LIGO SURF Progress Report II: Squeezer

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1 Current Progress, Observations, Problems

1.1 Cavity Lock

The Pound-Drever-Hall servomechanism has finally been stabilized to an acceptable level, locking close or at the peak transmission of the TEM 00 resonance. There was one problem with the Stanford Research Systems function generator which contaminated the electronics (specifically the photodetectors) with residual RF (oscilloscope trace exhibited oscillations at EOM frequency even without any laser light hitting the photodetector. The second problem was high frequency jitters in the RF range that the SR560 pre-amplifier probably could not filter out. A low-pass filter from Mini-Circuits with a cutoff of 1.9 MHz was employed (originally, 30 and 50 BLP filters were used, but the cutoff was probably too high) With both those issues resolved, the optics set-up can now stably produce green-light on the time scale of hours with the max be (longer measurement still has to be completed) with power fluctuations of 0.5 mW for an output beam of 25 mW. For future reference, the settings on the pre-amplifier are important to maximize performance:

- High Dynamic Reserve
- Low Pass filter at 1 hertz
- DC coupling

- Invert off (invert will change sign of control signal

1.1.1 Cavity Monitoring

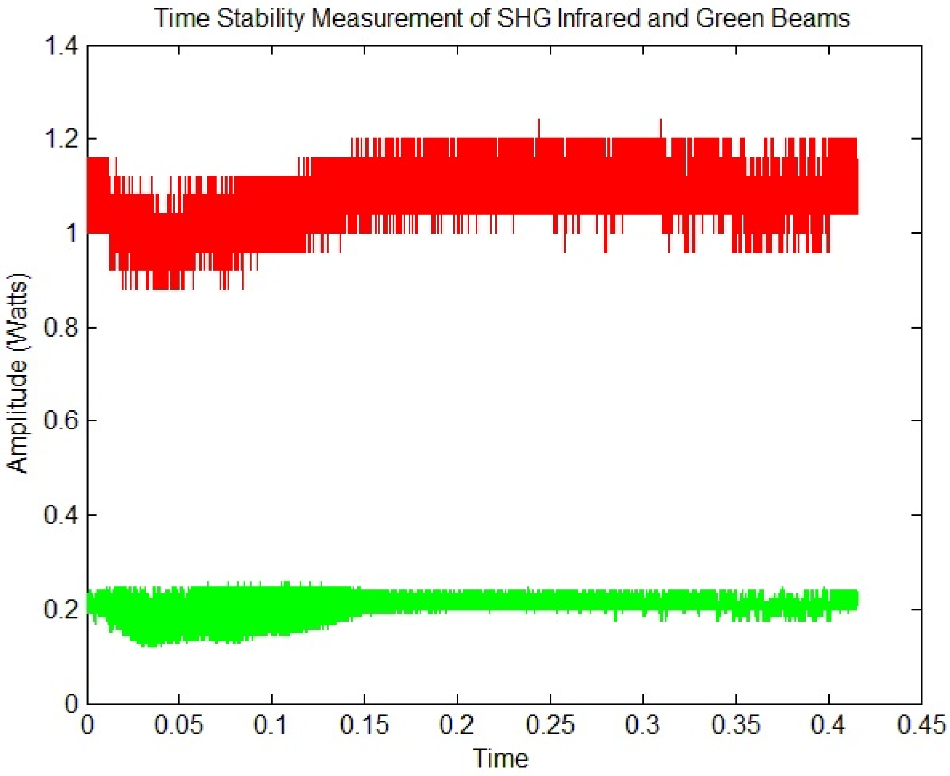

Figure 1: Oscilloscope Trace of Voltage Beam Intensity vs. Time. Note that the gains on the photodetectors are different so a conversion efficiency measurement cannot be extracted from this diagram

The graph shown in figure 1 is an oscilloscope trace over one and a half hours, each 0.005 unit of time is equivalent to 10 seconds (the sampling time). The program as it is now is not stable enough to go for more than six hours, but fixes are being made. Another interesting observation has been that even when the cavity locks, i.e. the infrared output becomes stable, the green light decreases for a period before it stabilizes. The infrared stabilization point does not seem to coincide all the time with the green peak. There is a possible persistent nonzero Pound-Drever-Hall signal. At times, a lock (even on peak resonance) does not correspond to where the PDH signal is zero. At the same time, the error signal being measured in the optical set-up has already been amplified on the order of 100 times so it may be small enough for all practical purposes.

With the servo stabilized, the extended time trace shown above was produced by a MatLab (Instrument Control) program and a RS-232 connection to a Tektronix TDS 210. Observations of future interest include time versus power of the beam of infrared and green light over 10 hours or more in addition to a histogram showing the distribution of energies present in the light. Presently, the hour-long oscilloscope trace shows high noise for the infrared beam and a possible increase in amplitude noise for green light whenever the amplitude of the infrared beam dips below a certain point. Considering the noise levels, a second graph should be produced measuring the averages of the power and plotted next to the raw data for a superior visual correlation of the beam's behavior as the power transmitted changes. A future recommendation would be to acquire communications modules for the more advanced oscilloscopes in the experiment (i.e. TDS 3034B).

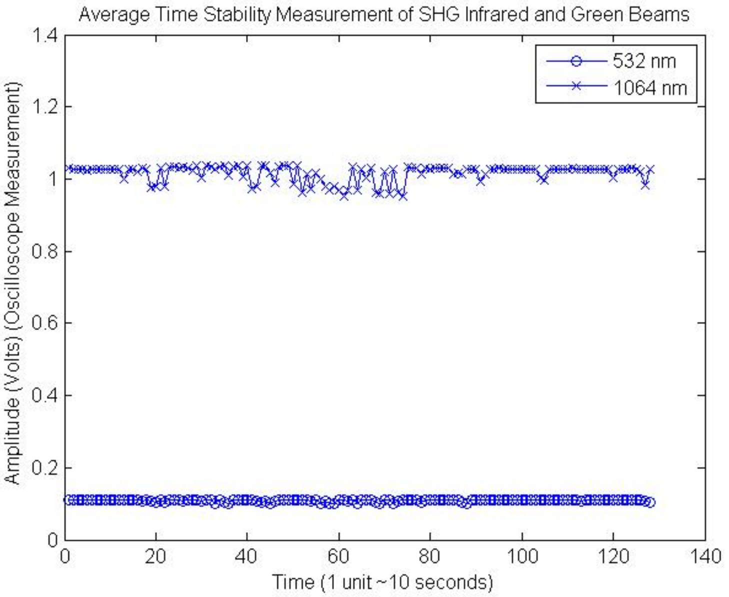

Figure 2: Average Green and Red Power

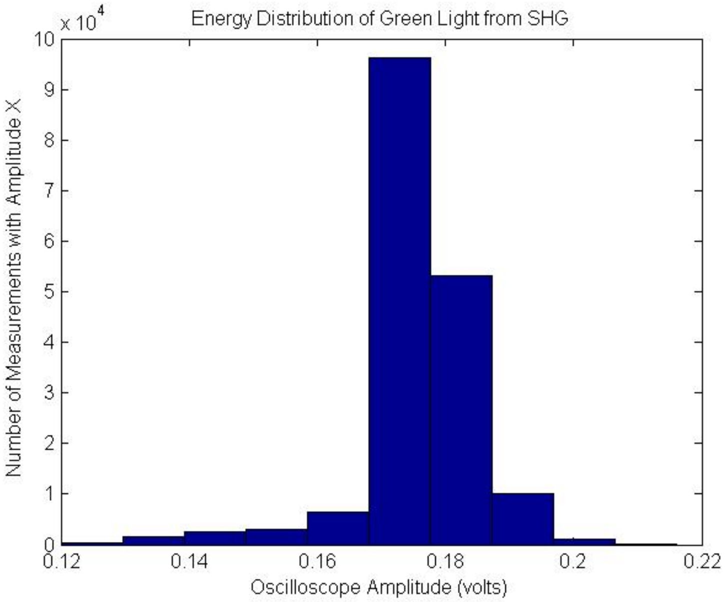

Figure 3: Energy Distribution of Green Beam from SHG Locked Near Peak Resonance

This initial sampling of measurements (125000 samples over a period of minute) shows a very sharply peaked distribution, which is a good indicator of stability. It is important to note that this sample was taken while the beam was locked. If the beam had lost lock, the distribution would likely have a much wider distribution.

1.2 Conversion Efficiency

The conversion efficiency of infrared to green has been boosted up to around 26% with the servo now stabilized and the power output hovering at roughly 100 mW. The temperature controller has been roughly optimized in the 6000-6400 ohms of resistance range, which translates to a temperature range of 36.3 to 38.8 degrees Celsius, which is slightly above the optimum 35 degrees of Celsius which was stated. Data from last year suggests the peak power was achieved at 33 degrees Celsius. A more thorough investigation clarify the discrepancy.

Increasing the conversion efficiency beyond what can be achieved with the

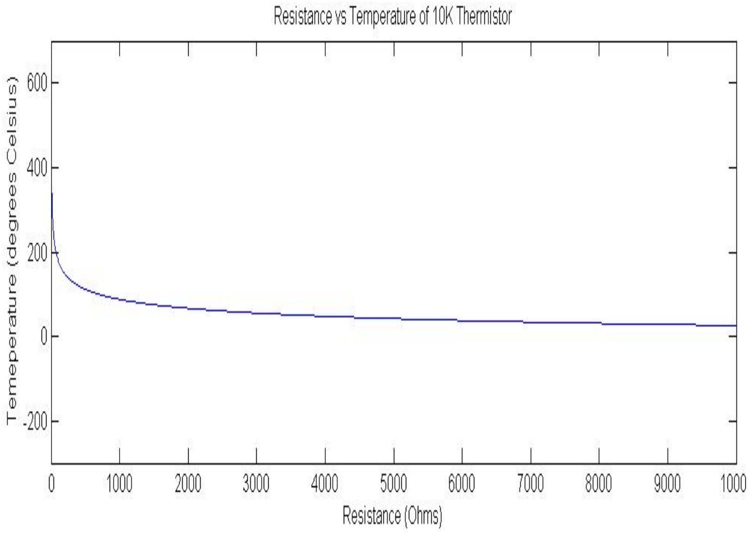

Figure 4: Resistance vs. Temperature figure for a 10K NTC Thermistor

temperature control and beam power is probably limited. Research suggests that tuning the angle the beam hits the crystal at is another method of phase-matching [1]. Implementing this idea could be as simple as putting the SHG on a rotation stage and increasing the height of the beam off the table to match it. This, however, will likely not be implemented in the remaining time for the project.

1.3 SHG and Temperature Control

The Beckhoff TwinCat temperature controller has now been installed on one of the dirty SHG's (no optics or crystal) and been tested for operational effectiveness. Sandwiching the TEC between copper and a large mass of aluminum (both very good conductors) ensures that the heat pump (TEC) operates effectively. Compared to the prototyping set-up of the TEC, which was glued to a thin copper strip resting on a piece of plastic, the servo has a noticeably better response time (i.e. in the prototype, the overshoot would be 0.4 volts delivered to the TEC, while in the SHG, it is only 0.2 volts). In addition, the code has been modified to increase the gain of the control signal, which has also improved the response. Though a bode plot of the frequency response is not available (since it is nontrivial to hook a SR785 to the Temperature controller set-up), the software control is sufficient to

Rise Time	3 mins.
Settling Time	6 mins.
Overshoot	1 degree Celsius or 3.3% of set temperature
Peak Time	4.5 mins.

Table 1: Important Servo Times for the Beckhoff

give a glimpse at the servo's response. The top plot in figure 5 shows that the servo overshoots once and settles down on the set temperature when the servo is turned on. This is actually ideal as it yields a faster ambient-to-set-temperature response time. The bottom plot gauges the RMS fluctuations as the servo settles down to its set temperature. The y-axis units shows that these fluctuations are indeed very small (on the order of 0.001 to 0.01 degrees). Overall, these two graphs indicate that the servo is fairly stable. The only possible improvement is response time. Seven minutes to reach the set temperature is a bit long, but depending on the tolerance (say, if we wanted the temperature within 35 plus/minus 0.25 degrees, then the settling time would decrease.

The mechanical set-up of two clean SHGs (ultra-sound cleaning and isopropanol)is nearly complete. The addition of the electronics/servomechanism components for the temperature control remains a challenge based on the current design. To address these flaws, a number of machining modifications have been implemented and documented in SolidWorks 2013. The thermistor ports on the copper blocks were initially too small but have since been enlarged to accept the current thermistors in the experiment. A small groove has also been added on the delrin bridge to help position this thermistor in the copper block. Finally, a small notch has been added to the brass ring centering the mirror in the cavity, which will provide a hole to feed the piezo wires out of the cavity.

2 Final objectives

First and foremost in the final objectives is the full assembly of a complete SHG that is ready to accept optics and a periodically-poled KTP crystal.

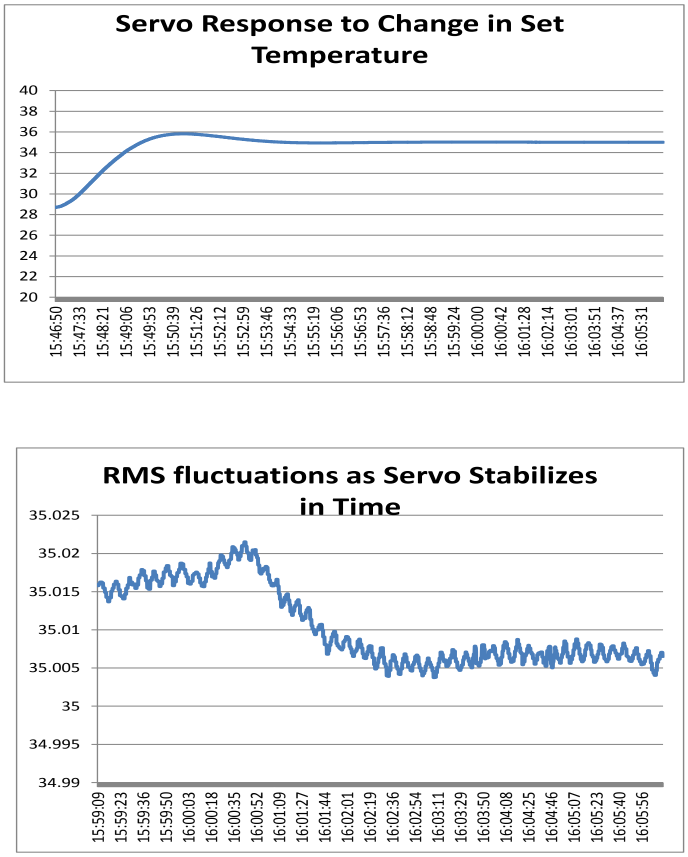

Figure 5: Temperature Response of Beckhoff Servo

This requires integrating the new Beckhoff temperature controller into a clean SHG and adding the electrical SHV connection. This is currently being done up on a third SHG but new parts are needed (SHV connector and cable) before it can achieve completion. Presently, there are two SHGs that are mechanically assembled minus the new temperature controller

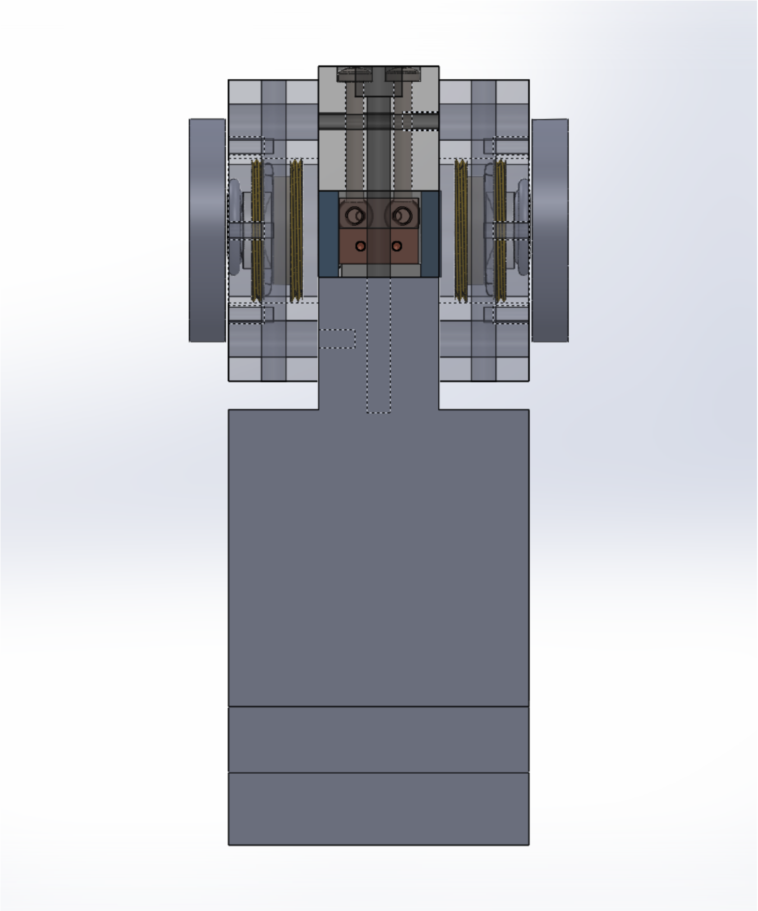

Figure 6: Solidworks 2013 view of the SHG (parts transparent to show cavity components

On the Beckhoff side of things, getting a frequency response will be challenging largely because the software is difficult to use (poor documentation) and there is no straightforward manner to add connections to input noise into the system and measure the response of the system (with a signal analyzer or oscilloscope).

Further characterization of the time stability of the beam is also just getting under way. This will confirm that the servo can work over ”long” time scales without any human intervention (’long' is operationally defined as 24 hours or more, but may increase if the servo gets better). In addition, the distribution of the beam amplitudes will be assessed to characterize the

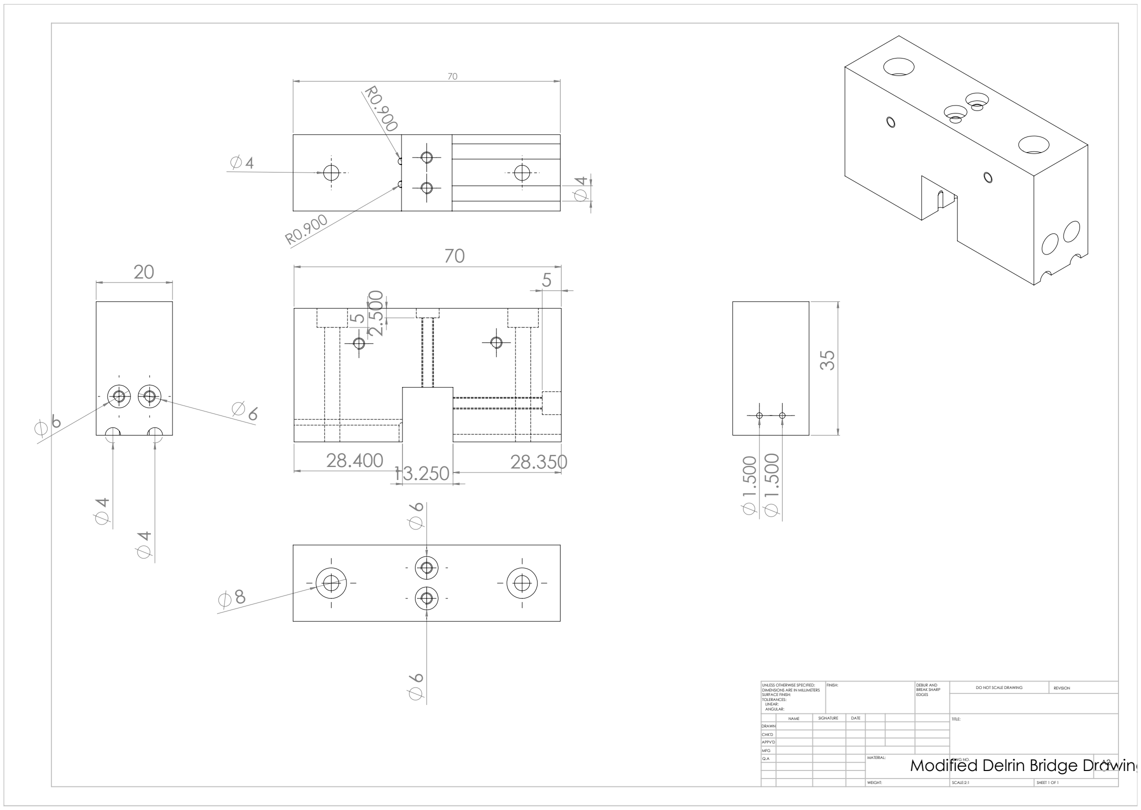

Figure 7: Solidworks 2013 Drawing of the Modified Delrin Bridge

"noise" in the laser light. An initial analysis shows a Gaussian type distribution, but only on second to minute timescales. More data will be collected in a larger number of bins before a graphical fit is made. Also in the works is how well the stability of green light production correlates with the conversion efficiency of green light (i.e. does the beam stay stable longer if there is more green power being detected, or not?). This question is interesting since the cavity locks onto the infrared laser light, so any correlation that is discovered means the servo is affected by the green-light produced by the KTP crystal.

Besides time stability, other aspects of the SHG are now open to characterization. Of prime importance is the conversion efficiency vs. power relationship. Last year's data run only included three data points, so adding more data points to produce a more accurate fit will be undertaken. Also of interest is seeing distortions in the phase matching curve as a function of temperature (with the mirrors on the cavity, pump depletion is a real problem). Many of these measurements are optimally done on the Ophir Vega power meter, which appears to have the capacity to be interfaced with a computer. If it can, then the ideal set-up would include a USB or RS-232 connection to a computer.

2.1 Future Considerations

2.1.1 Piezo Driver

There are two piezo drivers on the set-up; one from Thorlabs and one from TREK. both have limited voltage range (0-150 volts for the former, -125 to 125 for the latter). There are occasional dangers of the driver running out of range and the lock being lost, particularly for the ThorLabs. The reason why the ThorLabs Driver is used however is because it can be manually tuned whereas the TREK lacks this capability.

2.1.2 Optical Modeling of the Cavity

Simultaneously, modeling the beam path through the optical cavity has some informational merits for future work on the cavity. The equations below are the seminal parts of showing how the waist of a Gaussian beam propagates through space.

$$z_R = \frac{\pi \omega_0^2}{\lambda} \tag{1}$$

$$\omega^2(z) = \omega_0^2 (1 + (\frac{z}{z_R})^2) \tag{2}$$

In the limit that z is much larger than 1, then

$$\omega(z) \approx \omega_0 \frac{z}{z_R} \tag{3}$$

[2]

References

[1] Robert Boyd. *Nonlinear Optics.* Elsevier, Inc., 2008.

[2] Anthony Siegman. *Lasers.* University Science Books, 1986.