OPTI 521: Optomech Tutorial

System Alignment with a Beam Triangle

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Introduction

One challenge that optical engineers commonly face is that of system alignment. The alignment methods will vary by system since each has a different design and purpose. One common practice is to use two mirrors to form a 'beam triangle' to align the system to a set of given points as shown in Figure 1. While the geometry of the mirrors might vary, the term beam triangle will be used throughout the tutorial to describe any such setup. The purpose of this tutorial is to explain how an engineer might align a light source to a mechanical axis of their system either for testing, system alignment, or for system operation.

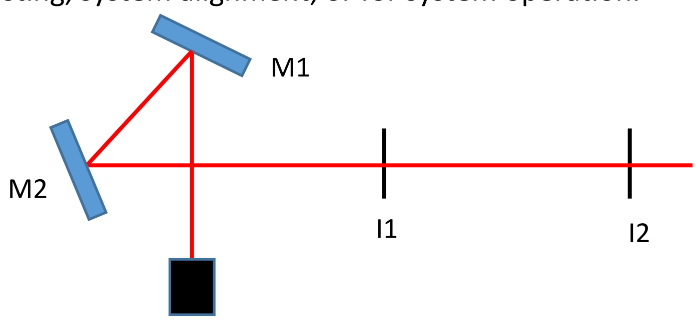

Figure 1: Example of a Beam Triangle Aligning a Laser to Two Irises

Setup

Two irises can be used to define a mechanical axis of the system. Any two points in three dimensions will define a unique line and this line will be the axis of our system. Each iris has 6 degrees of freedom, but we will ignore the three rotational degrees of freedom since small perturbations don't significantly impact the axis position. We can also ignore motion in the z direction of the mechanical axis since motion of the iris in this direction is still along the same line. The iris separation is important, but we'll assume that it's large enough and that the x-y perturbations are small enough that we can use the small angle approximation. We'll return to this later since it is significant in estimating alignment errors.

This leaves us with two degrees of freedom for each of the two irises, or four degrees of freedom in defining our axis. This means we must be able to make four separate adjustments in order to align our laser to our two irises. One solution is to use the laser itself as the datum for the system and adjust the irises (and therefore the system) with x-y translation stages. This can quickly become awkward and inconvenient as the system may be put under stress from trying to move and twist it to match our beam. Another unideal solution is to use the mechanical axis we've defined as our datum and adjust our source in x, y, tip, and tilt to match our irises. This is also problematic as most sources lack easy and precise adjustments in all four of these degrees.

The solution that I present here is the use of two fold mirrors which have tip and tilt adjustors. The geometry may be a periscope, a beam triangle, or something completely different, but we will need the four adjustors to match the four degrees of freedom our irises have. The first mirror will allow us to adjust the x-y position where the source strikes the second mirror. The second mirror will allow us to define the angle at which the light is reflected. In terms used way back in algebra, what we're doing is using a point and a slope to define a unique line in three dimensions as shown in Figure 2. If this unique line passes through

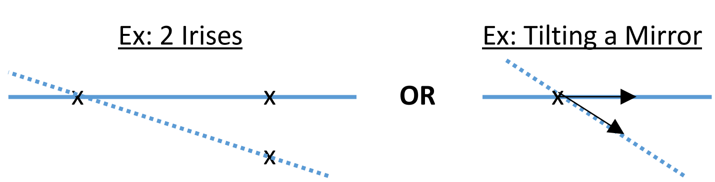

Figure 2: There are two ways to define a unique line: 2 points (left) or a point and a slope (right).

both irises, then we can be assured with some degree of confidence that the path of light from the source lies along the mechanical axis of our system.

Making Adjustments

To begin the alignment, allow the beam to reflect off of both mirrors such that it is centered on the first iris as shown in Figure 3. With any luck the beam will fall somewhere on the second iris

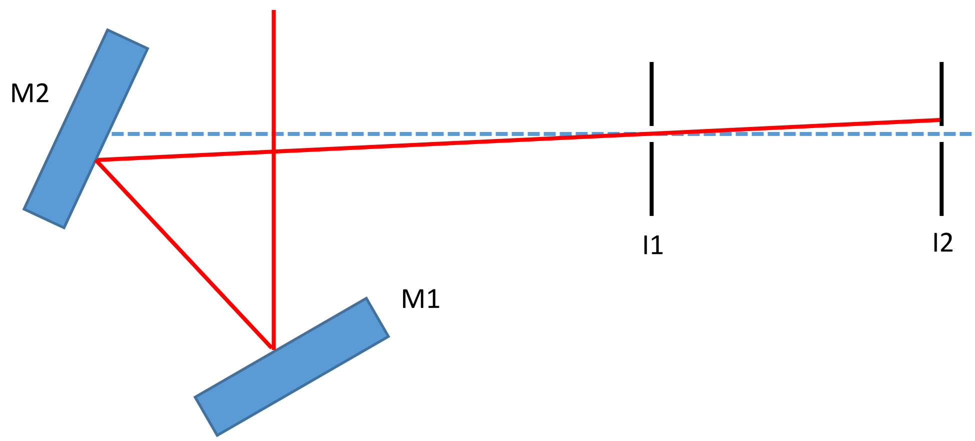

Figure 3: Starting configuration for the beam triangle.

and you'll be close to aligned. The next step is to assign each mirror a corresponding iris to center the light on. Referencing Figure 3, M1 will always be used to center light on I1 and M2 will always be used to center the light on I2. This will allow the iterative process outlined below

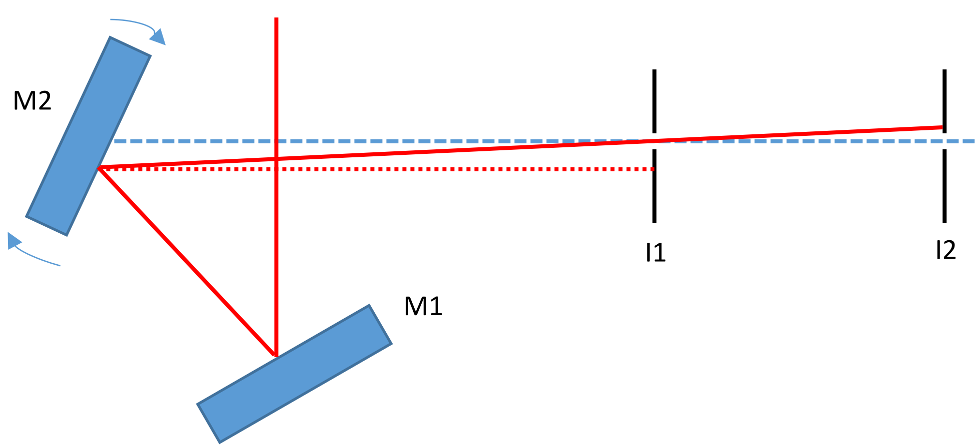

Figure 4: Adjusting M2 changes the angle at which the light reflects off of the mirror.

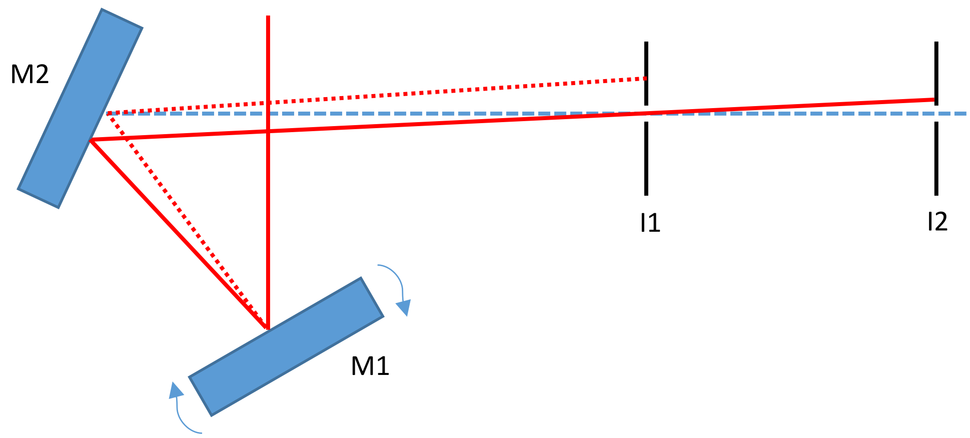

Figure 5: Adjusting M1 changes the position where the light strikes M2.

to converge to a solution. If the order is reversed, the process will diverge and things will rapidly become worse. With the light centered on the first iris, M1 has no adjustments to be made. Adjust M2 to bring the light towards the center of the second iris as shown in Figure 4. Since the process is iterative it's okay to overcompensate a bit to speed the process up a little. Once the light is centered on I2 or is blocked by the first iris, re-center the light on the first iris using M1 as shown in Figure 5. Repeating this will bring the light into alignment with the axis of the irises. Since the mirrors are finite in extent, you may have to translate M2 should the beam walk off the edge. If you wish to avoid this, more care can be taken in initial mirror placement or larger mirrors can be used.

Alignment Errors

We can estimate the error of this alignment using simple geometry. Let us assume that our light source is perfectly collimated and under-fills our iris as in Figure 6. D_1 is the diameter of the iris and D_2 is the beam footprint. The maximum angular error in the alignment of the source to the mechanical axis would be $\frac{D_1 - D_2}{\Delta z}$ where Δz is the separation of the irises. To reduce our error we now have 3 parameters we can adjust. We can close the iris (decrease D_1), we can magnify our

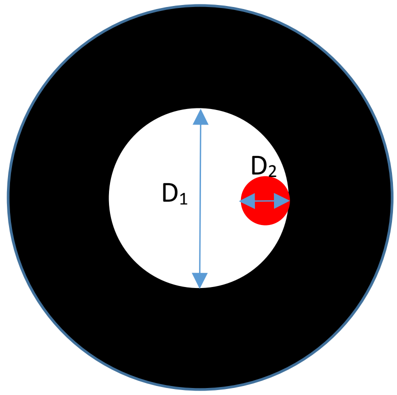

Figure 6: Image of an under-filled iris. D_1 is the iris clear aperture and D_2 is the beam footprint.

source or open it's shutter (increase D_2), or we can increase the iris separation (increase Δz). Ideally D_1 will match D_2 and the error will approach zero. If we break our assumption and over-fill either of our irises, then the precision will depend upon how well we can center the light source on the iris.

Inserting Elements

Now that we have a source aligned to a well-defined axis, it is fairly straightforward to insert optical elements between the irises. If space between the irises becomes limited, we can increase the iris separation by moving an iris in $\hat{z}$ so long as it remains centered on our beam. When a lens is inserted into the collimated beam, it will have some amount of decentration. Figure 7 shows that the light is bent towards the optical axis of the lens causing an angular deviation. If we position the lens so that its optical axis lies upon our predefined mechanical axis then there will be no angular deviation. In short, we simply need to move the lens until the

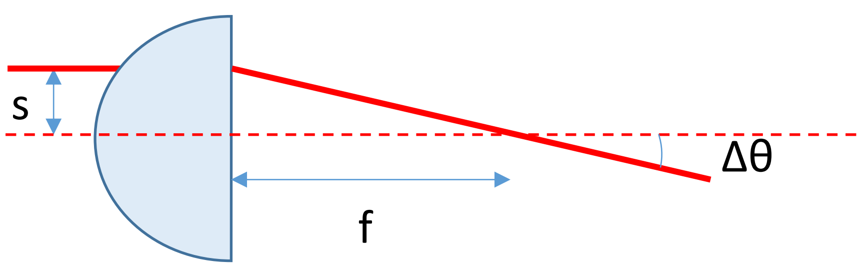

Figure 7: Effect of decentering a lens: $\Delta\theta = s/f$

light is once more centered on I2 to know that our element's optical axis is co-aligned with the mechanical axis we've set up. Repeat this process for each element and you'll soon have an optical system with a well-defined axis and well centered elements.