1. Introduction

The laser beam stabilization *Compact* is characterized by its very high precision. Laser beams can be stabilized with sub-micrometer accuracy. This is achieved by the optimal balancing of the system components with each other: Our detectors capture the beam position with the highest resolution. The sophisticated piezo technology of our mirror actuators allows the compensation of even smallest deviations with highest bandwidth. The analog control loop enables real-time stabilization without any disturbing latencies and steps.

2. Detector resolution

Figure 1 shows the resolution of our standard 4QD detector in nanometers [nm] at different beam diameters. The resolution also depends on the laser intensity which is plotted in the third axis. However, by selecting suitable filters and adjusting the gain, it is always possible to work in the optimal intensity range (see 6 V in the diagram). Even with relatively large beam diameters of 6 mm it is possible to detect with sub-micrometer accuracy. At smaller beam diameters, a resolution of better than 100 nm is possible.

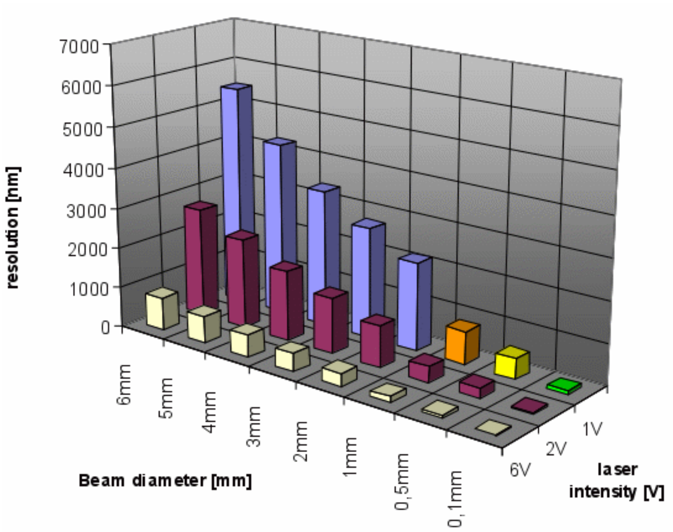


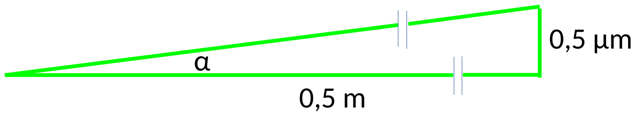
Figure 1: Resolution of a 4-quadrant diode at different beam diameters and laser intensities.

In practice, the achievable resolution also depends on stable mounts. By using the material Invar, which is characterized by a small coefficient of thermal expansion, the detectors are stabilized against thermal fluctuations, so that the accuracy is also sustained in the long term.

3. Angular resolution

The piezo tilting mirrors are controlled steplessly via the analog control loop. Consequently, the angular resolution is mainly defined by the resolution of the detectors. It can thus be determined with the values from figure 1 and the distance between the piezo tilting mirror and the associated detector in the setup.

Here is a numerical example: At a beam diameter of 4 mm, figure 1 shows a detector resolution of approx. 0.5 µm. With a distance of 0.5 m between the piezo mirror and its associated detector, the angular accuracy can be calculated as follows:



$$\tan\alpha = \frac{0.5\mu m}{0.5\,m} = 1\cdot 10^{-6}$$

$$\alpha = (0.573\cdot 10^{-6})° = 0.994\,\mu rad$$

4. Relation of the actual position to the measured voltage

The position signals of the detectors are available as raw voltages. They can be read out via the analog outputs on the controller as well as via the communication interface or the software. To determine the actual positions in micrometers, the voltage values can be converted. In the following sections we introduce the equations for the different detector types. For the calculation, you first have to determine the beam diameter, which is used in the equations. In the software, the equations are stored, so that the positions can be displayed directly.

4.1. 4-quadrant detector

As long as the beam is close to the center of the sensor, the following equations can be used for 4-quadrant detectors. Here, x and y are the position signals measured in volts or calculated in µm, D is the beam diameter ($1/e^2$) and I is the measured intensity signal.

$$x[\mu m] = \frac{D[\mu m]}{\pi}\cdot\frac{x[V]}{I[V]} \qquad y[\mu m] = \frac{D[\mu m]}{\pi}\cdot\frac{y[V]}{I[V]}$$

For a more exact calculation or in case of a larger distance of the beam from the center more complex equations can be used:

$$x[\mu m] = \frac{D[\mu m]}{2\cdot\sqrt{2}}\cdot erfinv\left(\frac{x[V]}{I[V]}\right) \qquad y[\mu m] = \frac{D[\mu m]}{2\cdot\sqrt{2}}\cdot erfinv\left(\frac{y[V]}{I[V]}\right)$$

where erfinv() is the inverse error function.

4.2. PSD detector

For the PSD detectors, the relation of voltage to position is almost linear so that the following equations can be used:

$$x[\mu m] = \frac{x[mV]}{(1.2\pm 0.03)} \qquad y[\mu m] = \frac{y[mV]}{(1.2\pm 0.03)}$$

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