Progress Report 1: Improvement of Fiber Optic Based Optical Levers By Elimination of Higher Order Cladding Modes

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I. INTRODUCTION

Advanced LIGO uses uses optical levers to control the pitch and yaw of the test masses in the interferometer[1]. The optical lever setup includes a fiber-coupled diode laser which is then projected through a telescope[2]. This beam is reflected off the test mass and onto a quadrant photodiode to read out the position of the test mass. In order to increase the sensitivity of this setup, the laser that is projected through the telescope should be as close to a perfect gaussian as possible. To eliminate noise and produce this gaussian a single-mode optical fiber is used. However, the output of the optical fiber is not a perfect gaussian – the tails of the gaussian contain some noise and a ring appears around the spot of the laser beam.

It is speculated that the single mode optical fiber used actually carries more than one fiber mode due to the cladding of the fiber. It may be that the optical fibers used are only truly single mode over the distance over kilometers. The mode matching of the diode laser is also poor and the cladding layer of the fiber may also support guided cladding modes. If the cladding mode content is time varying, it can produce optical noise.

II. TASKS COMPLETED

The first portion of this experiment was to use a Thorlabs BP209-VIS beam profiler to profile a Helium-Neon laser. I measured the transverse mode structure of the HeNe laser at several distances away from the laser. The beam profiler has an adjustable gain. At lower gains, the entire transverse structure of the laser can be seen, but at the expense of seeing the tail of the gaussian which is what I'm interested in. If the gain is increased, the tails of the gaussian can be seen, but the peak of the gaussian cannot be seen since the photodiode in the beam profiler becomes saturated. Thus, I wrote a simple Python function that stiches together a saturated measurement where the tails of the gaussian can be seen and a measurement where the whole gaussian peak can be seen. I looked at these stitched together profiles at several distances away from the laser. One example of these stitched-together plots can be seen in Figure 1. Discontinuities in the data can be seen where the two data sets are stitched together. I will probably have to investigate whether these are caused by my algorithm being naive or slight variations in the data itself. That being said, I found that the HeNe laser had almost a perfect gaussian form, even in the tails of the gaussian. It didn't seem like the distance away from the laser mattered in terms of noise in the tails of the gaussian.

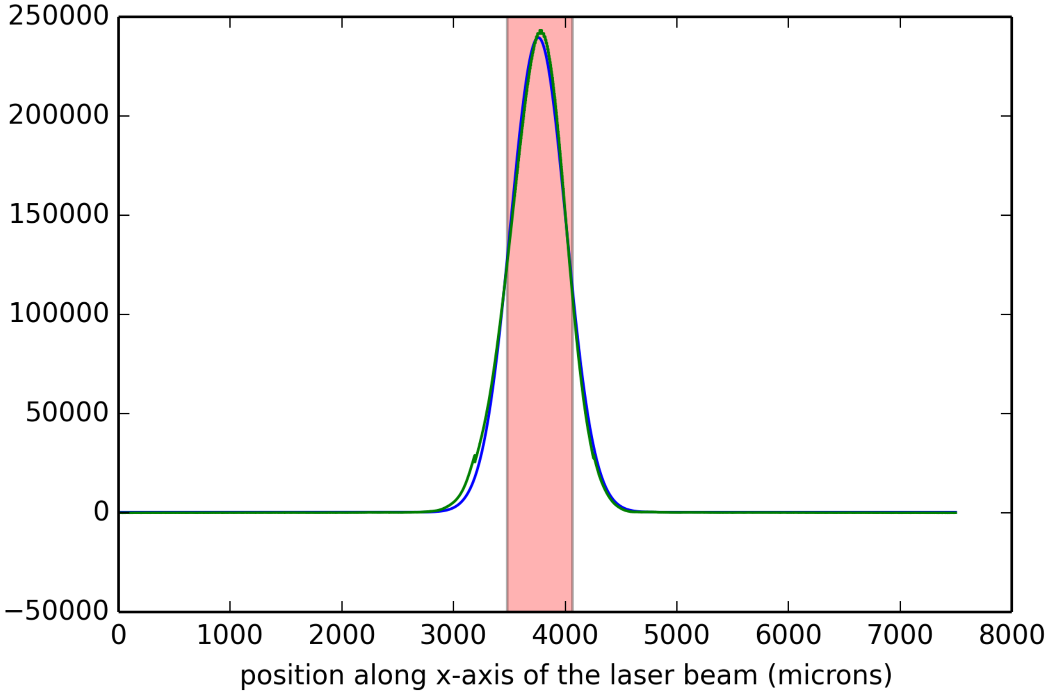

FIG. 1. Stitched together saturated and unsaturated plot is shown in green, a fit is shown in blue, and the full-width half-max is the red box. Discontinuities can be seen where the data are stitched together.

I then measured the transverse profile of the HeNe over a wider range of distances, ranging from right at the edge of the laser to about 1.3 meters away from the laser, but using only one gain setting. I wrote a Python function that fit a gaussian to each profile and another function that measured the width of the beam. I plotted the distance away from the laser versus the width of the beam and fit these data to the theoretical beam diameter. I found that my data fit fairly well to the theory. This plot can be seen in Figure 2 Using the fitted model, I found that the beam waist of the HeNe laser was 107.7 mm inside the body of the laser and the Rayleigh range of this laser was 867.7 mm.

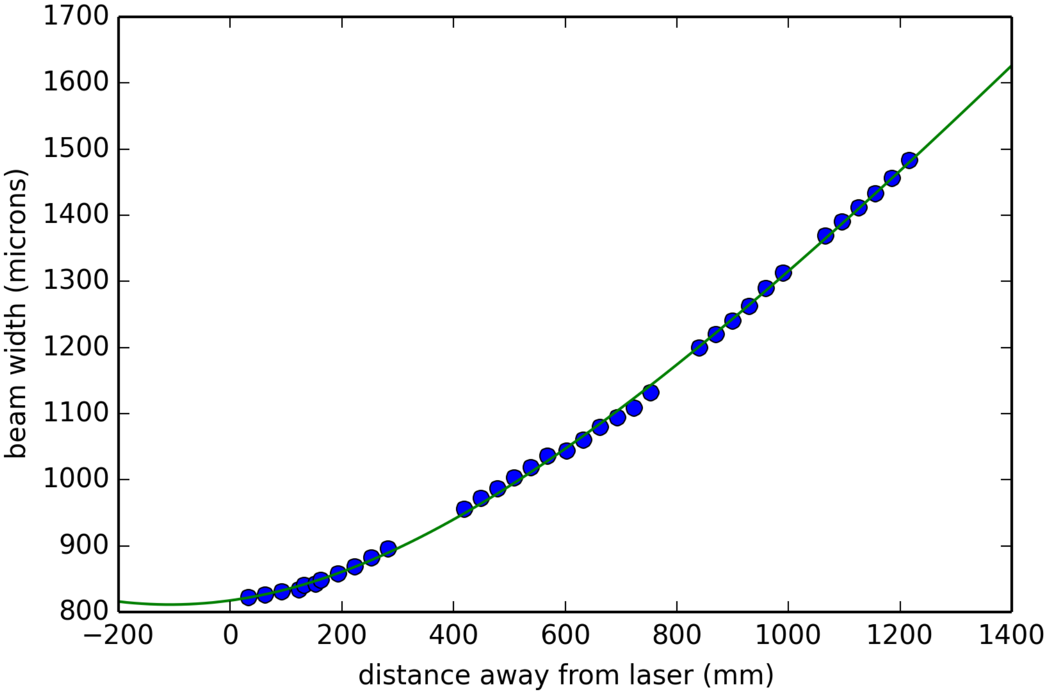

FIG. 2. Beam width of the HeNe laser at various distances away from the laser. The waist of the beam is located at 107.7 mm inside the laser body.

Next, I measured the width of the beam through a lens with focal-length of 200 mm. Obviously, I did not have to measure over as wide a range of distances as without a lens. Again, I plot and fit these data. This plot can be seen in Figure 3. Obviously, the beam should have the smallest width at the focal length of the lens. As shown in the plot, this is roughly the case. I had a bit of a hard time measuring the distance from the laser to the lens, and the distance from the lens to the beam profiler, since the only measuring tool I had was a crude tape measure. However, for the purposes of this experiment, it should be fine. The purpose of this experiment was to verify ABCD beam propagation, and I found I was able to model the beam using this technique.

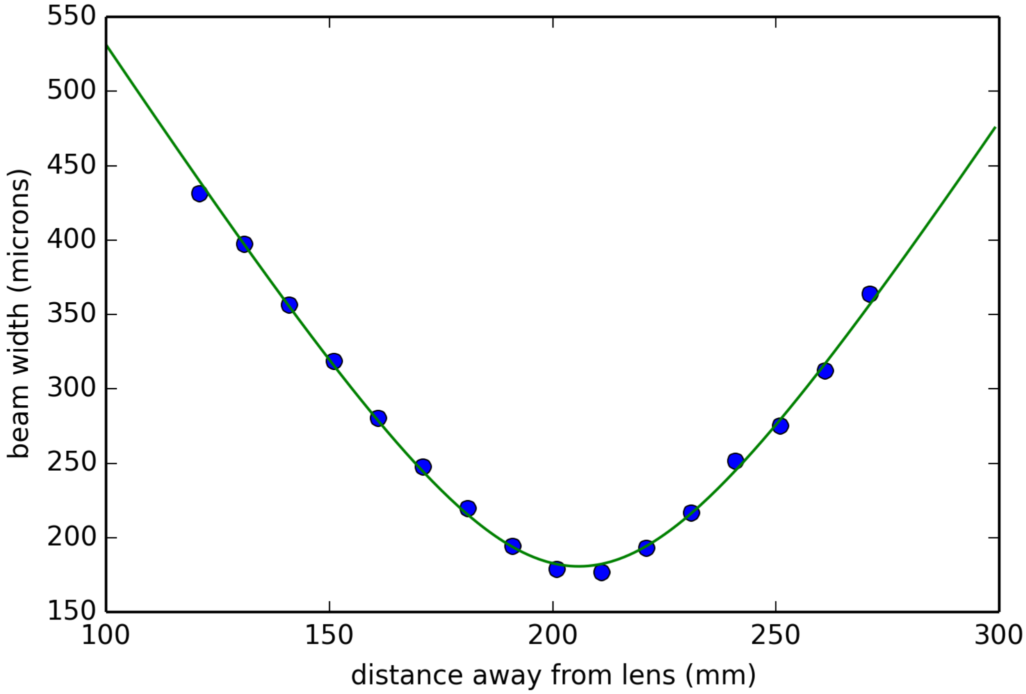

FIG. 3. Width of the HeNe laser after passing through a 200 mm converging lens.

Most recently, I attempted to profile the fiber-coupled diode laser that is actually used in aLIGO. However, I was not able to accomplish this for several reasons. First, the output of the fiber has a very large angle of divergence which means that the fiber has to be very close to the beam profiler. The problem with that was that I was seeing a lot of deformities in the beam profile that didn't move with the beam if I moved the fiber. I speculate that this is because there is a small metal ring that surrounds the output end of the fiber. This metal ring was not perfectly smooth, so I think that some reflections were coming off of this metal ring and causing the deformities in the beam profile. To solve this, I need a lens with a very short focal length such that I can collimate or focus the beam without it filling the lens. Unfortunately we didn't have this kind of lens available, so one is now on order. Once this lens has arrived, I will be able to continue this experiment.

III. WORK PLAN

Modeling the fiber and telescope system:

1. Use MATLAB FFT propagation code to propagate gaussian beam through fiber and telescope
2. See if noise appears near the edges of the gaussian
3. Change parameters to see if the ring around the center of the beam will appear in the theoretical model

Profile the fiber:

1. Use the same techniques from the HeNe profiling to profile the beam out of the fiber
2. See if extra noise appears in the tails of the gaussian

Try to remove noise from the fiber:

1. Use a razor blade to strip cladding off of one of the fibers
2. Pour index-matching fluid onto the exposed fiber core
3. Re-profile the beam using this fiber to see if any fiber modes have been coupled out

REFERENCES

[1] LIGO-T1000517-v5

[2] Engineering Note LIGO-E1300964- v1