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**Test on Super Luminescent LED as a Light Source for
Optical Lever System**

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1 Introduction

Due to the instability found in a laser diode [LIGO T1000070-v1], Super Luminescent Light Emitting Diodes (SLEDs) was considered to replace the diode lasers for LIGO optical lever system. This document reports tests on SLED's stability over power fluctuation, 65-hour stability, and stability under mechanical vibration.

2 Experiment Setup

The light source is a Qphotonics ASDM-680-2 SLED. Other equipments and setup follow the experiment in LIGO-T-1000070. The beam is focused and pointed to a 50% cube beam splitter. One beam goes to the quad photo diode, another beam goes to the CCD.

To study the effect of the spot size change on the reconstructed position (previously observed with the laser light source), the beam on the quadrant photodiode is positioned off the center by 100 microns from the center on both x and y directions. The input current is modulated with a triangular function between 130 – 150 mA so that the output power varies between 0.30 – 0.83 mW, the same as the laser power output swing used in T-1000070.



Fig. 1 Qphotonics SLED connected to an APC pigtail fiber.

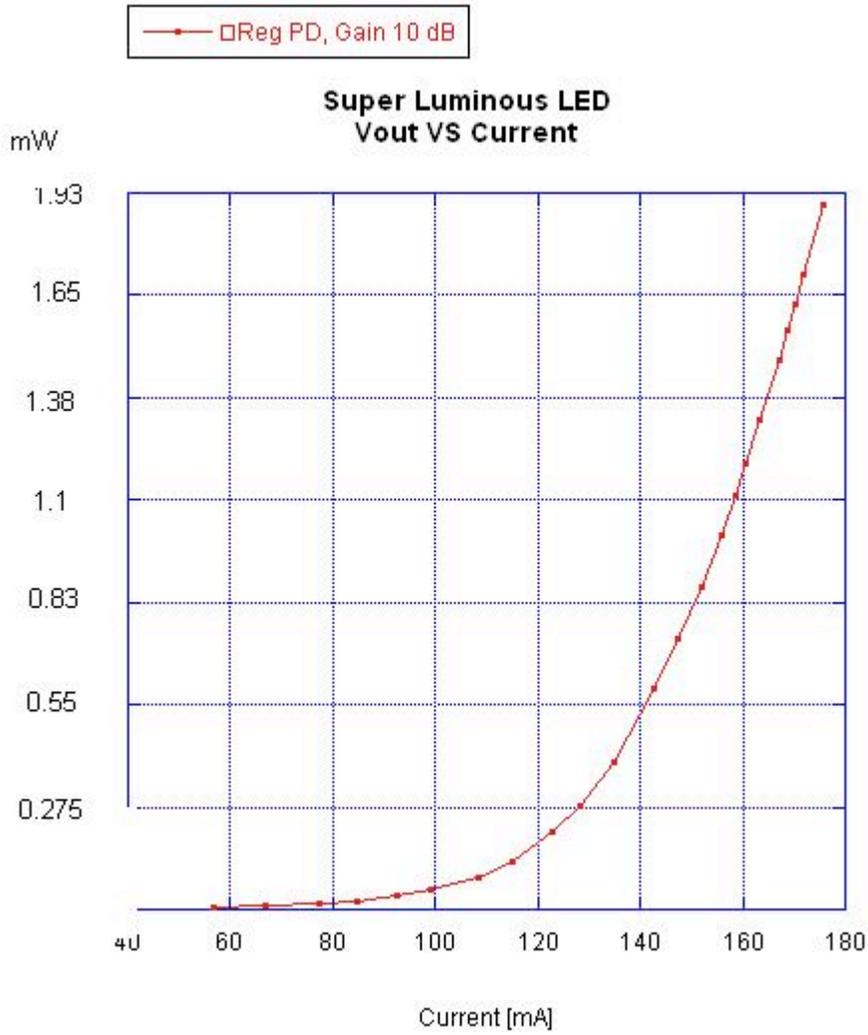


Fig. 2 Power output as a function of input current. The drive current is modulated between 130-150 mA to achieve the same power output swing used in LIGO T1000070-v1.

3 Results

3.1 Stability During Power Input Fluctuation

The current is modulated by a 1 mHz triangular function. The smooth change of the total power is observed on both the quadrant photodiode and the CCD (see fig3 (a) and (b)). The power reaches minimum and maximum at 250 and 750 seconds respectively.

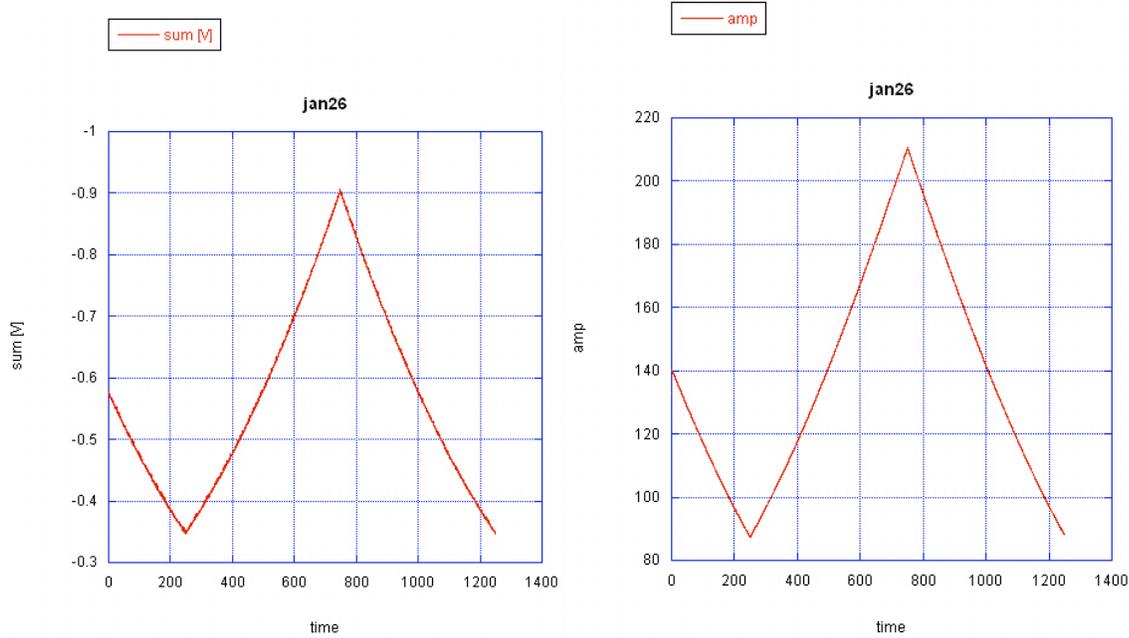


Fig. 3 Total power as measured by (a) sum of QPD's 4 quadrants (b) CCD.

X and Y normalized positions are reconstructed (fig4.) Aside from the drift at the beginning, there is no evidence of the fluctuation associated with the triangular current modulation with minimum at 250 s and maximum at 750 s. The stability from LED is much better than the laser, which fluctuates up to 10 μ rad [T1000070-v1].

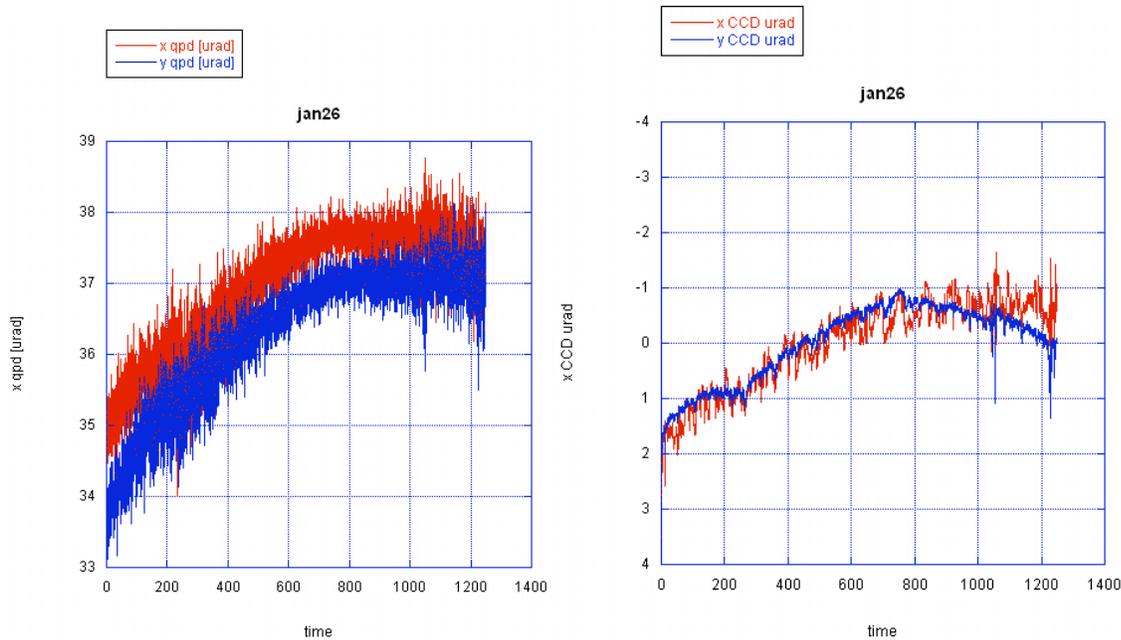


Fig. 4 X and Y positions in micro radian from (a) QPD, (b) CCD, both plots show 3 micro radian drift.

The fitted spot size is recorded. The change is smooth and follows the current modulation¹(see fig. 5.) This implies a better stability during current drifts.

¹ The actual spot size may only change a bit or not changing at all. This might be a problem with the fitting algorithm that does not take properly into account the residual ambient light and the dark current in the CCD as the signal changes by a factor of three. This effect would be inconsequential in actual operation. See Appendix 1.

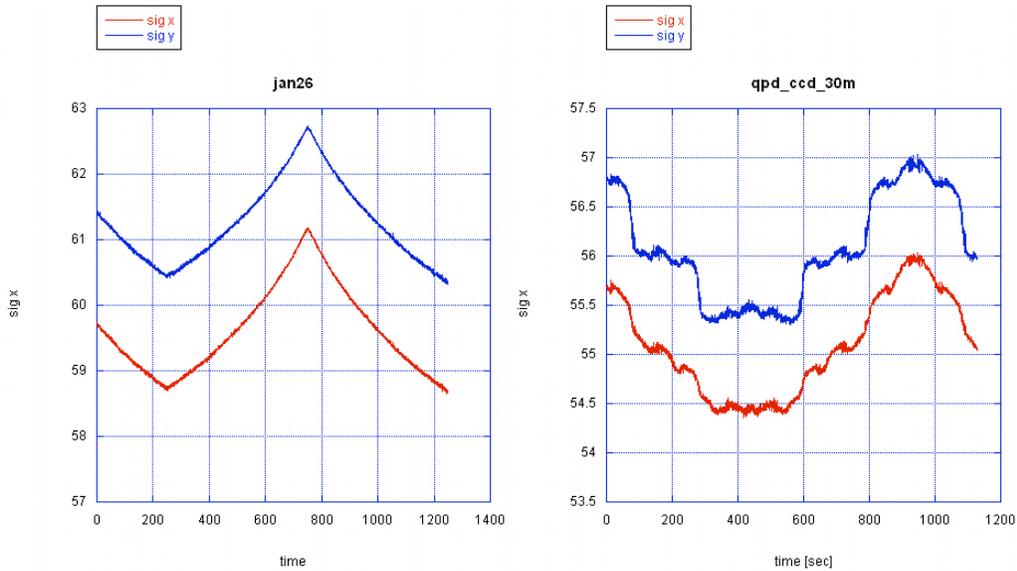


Fig5) Spot size vs time recorded by the CCD when the source is (a) LED which has a smooth change, compared with the case (b) of optical lever driven by pigtail diode laser (taken from LIGO T1000070.) The jumps observed with the laser light source at several current levels are not visible with the S-LED.

The jumps of spot size that occur in the diode laser (fig. 5b) cause fluctuations in the reconstructed positions. Fig7 below show how the apparent beam spot position with out normalization moves when the current is changing. The screen displays the un-normalized quad photo diode's right minus left signal on x-axis, and top minus bottom signal on y-axis. This should produce a straight diagonal line in a perfect system extending from the center (0,0).

The trace displays how the un-normalized apparent beam position moves as the power increases and decreases. The result from the SLED on fig. 6a agrees precisely with the prediction. The trace of the laser has a lot of deviations from the straight path. These deviations are reproducible and attributed to spot size variations after the supposedly single mode fiber from mode hopping in the laser.

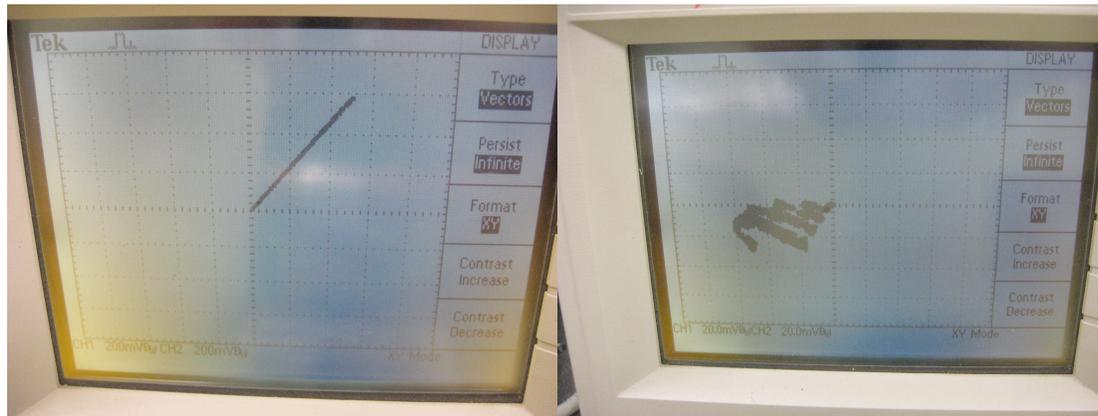


Fig. 6 Apparent beam spot as seen on the oscilloscope when the spot is near center and the power is modulated by the triangular function of fig. 4 with out normalization from (a) SLED, (b) the diode laser.

3.2 Stability over 65 hours

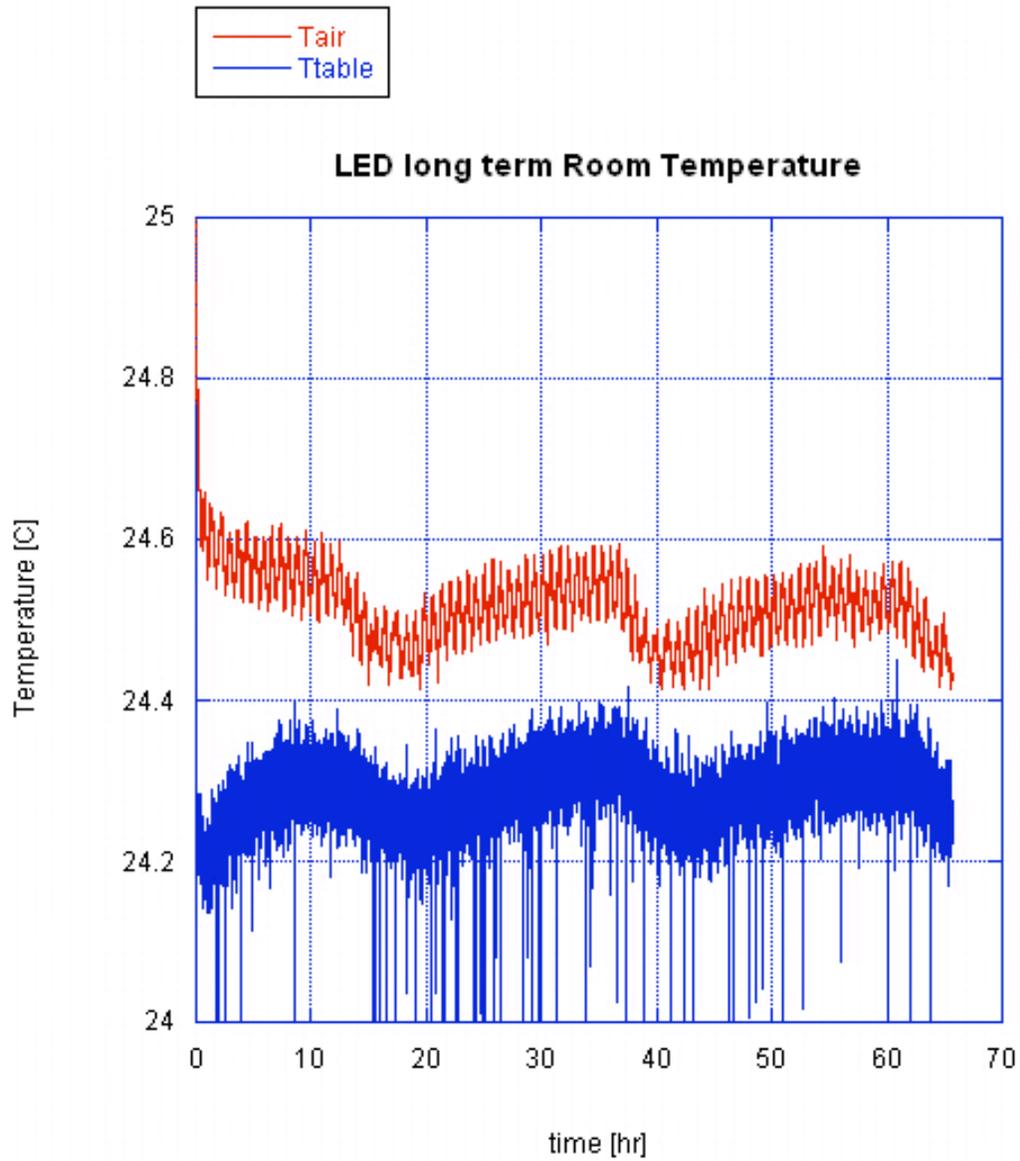


Fig 9) Temperature of the room air (red) and the optical bench (blue) over 65 hours. The room air condition is the only thermal control in the setup.

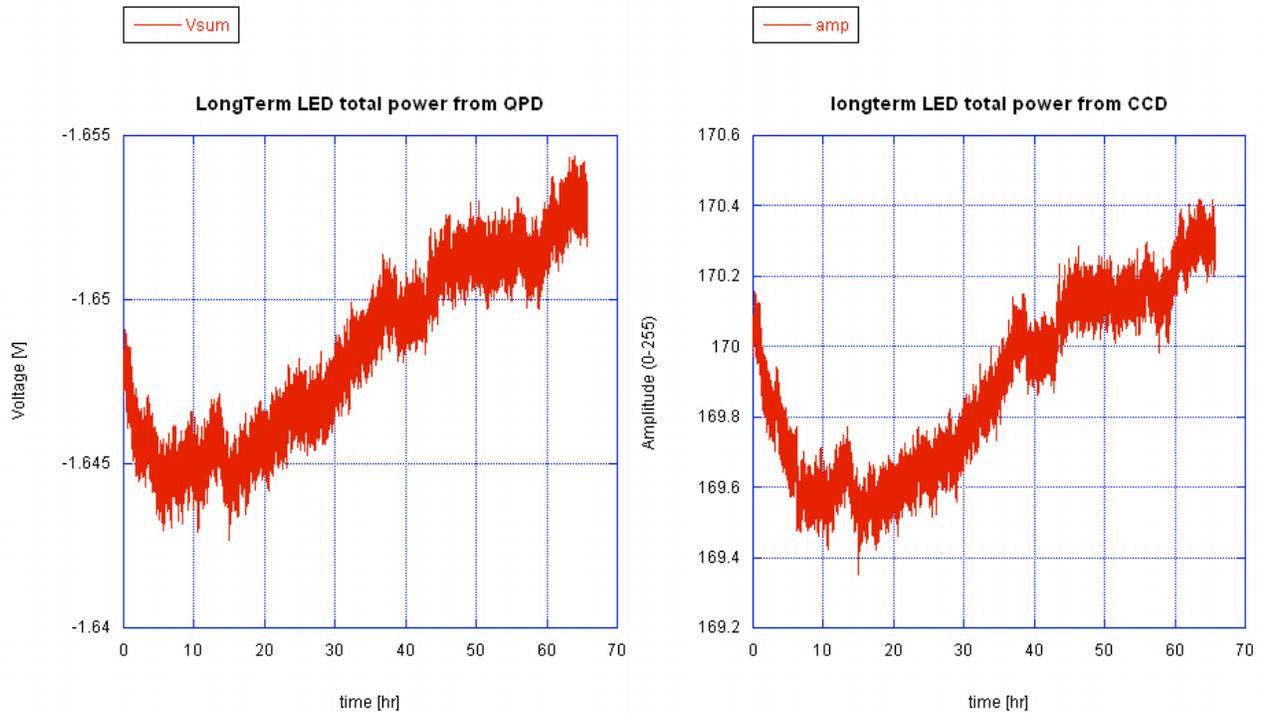


Fig.10 Measurement of total power from (a) the quadrant photo diode, the drift is about + 0.6% of the total power, (b) the CCD, the drift is about + 0.5% of the total power.

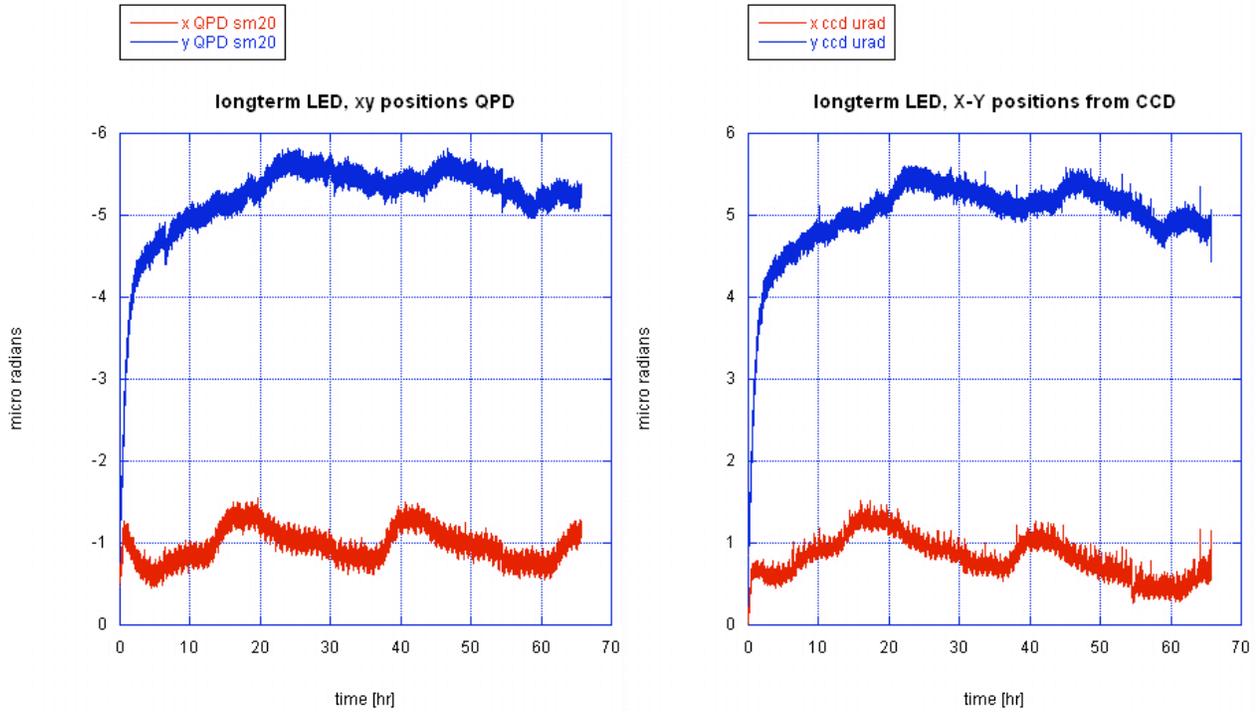


Fig. 11 X and Y positions in micro radians from (a) QPD, (b) CCD. Both plots track each other very well. Aside from the initial vertical drift, which is probably due to the fiber relaxing stress and applying weight to the telescope mount, the fluctuation is within 1 micro rad and mostly caused by thermal change (see fig. 9).

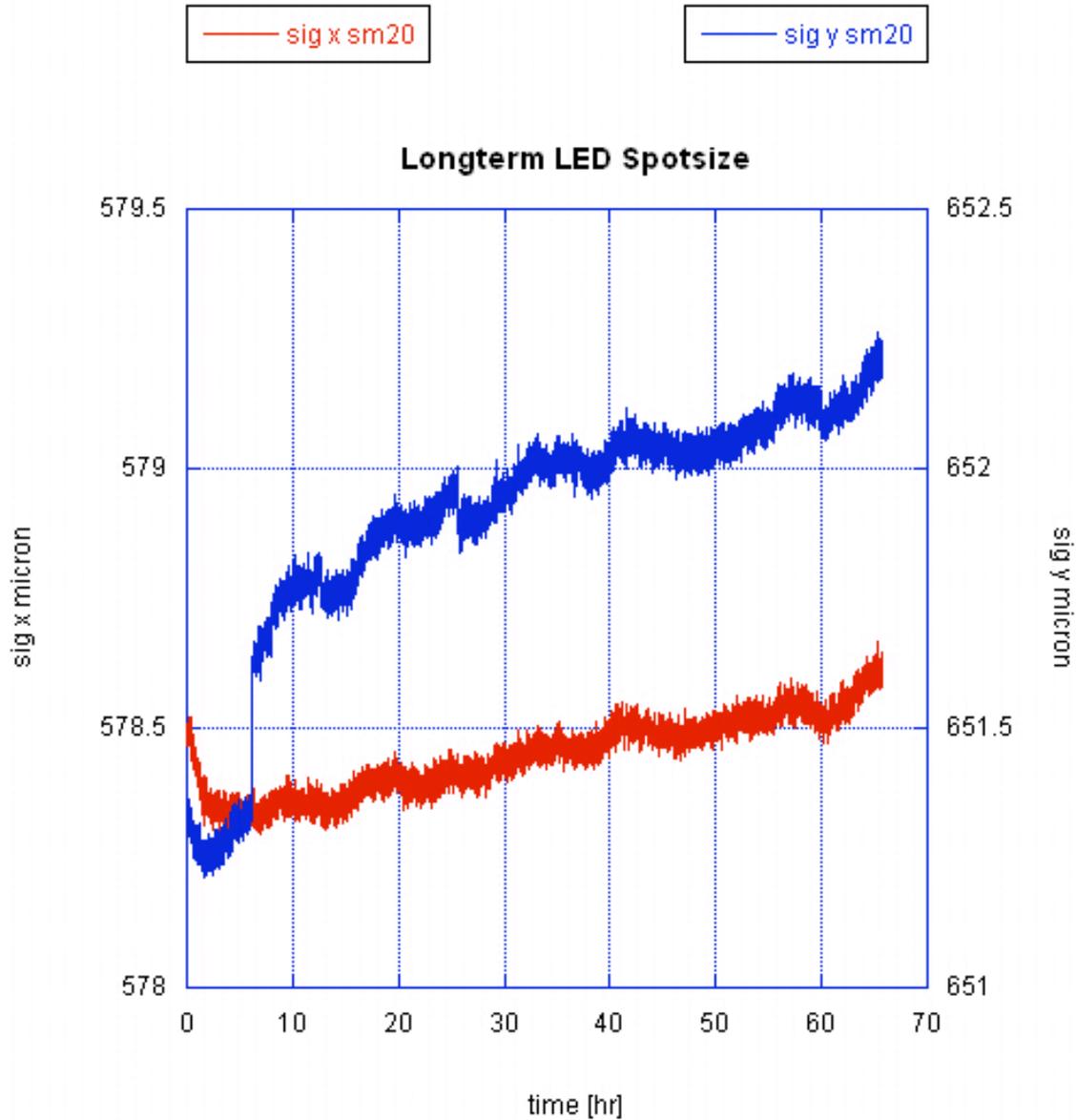


Fig. 12 Spot size as measured by CCD in microns.

3.3 Stability under vibration

The experiment setup is similar to the setup from T0900651-v1. The 5m test fiber is shaken by a loud speaker at different frequencies when the beam points to the quadrant photodiode.

The total power output, x and y positions are immune to vibration on the fiber (see fig. 13 and 14 below.) Since APC connector should eliminate the back reflection, and the SLED should not be effected by the back reflection, the disturbance from the vibrations should be negligible.

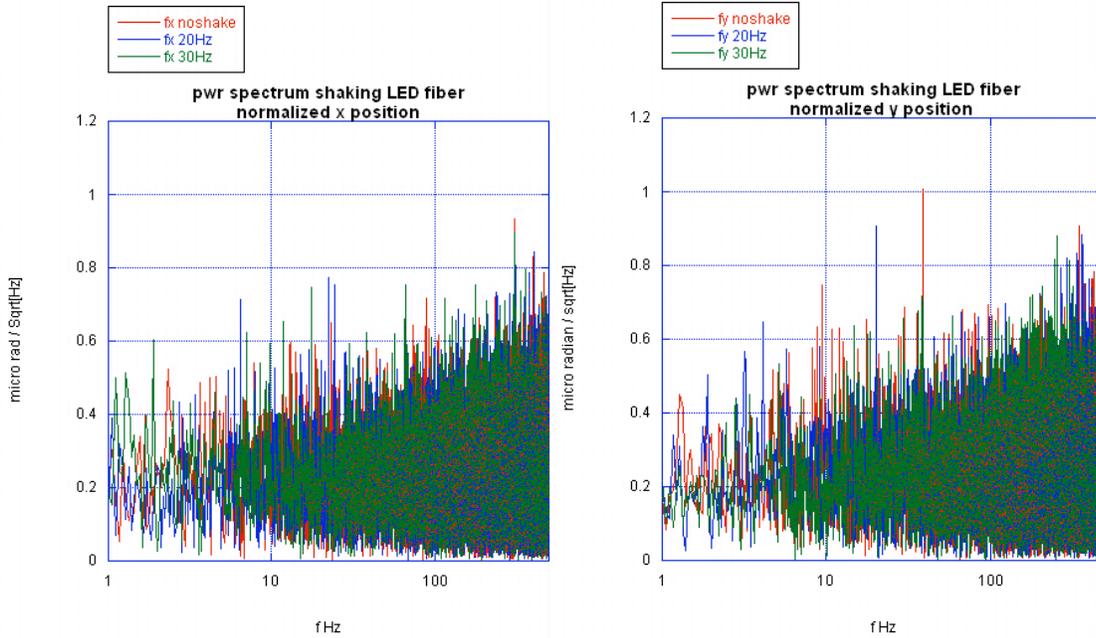


Fig. 13 Power spectrum from X and Y position. Red plots are the signals when the fiber is not shaken. Blue and green plots are the signals when the fiber is shaken at 20 and 30 Hz respectively. There is no significant effect from the shaking.

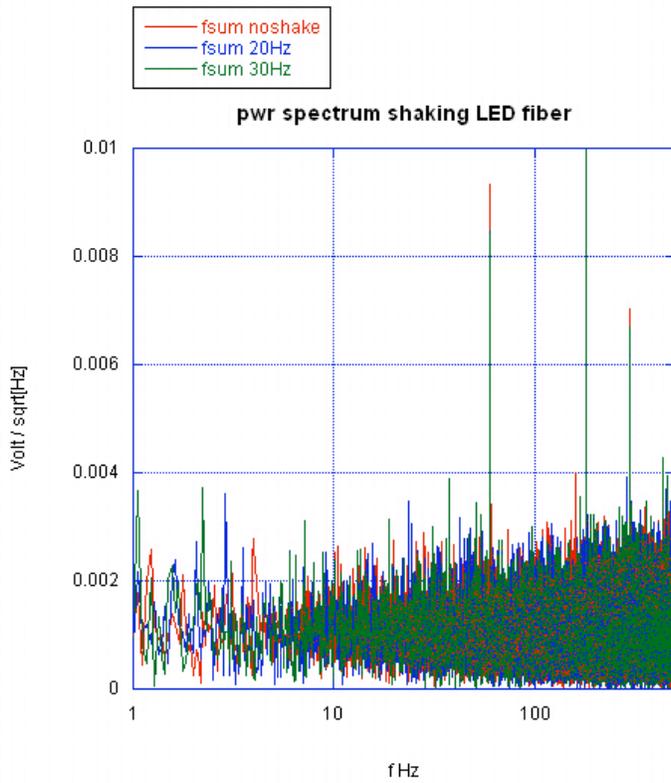


Fig. 14 Power spectrum of the total power. The vibration has no significant effect on the total power either.

3.4 Test at LHO

Following these tests a Superluminescent photo diode was implemented in H2, replacing the laser of the Beam splitter optical lever.

The LED was tuned at 217.1 mA to match the light output of the laser.

The idea is to make sure that the LED powered optical lever has no worse noise performance than the laser powered one.

The comparison in fig. 15 appears to confirm this fact

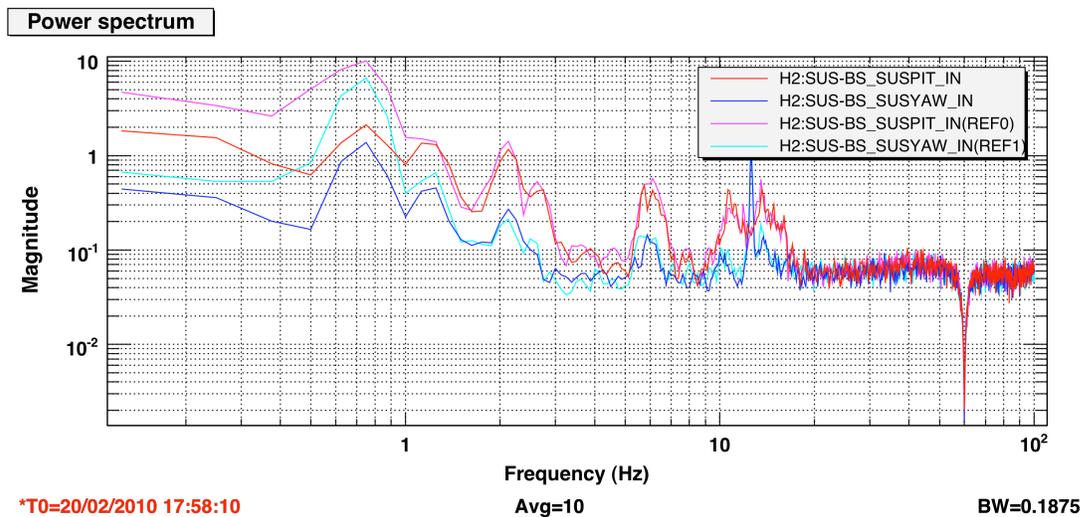


Fig. 15 Power spectrum of pitch and yaw signals between a laser diode and an SLED. Noise floors from both sources between 1-100 Hz are comparable, and the SLED has lower noise below 1 Hz.

The Superluminescent LED was left in service at LHO.

If any optical lever laser in H1 will fail, the LED will be switched in place as a test.

4 Summary

SLED is immune to the instability due to the input current fluctuation. Its pointing stability over 65 hr seems to be comparable to that of a diode laser. Its lifetime is yet to be verified. Therefore, SLED is possible to be a diode laser replacement for the Advanced LIGO optical levers.

Appendix 1

In this experiment, the beam size, recorded by the CCD and processed by a Gaussian fit algorithm, appears to change along with the input current, as seen from fig. 6a. However, when the current is kept constant, and neutral density filters are used to attenuate the beam, the spot size from the fit algorithm also changes along with the attenuated power (see fig 16.) The cause is yet to be determined. A likely cause is that the leakage ambient light onto the CCD forms a constant baseline level, which is imperfectly taken into account by the Gaussian fit applied over the beam spot shape which is probably an Airy function weighted by the angular light distribution exiting the fiber.

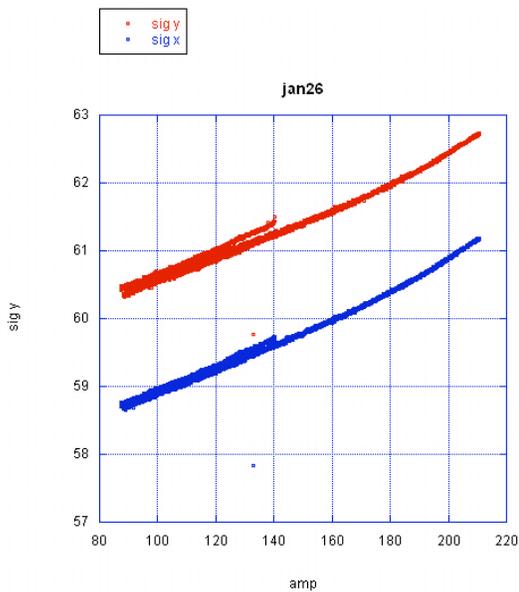


Fig. 16 Plot of spotsize (pixel) computed from the algorithm vs received power on the CCD (amp). The data are taken from fig 3b and fig 5a. As the input current changes, the fit algorithm sees the spot size changing.

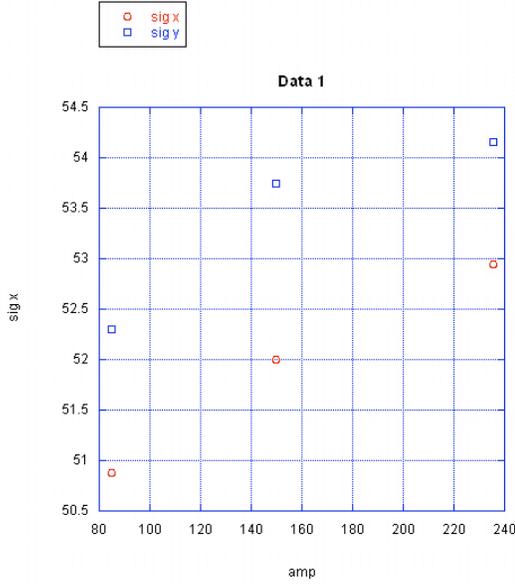


Fig. 17 Spot sizes (pixel) computed from the fit algorithm versus received power on the CCD (amp) with the attenuated beam. The input current is kept constant, different neutral density filters are used to attenuate the beam from 84 to 235 amp. The slope of the spot size change reconstructed by the Gaussian fit is comparable to the data on fig 16.

This indicates that the source of the apparent spot size growth with larger power may be originating from trivial baseline problems

To verify that the ND filters do not alter the spot size, and that the change of the spot size is actually a result of the fitting algorithm, the spot size is reconstructed from the response of the quad photo diode as the spot is scanned across the quadrant diode midline. For a perfect Gaussian beam, if the beam is moved horizontally across the quadrant photo diode, the normalized voltage output (sum on the right side minus sum on the left side, divided by sum of the 4 quadrants, $(R-L)/S$) versus the distance from the center of the QPD will be

$$V_{\text{norm}} = \text{ErrorFunction}(\sqrt{2} d / w)$$

When d is the distance from the center, w is the spot size where the power is drop by e^2 from the peak. Differentiating V_{norm} with respect to the distance to get the slope of the signal from $(R-L)/s$ at the center, which is

$$\sqrt{8/\pi} / w, \text{ or approximately } 1.6/w$$

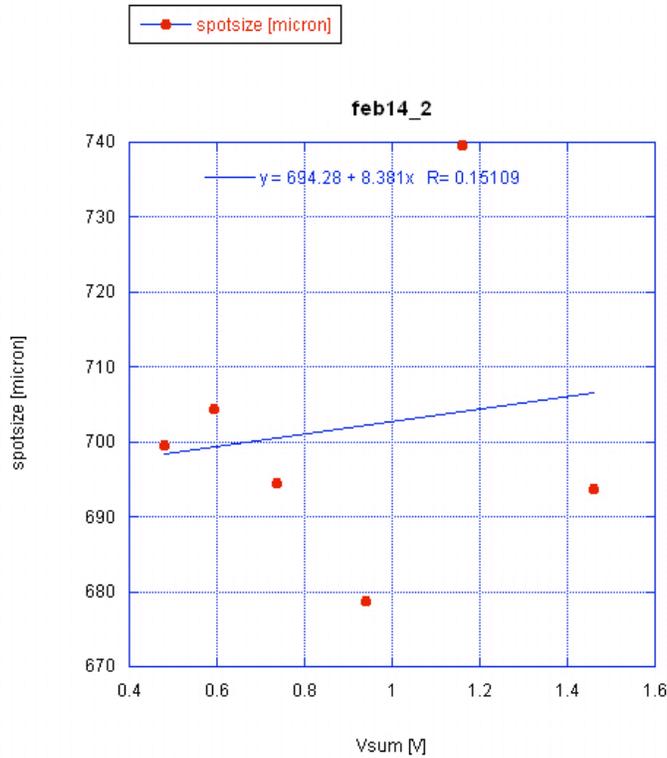


Fig. 17 Reconstructed beam spot vs Vsum on the quadrant photo diode.

The input current is kept constant, and the ND filters attenuate the beam to different levels. The spot sizes from various attenuated powers are then reconstructed. There is no significant variation of the actual spot size associated with the level of the received power (see fig 17.)

We have seen that for a constant input current, using different ND filters to vary the power of the beam, the spot size analyzed from the CCD changes with the power of the total beam, while the spot size analyzed from the quadrant photo diode does not. Hence, we are quite certain that the observed variations of calculated spot size from the fitting algorithm are not due to actual beam spot size variations. The problem in the algorithm will be investigated.