LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Optical Lever: Signal Instabilities due to Power Fluctuation

Tara Chalermsongsak, Riccardo DeSalvo, Eric Black

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of the LIGO Laboratory.

California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

1 Introduction

The purpose of this work is to study the observed instability of the apparent beam spot due to the power fluctuation found in a pigtail fiber diode laser used as a light source for the optical lever system. The cause of the jump is presumably mode hopping in the laser. The effect can mimic tilt signals as large as 10 micro radians on the quadrant photo diode.

2 Experiment Setup

The laser source is a 675 nm wavelength laser photo diode [Thorlabs LPS-675 FC pigtail laser] with angle cut pigtail fiber which connects to a variable length test fiber, then to a Thorlabs CFC-11-B collimator which focuses and points the beam to a beam splitter. The transmitted beam goes to a quadrant photo diode [LIGO D980325], the reflected beam goes to a Prosilica GC1380 CCD camera. Two test fibers, 30m naked fiber and 100m jacketed fiber, will be used to compare and determine if the length of the fiber will have any effects on the result. The laser is mounted on a heat sink support [Thorlabs TCLDM9] and powered by a current stabilized (or light power stabilized) controller [Thorlabs ITC502]. The controller is driven by a function generator to modulate the input current in a triangular shape. The minimum and maximum currents are 30 and 34 mA respectively, which drives the laser within its linear region (see figure 2), with 1 mHz frequency. The spot diameter is focused to around 0.8 mm, and pointed at 100 microns away from the quadrant photo diode's center on x and y directions.

In this test we used the laser driver in current stabilized mode.

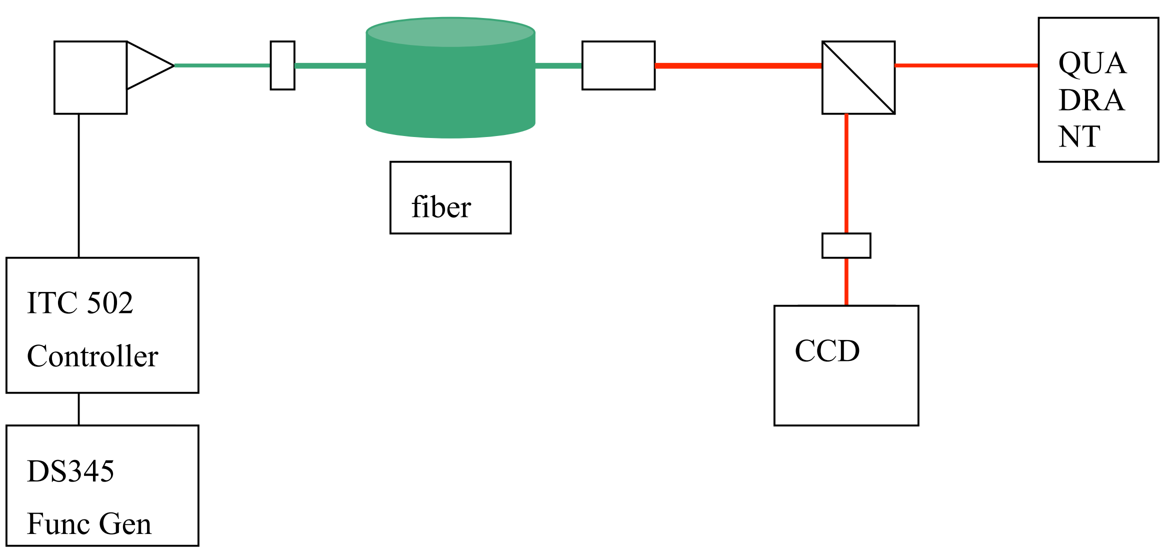

Fig 1: The experiment setup, the distances from the source to the quadrant photo diode and CCD are 2.0 m. The fiber (in a spool) can be changed between 30m or 100m.

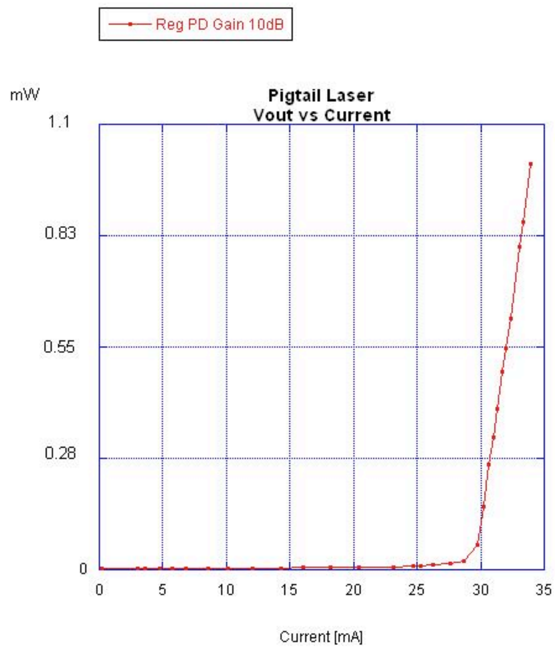

Fig2: laser power output versus input current. The laser is modulated between 30 and 34 mA, which is above the threshold current.

3 Result

The laser spot is positioned 100 micron off the center of the quadrant photo diode both in the vertical and in the horizonthal direction. In the quadrant photo diode, we denote R, L, T and B the sum of the two right, left, top and bottom quadrants respectively and the total voltage output (Vsum) of the beam is the sum of the voltage output from all 4 quadrants. X and Y positions are calculated from (R-L)/(R+L) and (T-B)/(T+B), then multiplying by its corresponding calibration, obtained by micrometrically moving the spot over the quadrant photo diode to obtain a measurement in millimeters. The CCD is used in fixed sensitivity mode. On the CCD, the data is processed by a Gaussian fit algorithm [Lottarini, T0900477] applied on a restricted area which removes Airy rings around the beam. The program calculates the light amplitude, in arbitrary units between 0 to 255, as the Gaussian fitted peak value (amp). It also calculates the fitted x and y positions, and beam size on x and y axes (sig x, sig y.) in pixels, which then are multiplied by the pixel size to get the measurements in millimeters.

3.1 30m fiber test

The total power of the beam on the quadrant photo diode and the CCD roughly follow the triangular input pattern (with minima at 420 seconds and maxima at 820 seconds. Jumps occur at repeatable power levels, for example around t = 600s and 800s, from the quadrant photo diode read out, but there is no clear power jumps seen on the CCD.

Note that the CCD program removes most of the effects of the Airy rings, while the quadrant photo diode integrates over them, one might conclude that some instability, possibly mode hopping, in the diode laser changes the injection pattern in the fiber modes, and therefore the light output spread angle at the end of the fiber (despite the fact that the fiber is nominally a mono mode fiber) and funnel a varying fraction of light power in the Airy rings.

In a separate measurement we found that the fiber length (5 to 100 m) has little effect in attenuating the Airy rings. Note that the fibers are mostly designed to be single mode in the infrared, they are rated for guaranteed high transmittance (measured in kilometers) in the central mode, but may easily have very large attenuation length also in the first transversal mode.

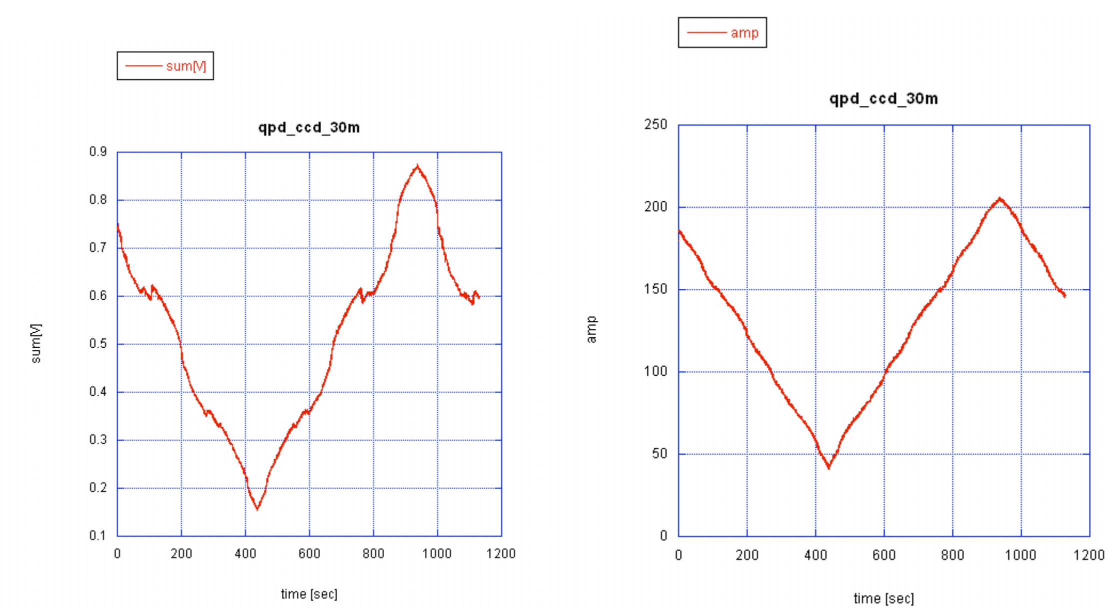

Fig3) Power output vs. time as measured by left, quadrant photo diode, right, CCD.

In correspondence of the power jumps, we observe fluctuations in the reconstructed beam spot position in both quadrant photo diode and CCD (fig4) with much larger amplitudes in the quadrant photo diode. The fluctuations are reproducible when the input current is changed back and forth. Notice the symmetries around 450s and 950s, when the power reaches the minimum and maximum. This suggests that the position change and the input power are highly correlated, very likely through the light changes in the Airy rings.

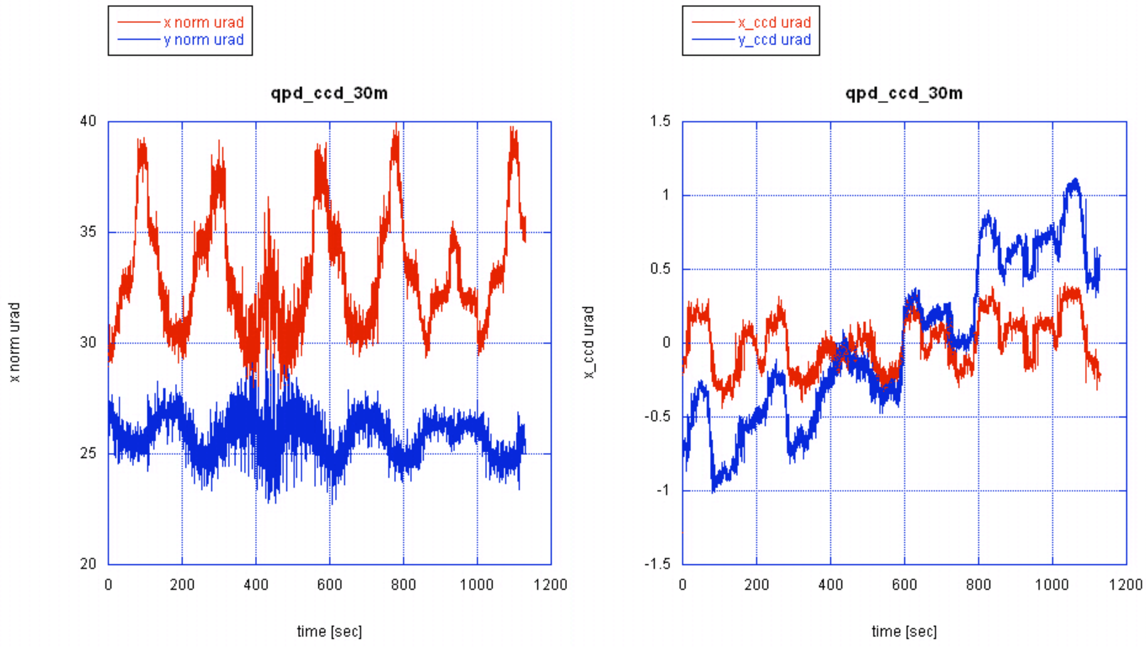

Fig4) X, Y positions (micro radian) as seen by a) quadrant photo diode (+/- 10 urad) b) CCD (+/- 0.5 urad). The small drift in the vertical direction observed by the CCD, possibly a stand drift, may easily be hidden within the larger fluctuations recorded by the quadrant photo diode.

The position of the instabilities as observed from the quadrant photo diode and the CCD also coincide, but the quadrant photo diode has higher amplitude (Fig5.)

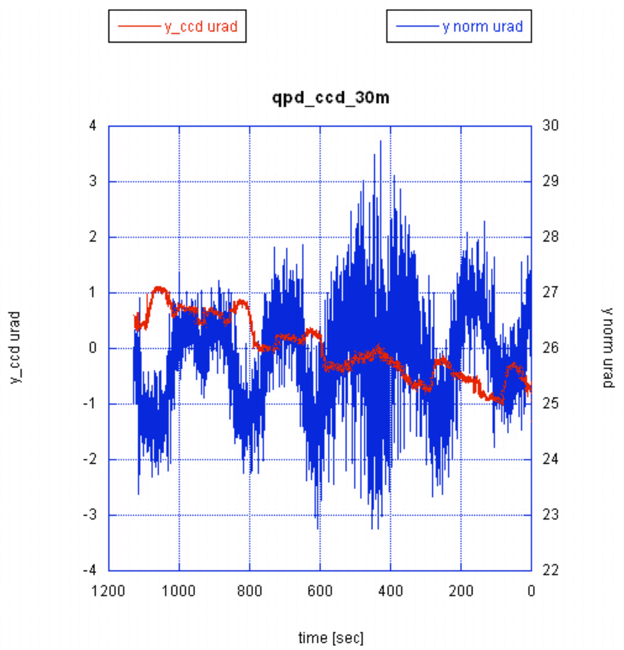

Fig. 5) Comparison between QPC and CCD readout Y positions.

The beam spot sizes fitted over the CCD images, Wx (sig x) and Wy (sig y) track each other well. A 2% beam size change is observed, roughly tracking the beam power. The jumps (deviations from triangular shape) in the beam size again at determined power levels, corresponding to the reconstruction position instabilities (see figure 7) and might occur because of laser mode hopping (fig6.)

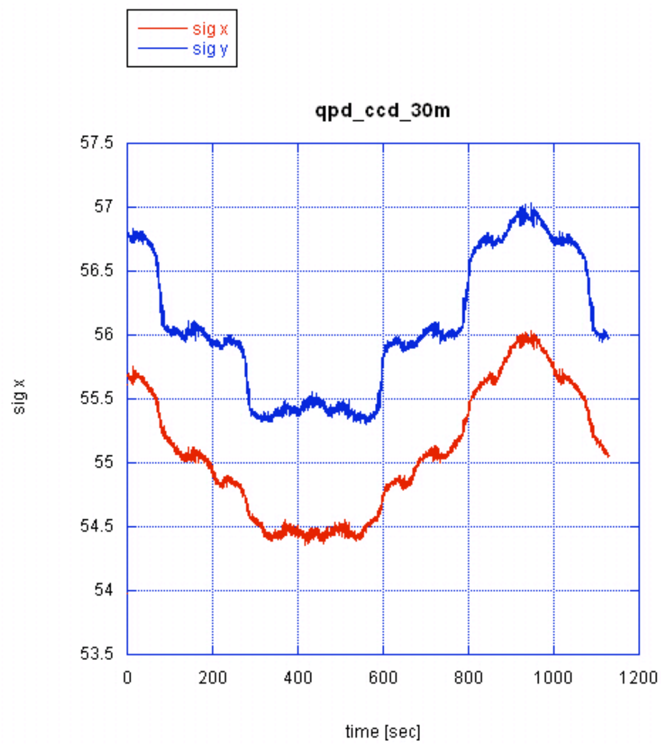

Fig.6) spot size on x and y directions from CCD.

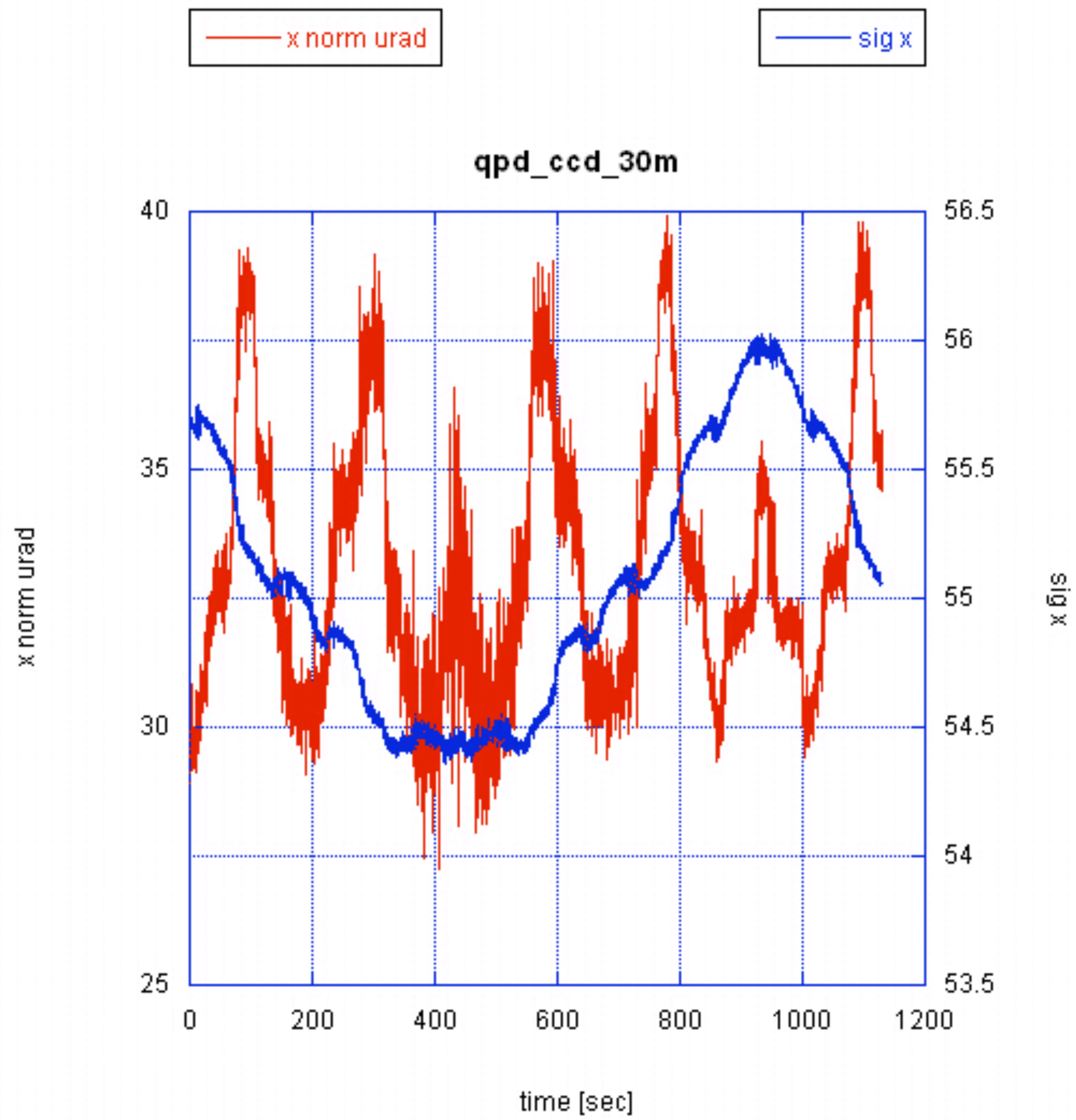

Fig.7) Plot of apparent beam x position and as seen from quadrant photo diode and the spot size from CCD. The jumps on both plots are strongly correlated. There are also symmetries on maxima and minima of the modulation (around 450 s and 950 s)

3.2 100m fiber test

The same measurement is repeated, with a 100m fiber. The overall results are quite similar to those of 30m fiber. With 100m fiber, jumps of the total power are observed in both quadrant photo diode and CCD (Fig. 8,) X,Y position fluctuations magnitude are comparable on quadrant photo diode and a little larger on CCD (Fig. 9,) and the correlation between the position fluctuation and spot size is very clear (Fig. 11.) In addition, a longer fiber doesn't seem to reduce the effect.

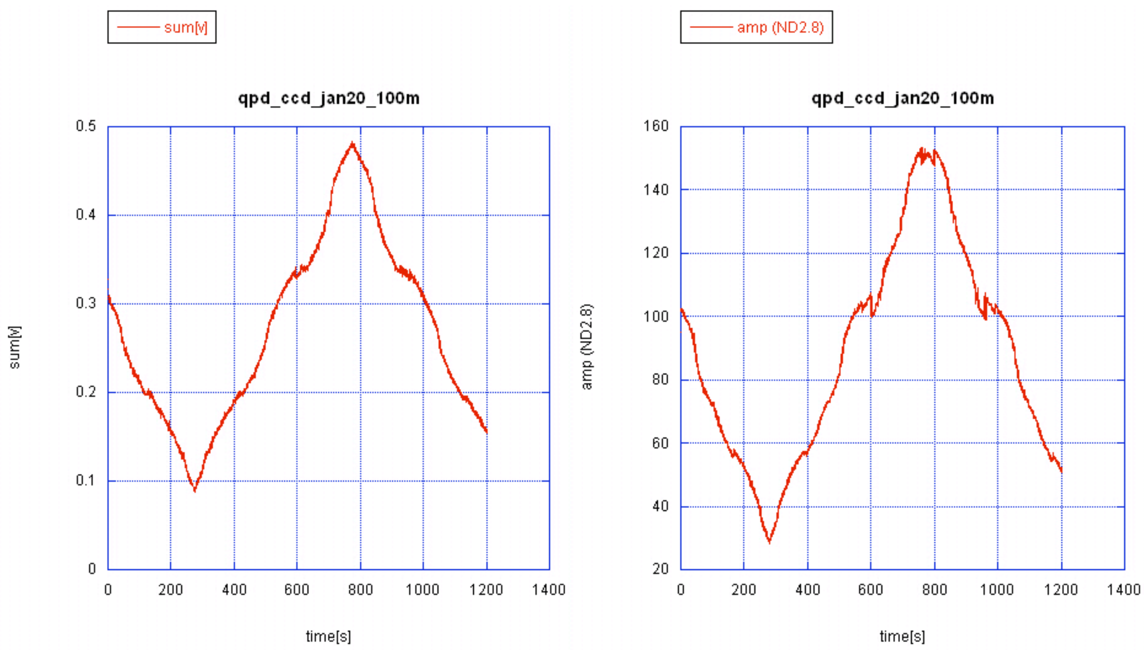

Fig8) a) sum from quadrant photo diode b) amplitude of Gaussian beam from CCD. This time the CCD also clearly sees jumps.

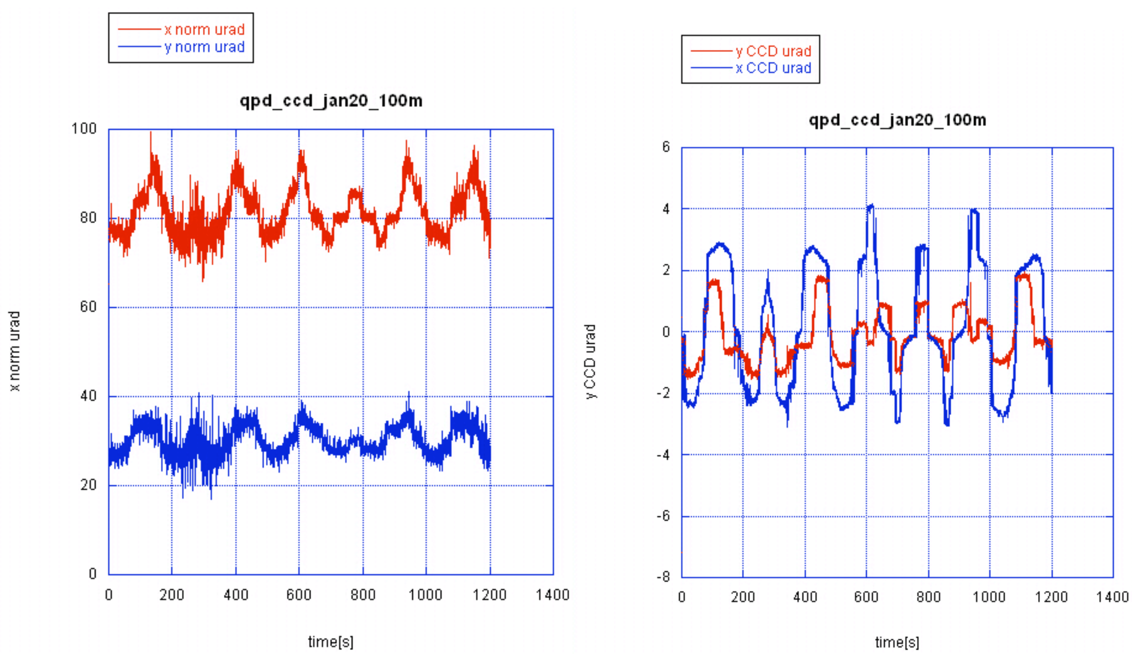

Fig. 9) Normalized beam positions a) quadrant photo diode (+/- 10um) b) CCD (+/- 2um). The longer fiber produces larger fluctuations on both quadrant photo diode and CCD readouts (see

Fig2). The reconstructed position errors of the CCD remain mush smaller than those of the quadrant photo diode (figure 10).

As before the reconstructed position jumps occur in correspondence of the spot size variations (figure 11).

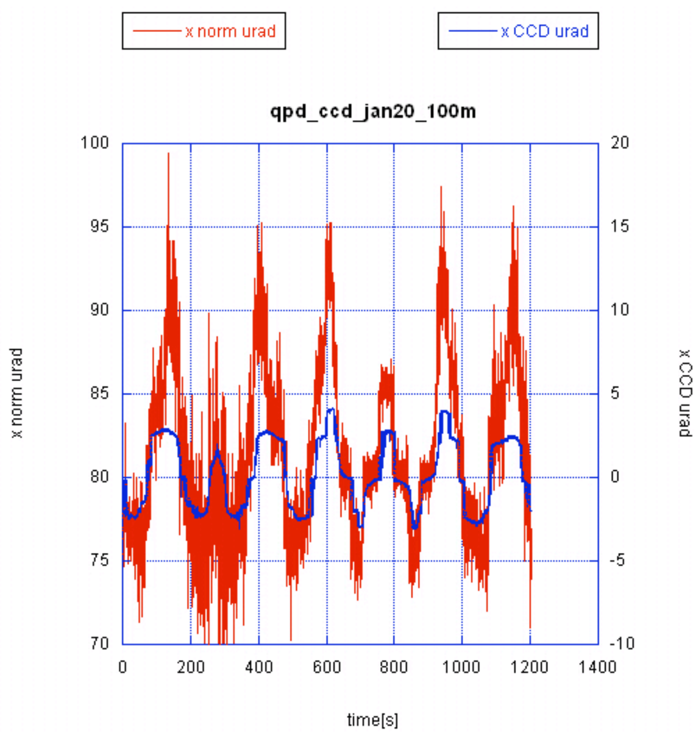

Fig. 10) Comparison between quadrant photo diode and CCD position readouts

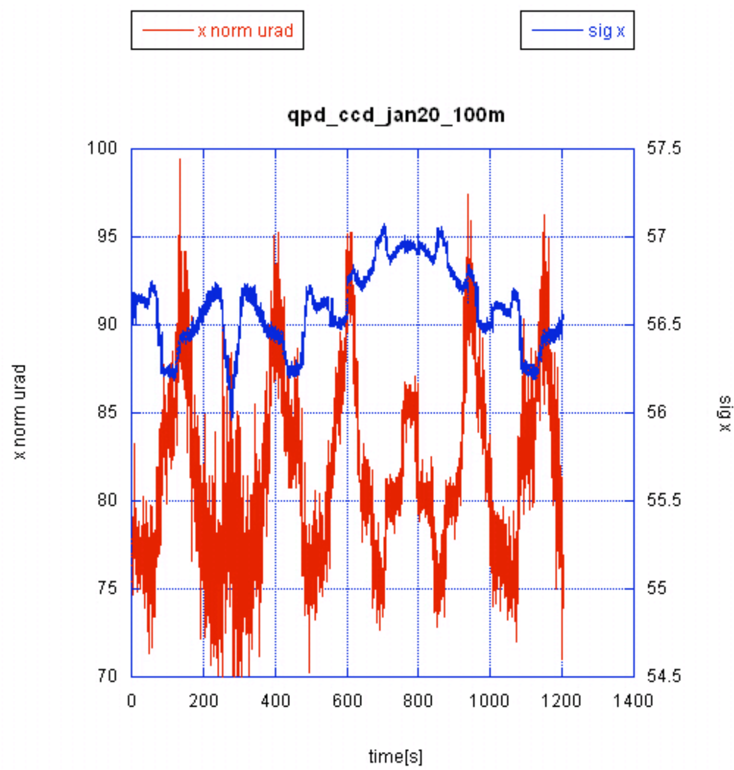

Fig. 11) Plots of beam x position from quadrant photo diode and the spot size from CCD. Notice that the jumps occur simultaneously on both plots.

4 Conclusion

Instabilities, likely mode hopping, in the laser observed when the drive current is changed can cause the change of the spot size and normalized position readout. The reconstructed position error vanishes if the spot is centered on the quadrant photo diode.

Because over time other causes, other than drive current variations, may cause these instabilities, the fiber pigtailed diode lasers are deemed unsuitable as a light source for precision optical levers.