1. Introduction

The *Compact* Laser Beam Stabilization has two independent control stages, each with a piezo actuated mirror working together with a detector. In most cases, the components can be integrated into the laser setup without the use of lenses. In some cases, however, it is advantageous or necessary to use lenses. This description shows different use cases with lenses. The related components of a control stage are designated with 1 or 2. In most setups, control stage 1 stabilizes the position and control stage 2 stabilizes the angle of the laser.

2. Adaptation of large beam diameters to the detector size

One use of lenses is simply to reduce the beam size when the beam diameter of the laser is larger than the sensor area of the detector. For this purpose, a lens can be placed in front of the detector.

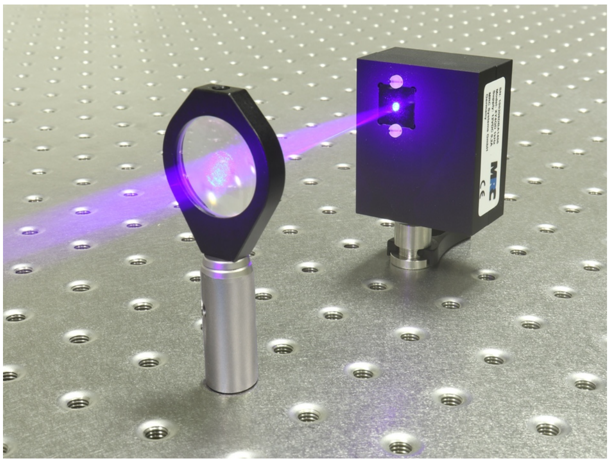

Figure 1: Use of a lens to reduce the beam on the detector

The beam should only be made as small as necessary. The sensor area of our *Si-4QD* detector is 10 x 10 mm². Here, the beam diameter should be reduced so that it is not larger than 6-8 mm on the sensor. Our PSD, UV and IR detectors have smaller sensor areas, which you can find in the data sheets. Correspondingly they require smaller beam diameters.

Please note that the detector should always be placed before the focus of the lens if you want to reduce the beam diameter. Placing the detector into or behind the focus can lead to two undesirable effects which we explain below.

If the detector is placed in the focus of the lens, position deviations of the beam cannot be detected. The reason for this is that parallel beams are always focused on the same point by the lens. Consequently, the detector cannot detect any deviations. The second illustration of figure 5 shows this situation. For control stage 2, there is the special case of using the focusing specifically for angular stabilization (see section 4).

If the detector is placed behind the focus, a plane in the beam path is always imaged onto the detector (according to equation (1)). This can accidentally image a position onto the detector that is unsuitable for stabilizing the beam. If, for example, the imaged position onto detector 2 is on or even in front of the corresponding actuator 2, the detector cannot measure the movements of the actuator. In this case, the signal for controlling stage 2 is missing. Consequently, the beam cannot be stabilized properly. However, there is also a special case in which imaging is applied intentionally. This case is described in section 3.

3. Use of lenses to optimize the positioning accuracy (Imaging)

In many cases, it is perfectly sufficient to achieve a high position accuracy in control stage 1 by placing detector 1 in close distance to actuated mirror 2. This is particularly the case if there is a large distance between the two piezo mirrors. (We recommend a distance of 0.5 m or more). The relatively short distance between detector 1 and actuated mirror 2 then leads to the desired situation that the position of the beam is fixed near actuated mirror 2. If, for example, actuated mirror 1 corrects a position error of the laser by changing the angle of the beam, the difference between the optimum beam position on actuated mirror 2 and the fixed position is only very small. Figure 2 illustrates this fact.

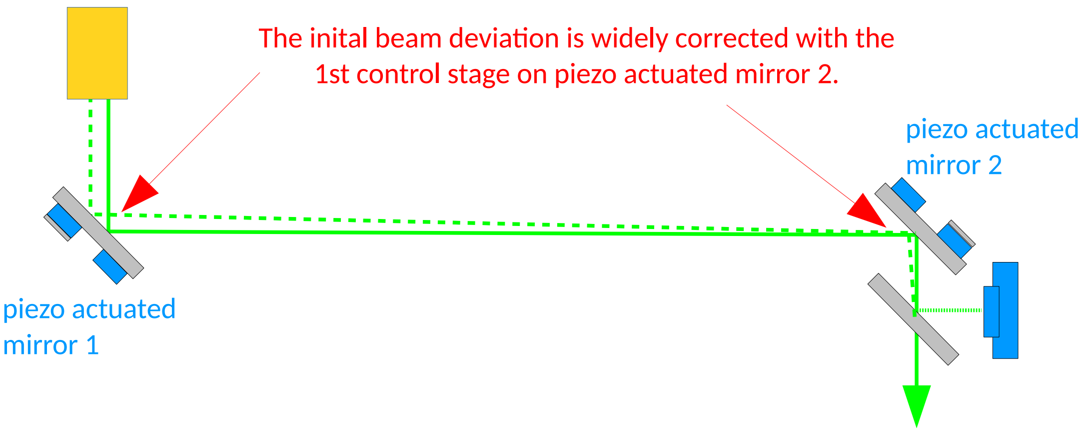

Figure 2: The principle of correcting a position error

In case of unfavorable distance conditions, we recommend a setup which we call "imaging". Here, a lens is used in such a way that an imaging of the mirror surface of actuated mirror 2 onto detector 1 is generated. This can be applied, for example, when the distance between the two actuated mirrors is relatively short and, at the same time, the distance between actuated mirror 2 and detector 1 is rather long. Imaging can be applied regardless of whether the detector is positioned along the beam path or in transmission behind actuated mirror 2. The case of transmission is illustrated in figure 3.

Imaging always ensures that the beam position is fixed on actuated mirror 2. For this purpose, the lens equation (1) must be fulfilled where f is the focal length of the lens, b is the image distance, and g is the object distance (figure 3).

$$\frac{1}{f} = \frac{1}{b} + \frac{1}{g} \quad (1)$$

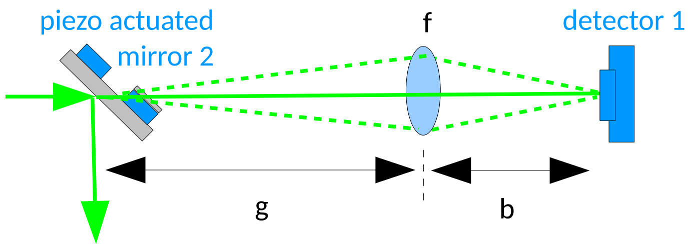

Figure 3: Imaging with a lens

Numerical example

The following example is intended to show how the distance between lens and detector can be calculated for an imaging. Figure 4 shows a setup in which the distance between actuated mirror 2 and detector 1 is relatively long. Detector 1 is placed behind a beam splitter, which is positioned in the beam path after actuated mirror 2. In addition, the distance between mirror 2 and detector 2 is rather small. Both factors lead to the fact that the position information on the two detectors differs too little so that a highly precise stabilization result is not possible. This would also be the case if detector 1 was placed in transmission behind actuated mirror 2 at a larger distance, as shown in figure 3.

To optimize stability, a lens is positioned so that the laser spot is imaged from the mirror surface of actuated mirror 2 onto detector 1. This stabilizes the position of the laser exactly there.

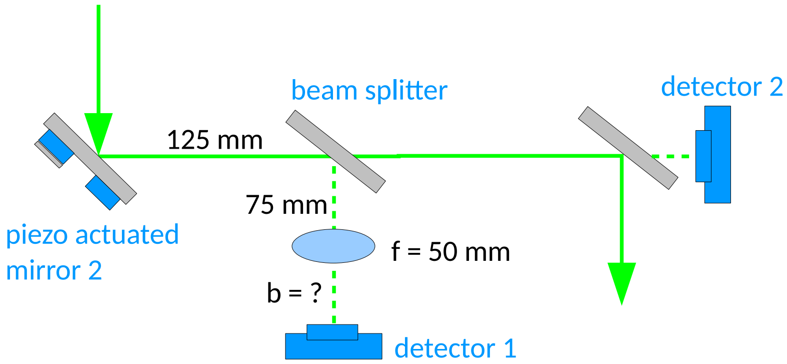

Figure 4: Setup with numerical example

To solve the lens equation, both the distances b and g and the focal length f of the lens can be varied. Depending on the available space and the boundary conditions of the setup, one can decide how to change the variables.

For example, with a given lens of focal length f = 50 mm, a fixed distance between actuated mirror 2 and the beam splitter of 125 mm, and a practical distance between beam splitter and lens of 75 mm, the distance b between lens and detector 1 is calculated as follows:

$$\frac{1}{f} = \frac{1}{b} + \frac{1}{g} \longrightarrow \frac{1}{\mathrm{b}} = \frac{1}{\mathrm{f}} - \frac{1}{\mathrm{g}}$$

$$\mathrm{f} = 50\,\mathrm{mm} \text{ and } \mathrm{g} = 125\,\mathrm{mm} + 75\,\mathrm{mm} = 200\,\mathrm{mm} \text{ lead to}$$

$$\frac{1}{\mathrm{b}} = \frac{1}{50} - \frac{1}{200} = \frac{3}{200} \longrightarrow \mathrm{b} = \frac{200}{3}\mathrm{mm} = 66\,\mathrm{mm}$$

4. Use of lenses for angular stabilization

For the second control stage, it is also good if the distance between actuated mirror 2 and detector 2 is relatively long. Since the beam position on mirror 2 is fixed in the first control stage, it can be advantageous, especially in case of short distances, to use a lens to stabilize the beam angle with control stage 2. For this purpose, detector 2 is placed in the focus of the lens. This is explained in more detail in figure 5:

As the upper figure shows, beams of different angles are focused on different points with the lens. These deviations are therefore detectable and can be corrected by the *Compact* system. However, if the beams have different parallel offsets, as in the lower figure, they are focused onto the same point and can thus not be distinguished.

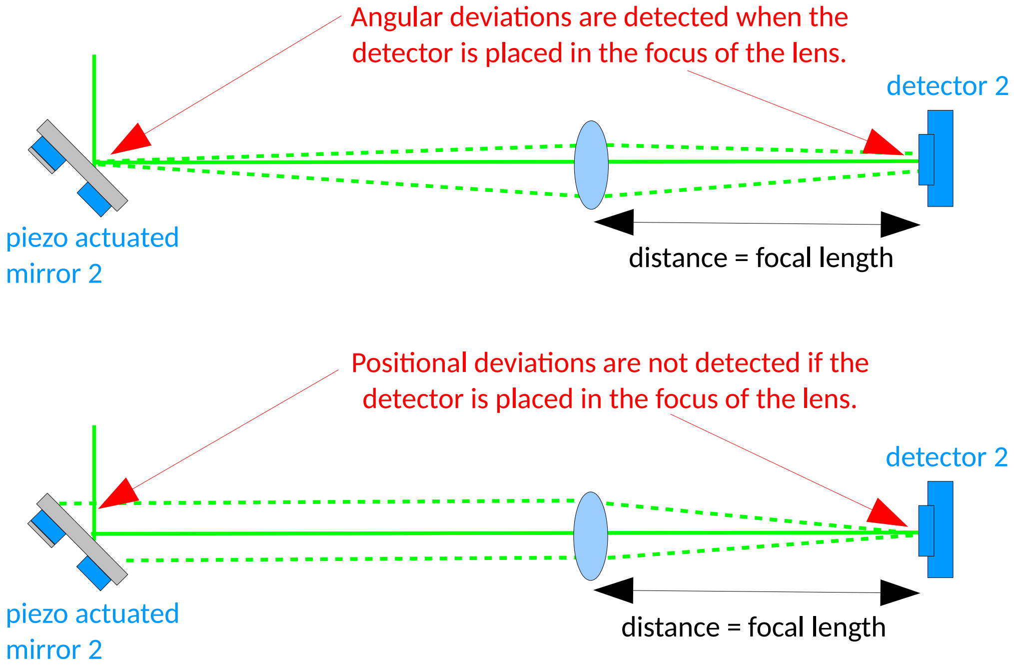

Figure 5: Effect of a lens on angular deviations (upper figure) and positional deviations (lower figure)

This can be used specifically in cases where space is limited, e.g. when the distance between actuated mirror 2 and detector 2 is significantly less than 0.5 m. The lens makes the control accuracy independent of this distance. This setup can also be advantageous for focused applications, where mainly the stabilization of the beam angle is crucial. For this purpose, we recommend to use lenses with focal lengths not less than f = 200 mm, so that the focus spot does not become too small.

The 4QD detectors have a gap between their quadrants that is about 30 µm wide. The focus spot should therefore not be smaller than approx. 100 µm in diameter.

5. Extension of the capture area for laser beams

With very long distances between an actuated mirror and a detector, a large beam offset can result in the situation that the laser beam no longer hits the detector after a phase without stabilization. By using a collimating lens in front of the detector, the capture range for the laser beam can be easily extended in such cases. For example, if the detector is placed at half the focal distance of a large collimating lens, the capture range is increased by a factor of 2. This allows easier adjustment and prevents the laser beam from leaving the detector, e.g. during an interruption of laser operation.

6. Conclusion

There are several ways to place the optical components of the laser beam stabilization system. Its modular design always helps to find the best solution. You can also find further setup variants in the user manual.

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