LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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LASTI LED Failure Report

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LIGO Science Collaboration

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1 Objective

On the 27th of February, I was asked to help determine the root cause of the many LED failures at LASTI. The investigation is currently ongoing, but here is a discussion of some things have been learnt so far.

2 Timeline

The first thing that I tried to determine is a real timeline of the failures, and a description of how they occurred. After meeting with some people, email discussions and a thorough reading of the LASTI ILOG, the following timeline was developed:

Day	SNs	Occurrence	Wire Broken	Location	Result
Fri. 2/17	**??**	**LED failed.**	**?**	**TP2, M1, R**	**Replaced 2/21**
Thur. 2/23-2/24	**60, 79, 59, 38, 63, 69**	**LEDs failed during install.**	**?**	**Quad Top mass, UI mass, penU mass**	**Shipped to Caltech & replaced**
Fri. 3/3	**56**	**LED failed.**	**?**	**Q, L2, PenU, LR**	**Replaced 3/9 with SN78**
Mon. 3/6		**M0 half of quad cable faulty?**		**Quad**	
Tue. 3/7	**42**	**LED failed**	**Yes**	**Q, M0, S**	**Replaced with SN29**
Tue. 3/7	**72**	**Never installed, broken wire.**	**Yes**	**Uninstalled**	**Shipped to CIT**
Wed. 3/8	**??**	**LED failed.**	**Yes**	**TP2, M1, R**	**Replaced w/ SN??**
Fri. 3/10		**Face 1 & Face 2 osems lost magnets and flags**	**N/A**	**Quad?**	
Fri. 3/10	**??**	**LED in this position failed again.**		**TP2, M1, R**	
Mon. 3/13		**Face 1 & Face 2 osems lost flags.**		**Quad**	**Flags replaced**

If the timeline is evaluated by category, the following story emerges:

2.1 TP2, M1, R

On Friday the 17th of February, the Right LED of unknown serial number failed on the M1 (Top mass?) of TP2 (the second triple of the dual triple experiment?) This LED was connected to LED Receiver A Channel 15. On Wednesday, March 8th, another LED (SN?) fails at the same location, connected to the same electronics. It was replaced March 9th with a new LED (SN?). When this LED was replaced, the electronics were also swapped out (SNs?) The next day, another LED at the same location fails. At this point the wiring is suspected, but testing shows that there is nothing wrong with the cable.

2.2 Quad Upper Intermediate Mass

On Thursday & Friday, Feb. 23rd & 24th, three OSEMS (SNs 59, 60, 79) fail at this location, one after another. After the third OSEM, the cabling is suspected. Upon inspection, the cable was found to be faulty. Once the problem was repaired, the fourth OSEM was installed and works fine to this day. The three LEDs were sent back to CIT for analysis, and all were found to function fine. There was no functional problem with these LEDs.

2.3 Quad Penultimate Mass

On Feb. 23rd or 24th, one OSEM (SN 38) failed and was sent to CIT from this location with a suspected failure in the LED. On inspection at Caltech, the PD board was found to have broken free from the ceramabond glue, and was grossly misaligned. The LED was functioning fine, and the problem here was due to the unglued PD board. On 3/3, the LED at this location failed again (SN 56). It was replaced with SN 78, which is working fine now. SN 56 was found to have a broken wire to the LED board. Upon arrival to CIT, the LED was found to be non-functioning.

2.4 Quad Top Mass

On Feb. 23rd & 24th, Four LEDs were reported to have failed on the Quad top mass. I am uncertain of their position on the mass, whether they were all collocated or not. Of the four, two were sent back to CIT for analysis (SN 63 and 69). These two were found to be non-functioning. On March 6th, the LED on the side of M0 Local (Top Mass?) failed (SN 42). It was replaced on the 7th with SN 29. It was going to be replaced with SN 72, but 72 had a broken wire, so it wasn't installed. The original LED failure (SN 42) also had a broken wire to the LED.

2.5 SN 31

This LED was found to be defective while Bob was making the Quad suspension at CIT. It was never installed, and Bob recalls that it had a broken wire.

3 Analysis

3.1 Failed LEDs

In order to determine how the LEDs failed, six of the above LEDs were shipped to James Marple at Honeywell on March 17th . Their SNs are: 31, 21, 42, 63, 69, and 72. James is the lead engineer on these LEDs (SME 2470), and is having his QA people look into how they may have failed. I am hoping that they will be able to tell the difference between overcurrent, ESD, or some other failure mode. He has not yet gotten back to me with any results, but he has asked me some questions regarding their date/lot code and provenance. I am expecting some sort of reply any day.

3.2 GEO Electronics

Jay, Mohana and I ran some tests on the GEO electronics, and found that some interesting conditions existed. First, Jay noticed that the output of the LED driver was a current source, and if the cable were disconnected to the LED, the voltage at the output could rise to levels that, upon reconnection, could possibly damage the LEDs. Voltage limiting diodes were placed on the output to prevent this occurrence. We also noticed that the driver's voltage regulators could latch up depending on the sequence that the positive and negative supplies were connected. I saw in the spec sheet for the regulators that two diodes could be installed to protect against this latch-up. These were also installed. A final diode was installed to protect the positive regulator, but this shouldn't do anything to change the LED situation. Two boxes were modified by Mohana, and shipped to LASTI. I am unaware whether they are currently installed or not.

3.3 Physical

Of the LEDs that were reported on, a fair fraction of them had broken LED wires. Some were reported as failing without discussing whether they had broken wires or not, but when any report was made, they often did (SNs 31, ??, 42, 72, and 56).

4 Hypothesis

Pending results from Honeywell, I have a possible hypothesis of why these LEDs are failing. Keep in mind that this is just an educated guess. Several factors all must exist for the failures to occur: 1) the LED driver has a propensity to supply high voltage when it sees no load, 2) the wire stripper that we are using can work-harden the copper wire by spinning the wire or planishing the wire's surface, 3) when the base plate is pushed onto the OSEM, the joint between the work-hardened wire and solder is stressed. Once these conditions exist, here's what could happen: The wire cracks and/or breaks at the wire/solder interface creating a potentially bad contact that goes unnoticed in preliminary testing. Once installed, the contact becomes intermittent. At the

moments when the contact is broken, the voltage rises at the LED driver, and when the contact is remade a surge of current is delivered to the LED. After enough of these cycles (#?) the LED fails. When we open the OSEM up, we assume that the broken contact (that is now plainly evident) is the reason that the LED is not illuminating, but in fact, we find that it is permanently dead even after re-soldering the wire and testing.

5 Possible Solutions

The first possible solution is to stop using the mechanical stripper, and go to a chemical stripper. There are several relatively safe models available at www.eraser.com that would be suitable (DSP1, DSP2 or USP1). They are all high temperature (100-800 deg.F) stripping pots that use a substance called Dip-Strip to remove the HML insulation. I spoke to them, and they said that if we sent them a sample of our wire, they would determine the optimal tools and procedure for our situation. The benefit of this approach is that it would not stress the copper wire, and should make a more robust solder joint.

The second possible solution would be to modify all of the driver electronics to protect the diodes from over-voltage.

And the last would be to double-check or replace all of the wiring that is suspicious, such as the wiring on TP2 M1 R. Other than that, we can wait to hear from Honeywell and see if they offer us any insight into our problem.

6 Further Suggestions

Other things that I have noticed as this investigation has proceeded may help with failure diagnosis or just make the production of the OSEMs easier and quicker.

6.1 OSEM Serial Number Location Map

We should continue the recent trend of recording the position of each OSEM on each of the current suspensions. It would be good to have a diagram of each suspension that shows the serial number of each OSEM in the place where that OSEM resides on the suspension, and a history of which other OSEMs have been in that location before. This would help us track down failure modes for the LEDs, and might point us to possible solutions to the problem.

6.2 Test Jig

When making an OSEM, a photodiode and LED are paired and tested to see if enough voltage is generated by the photodiode. If the voltage is below acceptable levels, the LED is swapped for another one. If the assembly continues to fail after several LED swaps, the PD is changed, and the LED swaps continue. If the PD has low quantum efficiency, it takes multiple tries before this can be detected. If we made a test jig that had a standard LED and a standard PD, each LED and PD under test could be judged independently against one standard, and we could pass or fail them solely by how they perform in the test jig. I believe that this would make Bob's assembly job quite a bit easier, and could lead to more consistency in the OSEM production.

7 LASTI ILOG Excerpts

7.1 Double triple pendulum experiment, weekly report

13:53:27 Fri Feb 17

The cavity got locked a first time Saturday
…

Wednesday, The temperature in the high bay Tuesday was 86F (heating issue), it came back to a normal 72F wednesday. Unfortunatly this temperature change also moved the 2 pendulums up by about 30% of the osem range. We re-aligned the osems a bit, in the future we'll have to remember to avoid doing alignement when the heating is broken :-).
I also tried to install the M2 LR osem (the bracket was missing and we received it from Caltech), unfortunatly because of a bad manipulation and a stuck screw, I broke the magnet on the mass. We decided to continue without this osem/magnet.

Thursday, We closed the door and got ready for pump down, I am working on the software to be able to plot transfer functions. Everything works fine

Friday, the TP2_M1_right osem's LED broke this morning, it was working at 11am and not at 11:30. It is definitly a LED failure and not in the electronics. we'll have to open the chamber next week and replace it.

I'll attach some picture of the experiment this week end

- ***Laurent Ruet***

7.2 Double triple pendulum, weekly report

15:59:42 Fri Feb 24

Tuesday **(2/21)**, We opened the chamber and the dead OSEM (TP2 M1_right)got replaced, the LED was dead. The new osem works well so far. (the OL voltage for this osem is 94.4). We placed some instruments on breadborad on the pier, 2 geophones in horizontal and vertical geophones.
Friday **(2/24)** (temperature in the HB is high again, the pendulums moved a bit), The door got closed, before we pumped down, I turned the laser on to see what it's look like with the door closed. The difference is huge, no saturation, no 100Hz big noise, the lock is more stable and the signal much easier to compute without the saturation. I just took a quick power spectrum (over 6 min of lock) before we started to pump down.

7.3 Quad Update

19:42:20 Fri, Mar 3

The local control Osems work just fine. There were some problems with the global control Osems. Fortunately (relatively), some of this was easily fixed due to some loose cabeling on the elctronics. The LED on the lower right penultimate mass (L2) has gone out however. This is at least the second to go out in this same location in a couple of weeks. The global control also needs to be aligned. The Osems on the UI mass likely can not be aligned too well before we get some brackets from CalTech that will allow them to shift horizontally around the flag.

There is also some preliminary transfer function data from 1 to 100 Hz. What is interesting is that some resonances show up above 50 Hz. Since the pendulum should not go that high, it is likely coming from the structure.

- ***Brett Shapiro***

7.4 More OSEM failures!!

19:05:04 Mon, Mar 6

Brian, Laurent, Rich, Brett
We noticed there was a problem with an OSEM when the power supply shorted out. We narrowed the problem down to the M0 half of the M0/R0 cable. We disconnected the cable at the rack side of the electronics and measured acrossed its pins with an Ohm-meter. The only anomaly we could find was across the LED of the side OSEM on the main chain (M0). At least we think it is this one since the cable numbering appears to be flipped from what's on the schematic i.e. 1 -> 13, 2->14, etc. The resistance across the LED measured at infinite both directions instead of 11.3 M-Ohms one way.

7.5 Side OSEM replacement

15:37:54 Tue, Mar 7

Brett, Brian

We replaced the side OSEM on M0 local after getting some helpful advice from Calum and Bob Taylor at CIT.

SN #042 was removed, note that this S/N does not match the backplate S/N since this OSEM was replaced twice before (I think that's what I was told). When we removed it we noticed that one of the small wires between the baseplate and the LED(?) was broken (pictures to follow).

Initially we were going to use SN #72 as a replacement, but we found a broken wire on this as well. We're pretty sure we didn't break it on the attempted install, but I suppose it is possible.

We ended up replacing it with SN #29. In the process we dropped one of the large plastic spacers so we scavenged one from SN #57.

SN #57 is back in the spares drawer, the other two OSEMS will be shipped back to Bob Taylor at CIT for repair.

The OSEM is centered and appears to be working fine again.

7.6 Triple pendulum OSEM failure

12:44:29 Wed, Mar 8

The LED M1_right on TP2 failed again today (we replaced this same osem less than 2 weeks ago).

We'll replace it tomorrow and I'll add the serial number and informations I can gather about the LED here.

It is the second time the OSEM plugged on LED/RECEIVER_A - channel5 fails in 2 weeks. We are going to try to swap the electronics with a spare we have.

- ***Laurent Ruet***

7.7 Replaced OSEM on Quad penultimate mass

14:47:02 Thu, Mar 9

Brett, Brian

We replaced the broken OSEM on the LR of the penultimate mass of the quad reaction chain. The removed OSEM was SN #56 it was replaced by SN #78. The broken OSEM will be shipped with the other bad OSEMs to Jay Heefner at Caltech.

Once again when we removed the wiring harness and looked under the baseplate we found a broken wire. This one appears to have come off at the solder joint, rather than breaking at some fatigue/pinch point in the wire.

We also noticed that this OSEM did not have a filter installed, the new one does. We checked functionality and will center etc.

7.8 More OSEM problems

10:25:53 Fri, Mar 10

All OSEM LEDs are now working however, sometime between yesterday, when we replaced the lower right OSEM on the penultimate mass, and last night 2 OSEMs lost there magnets and flags. These are the Face 1 and Face 2 OSEMs.

- ***Brett Shapiro***

7.9 Triple pendulum, another OSEM failure

15:35:43 Fri, Mar 10

The TP2 M1 right LED failed again, one day after we installed it and plugged it on a different elctronics. We are suspecting some temporary short in the chain but it is still impossible to find where it is coming from, the cables look fine when we test them.

- ***Laurent Ruet***

7.10 Quad OSEM Status

14:19:35 Mon, Mar 13

On Friday I noticed that the Face 1 and Face 2 OSEMs on the main chain had lost their flags. They are now replaced. The earthquake stops were also not positioned well on the top mass of this chain which may have contributed to their breaking off. The side OSEMs on both chains were not protected at all by earthquake stops. Thus, I inserted stops to protect the side OSEMs and moved all the rest closer to their mass.
All 20 OSEMs should now be working.

- ***Brett Shapiro***