for fine control of motion using a piezo motor. The piezoelectric effect is responsible for the fine motor control allowed with the stages. The piezoelectric effect in this case is the mechanical deformation of a crystal when a voltage is applied [4]. The applied voltage comes from a piezo controller that applies an output voltage to the stages. The voltage can be configured through the controller interface or through software to achieve the desired configuration of the stages.

The automation of the alignment process in response to feedback from the apparatus is known as active alignment. This is in contrast to passive alignment where components are aligned while the system is inactive. Active alignment has some advantages to passive alignment. For one, it can respond to measured aberrations in a system, reducing reliance on theory. In addition, it can continuously adjust for disturbances in the environment. This dependence on continuous adjustments means active alignment is only practical when automated.

2. Experiment

The goal was to assemble an apparatus capable of actively aligning a beam expander in three dimensions.

The optical apparatus is shown in Fig. 1. The beam from a HeNe laser was passed through a 2x beam expander composed of a 25 mm and 50 mm convex lens. A Thorlabs BC106N-VIS beam profiler was used to monitor the expanded beam. The beam profiler was mounted on a motorized stage to make it possible to measure the collimation of the beam. A beamsplitter was also placed between the beam expander and beam profiler to reduce the intensity of the beam and to create a second beam so that the setup could potentially be used as a part of a larger experiment.

The 25 mm lens was mounted on a Thorlabs NFL5DP20 piezo stage so it could be translated along the optical axis. The 50mm lens was mounted to two orthogoal NFL5DP20 piezo stages using a 90° angle bracket for translation in the transverse plane. Each stage was driven by a separate Thorlabs KPZ101 Piezo Driver.

The piezo drivers were operated using the Thorlabs Kinesis software, while the beam profiler was operated using the Thorlabs Beam 6.0 software. The Beam software provided an interface to save both 2D and 3D profiles of the transverse

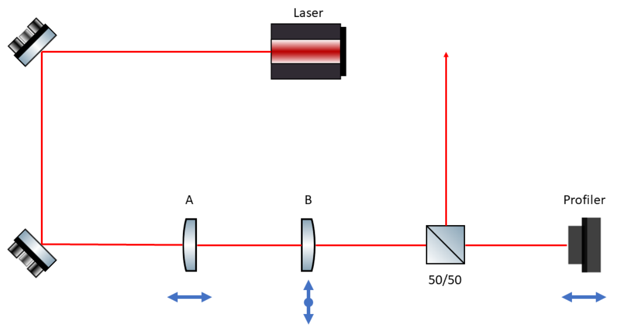

Fig. 1. Schematic of optical setup. The beam from a He-Ne laser is passed through a 2x beam expander before reaching a 50/50 beamsplitter. A Thorlabs beam profiler monitors one of the split beams to provide feedback for the positioning of Lenses A & B. Lens A has a focal length of 25 mm and is adjustable along the optical axis while Lens B has a focal length of 50 mm and is adjustable in the transverse plane. The two lenses are separated approximately by the sum of their focal lengths.

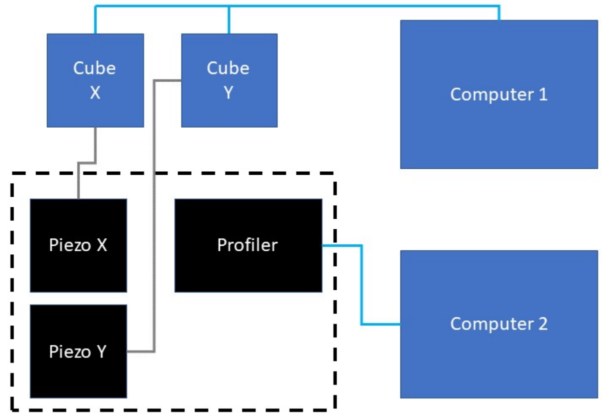

Fig. 2. Box diagram of electronics for transverse alignment. Computer 1 is used to adjust the position of two piezoelectric stages through two Kinesis K-Cube Controllers using the Thorlabs Kinesis software. Computer 2 is used to gather calculations and images from the beam profiler using the Thorlabs Beam 6.0 software.

beam intensity. It also performed calculations to provide parameters of the beam such as its diameter and ellipticity. The software defined ellipticity as the ratio of the minor axis of the beam profile to the major axis, making an ellipticity of 100% characteristic of a perfect Gaussian profile.

Measurements of the ellipticity of the expanded beam as a function of transverse position of the second lens were taken to check if the beam profiler was a viable device for detecting fine changes in alignment. The piezo drivers were set to voltage values in the range of 0 to 70 V to adjust the lens alignments. The max voltage of the drivers was 75 V with a 20 micron piezo travel distance. 2D beam profiles were recorded for each position as well as 3D profiles for the max and minimum ellipticity positions. A diagram of the electronics setup for the measurements is shown in Fig. 2.

Python code for optimizing the alignment of both lenses of the beam expander was developed but there was insufficient time to test it. The code was designed to continuously refine the alignment of the beam expander while controlling the beam profiler through macros. This would have allowed the equipment to be controlled autonomously from a single computer.

3. Results

Ellipticity measurements of the expanded beam were mapped across the piezo stage travel distance for the second lens. This mapping is shown in Fig. 3.

Ellipticity values generally increase as the second lenes is moved away from the (0, 0) V position. At (0, 0) V the beam has a maximum ellipticity of 92.86% and at (70, 70) V the beam has a minimum ellipticity of 89.60%. The change in ellipticity indicates an increase in aberrations as the second lens is moved in the positive x & y direction.

3D profiles were also taken for the best and worst transverse alignment positions. These are show in Fig. 4. The profile for the best alignment position more closely matches the ideal Gaussian shape than the profile for the worst alignment position. Both profiles show signs of coma aberrations due to their comet-like spread [1].

With the highest ellipticity value lying at the edge of the map, it is likely the best possible alignment position was outside the travel range of the piezo stages. However, the change in ellipticity over the travel distance of the piezo stages show the beam profiler is sensitive enough to probe the transverse alignment of the beam expander.

4. Conclusion

The trend in ellipticity in Fig. 3 indicates the Thorlabs BC106N-VIS beam profiler is adequate for active alignment of a beam expander in the transverse plane.

The trend also illustrates an important limitation of the piezo stages. Careful pre-alignment is necessary to ensure the optimal alignment configuration lies within the travel distance of the stages. A promising strategy would be to manually align the beam expander with the piezo drivers set to half the maximum voltage of the stages. This two-step approach is similar to that described by Brecher et al. for automated laser

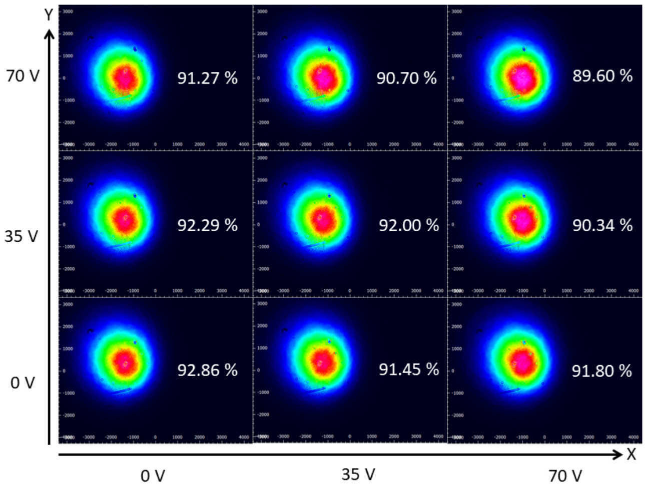

Fig. 3. Mapping of ellipticity as a function of transverse position in terms of applied voltage. Voltages were applied to the horizontal and vertical piezo stages to adjust the position of the second lens. The stages have a piezo travel distance of 20 µm. Measurements were averaged over 10 frames to reduce noise fluctuations.

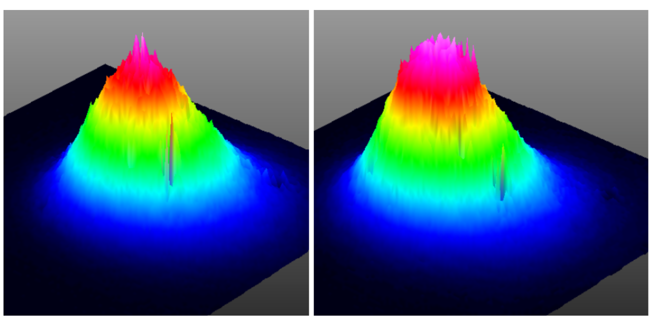

Fig. 4. Three dimensional view of beam profiles for inputs of (0,0) V (left), and (70,70) V. The left image has a more defined Gaussian shape, which is consistent with its higher ellipticity of 92.86%. The right image appears more deformed, consistent with its lower ellipticity of 89.50%.

resonator alignment [5].

A working model for active alignment of a beam expander would hold potential for many applications. For example, the precise alignment of a beam is crucial for systems that involve beam coupling into a fiber optic. Precise alignment is also important for many interferometer systems, such as the Fabry Pérot interferometer, which are very sensitive to positioning of optical components. The automated optimization of component positions would reduce time spent with manual alignment and create some resilience to environmental noise.

In addition to aligning a beam expander, the algorithm could be built upon to optimize the position of other critical optics. The active alignment of a Michelson interferometer is described by Kalamatianos et al. where one of the mirrors was mounted on piezoelectric transducers. This allowed the mirror to be tilted and translated in response to the diffraction pattern [6].

5. Future Work

While the apparatus showed viability for transverse alignment, there are several steps which need to be taken to finish prototyping the active alignment of the beam expander.

The first step is exploring the change in collimation as the first lens is adjusted along the optical axis through the piezo stage's travel distance. It was found that the beam profiler was adequate for probing transverse alignment, but its ability to detect changes in collimation should also be tested.

The next step is finding an effective way to interface with the beam profiler through Python. A successful method was found using macros, but that approach has some drawbacks. Using macros is likely slower than interfacing with the device directly, and interferes with user input while the program is running.

The last step is interfacing with all three piezo drivers and the beam profiler at the same time and writing an algorithm to automate the alignment process. Based on data taken by the beam profiler, voltages would be applied to the piezo stages to optimize the lens positions iteratively. Active alignment of the beam expander with programming would take advantage of computer processing to reduce the time spent on manual alignment.

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