LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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aLIGO OMC: Spare OMC production plan

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1 Introduction

At the H1 interferometer on July 26th, 2016, lack of the functioning shutters in HAM6 caused burning of one of the OMC mirrors by a high-power pulse of an interferometer lock loss[1]. H1 recovered an OMC about two weeks after the incident by installing the 3rd IFO OMC.

Since we consumed the 3rd IFO OMC as a spare, we have neither the 3rd IFO OMC nor a spare OMC at the moment. In order to improve this current situation, OMC spares will be produced. This document describes the plan to prepare temporary partial-working and full-functional spares.

The rest of the document is organized as follows:

- Section 2 describes the overall OMC repair and production plan.
- Section 3 describes how we can turn the damaged OMC to a useful spare.
- Section 4 describes the plan to fabricate fully-functional OMC spare(s).
- Section 5 describes the improvements we may want to incorporate in the spare OMCs.

2 Overall OMC repair / production plan

Figure 1 shows the outline of the repair and production plan for the OMC units. In response to the urgency to prepare a working OMC unit even with unoptimized performance, the damaged unit (Unit 2) will be turned to be an emergency spare unit by replacing the damaged optic. After securing the emergency spare, a fully functional unit (Unit 4) will be produced from scratch. Then, the emergency spare will be refurbished with more aggressive repair like removing UV epoxy joints. Having two functional units (one for 3IFO and another for the spare), we have an optional opportunity to repair the LLO unit (Unit 1). In the end, we will have three OMC units for the three IFOs and one spare.

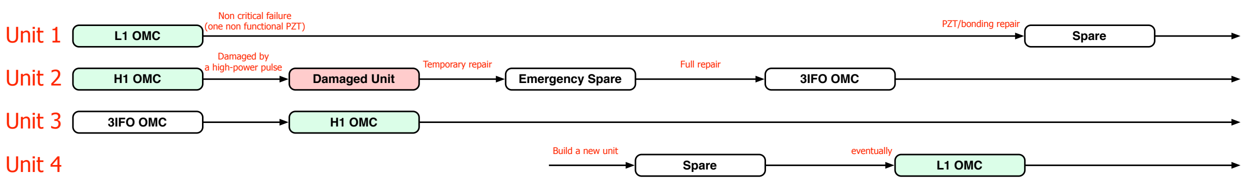

Figure 1 Repair & production outline

3 Restoration plan for the damaged OMC

The problem of the damaged OMC was that the loss of the cavity became too high to allow regular Gaussian modes to resonate. We can observe a white spot on one of the PZT mirrors, so-called CM1.

If we can somehow recover the function of the OMC, we can use the unit as an emergency spare that has a slightly compromised performance. The presence of this emergency spare will allow

[1] LHO ALOG 28683 (https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=28683)

us to cost more months to work on full-spec OMC spares. Furthermore, we can try to remove the damaged prism piece so that we can restore the full specification of this unit.

3.1 Step 0: Failure inspection

Before touching anything, we want to do a thorough forensic analysis.

Steps to be taken: (Total 1~2 weeks)

- Taking precise photographs of the damaged spot on CM1 and all glue joints
- Careful inspection of the other cavity optics
- Microscopic inspection of the damaged spot
  - Dark field microscope from the back side of CM1
  - Fiber microscope
- Making an attempt to resonate the beam in the defective cavity
  - Quantify the reduction of the transmission

Note (Oct 9, 2016): The inspection results are stored on DCC as E1600268.

3.2 Step 1: CM1 cleaning

We can try to clean the mirror in order to see how much transmission we can recover. If we can recover a reasonable amount of transmission (like 80~90%), this OMC can directly be stored as an emergency spare that has a slightly compromised performance.

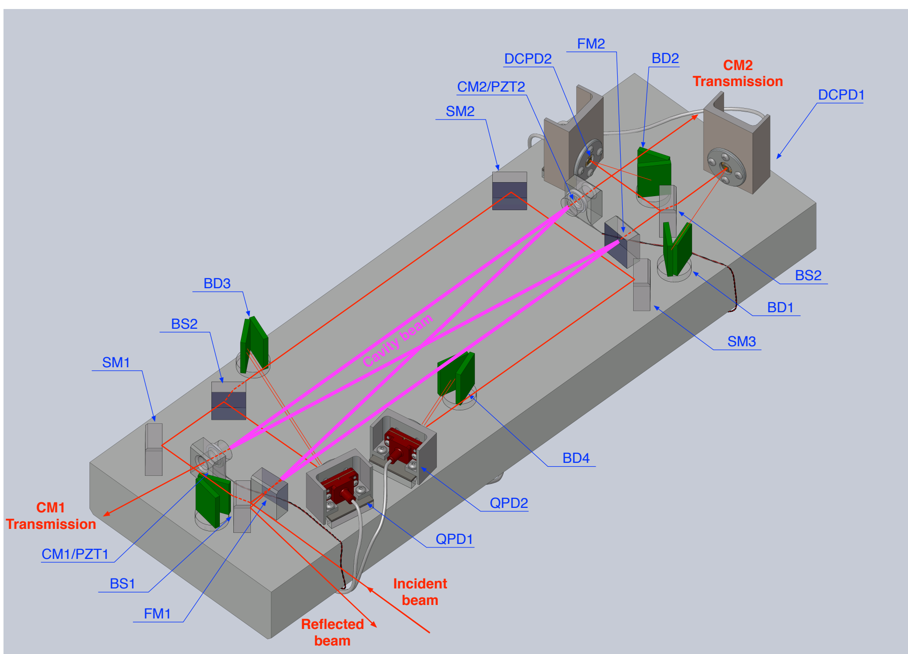

Figure 2 Optic side of the OMC Breadboard - "Bottom Side"

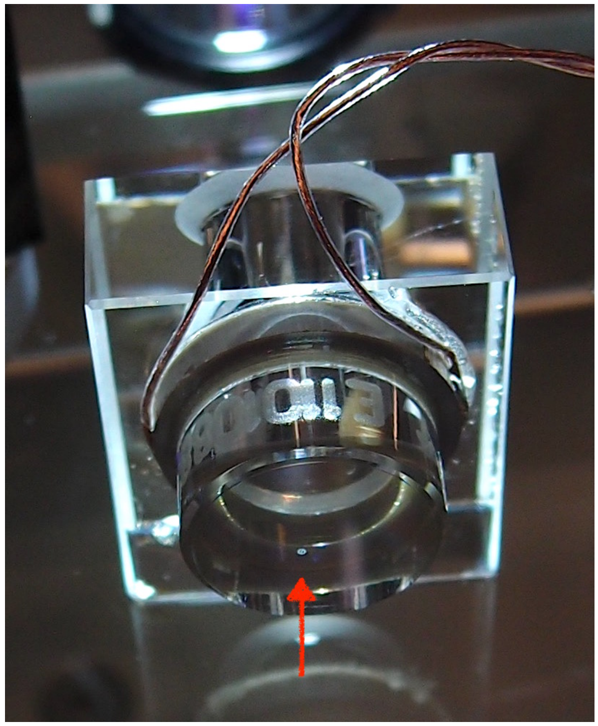

Figure 3 A white spot on CM1

New items for the work: None

Steps to be taken: (Total 2~3 weeks)

- Sample the damaged mirror and other cavity mirrors for FTIR test. (i.e. Freon wiping)
- Perform cleaning of the CM1 mirror
    - Probably we should start with acetone on a Q-tip.
    - In the end, FirstContact is applied.
    - We may wait for the FTIR result to come as it tells the character of the contamination.
- Visual or microscopic inspection to identify physical damage of the mirror surface
- Measure resulting cavity transmission.

Note (Oct 9, 2016): The inspection results are stored on DCC as E1600268. Application of FirstContact resulted peeling of some coating materials from the optic. This meant that the damage was not just a contamination spot, but a physical "crator" that could not be recovered by cleaning. We decided to go forward to Step 2.

3.3 Step 2: CM1 replacement

If the cleaning of CM1 does not recover useful transmission, we can try to replace the CM1 mirror. The prisms on the OMC are almost impossible to remove due to UV-epoxy bonding. Fortunately, we have a chance to remove the CM1 optic because it is mounted on the PZT.

EP-30-2 bonding of the CM1 optics mirror is scraped off by chemical or physical methods. Then glue another mirror (or the same mirror with rotation?), on the PZT.

This will certainly recover the transmission of the OMC cavity. However, we, in general, can't expect to maintain important cavity parameters that are the ratio of the FSR (free spectral range) and the TMS (transverse mode spacing). This means that the total performance of the OMC may be worse than the nominal. The alignment of the OMC cavity will be changed. This can be absorbed by realignment of the DCPD/QPD subassemblies.

New items for the work:

- An NPRO Laser with fast frequency tuning. The laser head and the driver unit were moved from the contamination testing lab to the OMC lab. SOP: M1600224
- Adjustable fixture for in-situ bonding of the optics on the PZT (D1600338). This fixture allows us to adjust the cavity alignment, test the cavity transmission, and inject the epoxy.

Steps to be taken: (2.5~ 3 months)

- Design and prepare the in-situ gluing fixture (need to be Class B)
- Replace the laser in the OMC lab. Write an SOP for the laser. (~2 weeks)
- Removal of the CM1 optic
- Reconstruct the OMC fabrication optical setup (~2 weeks)
- Place the optic and characterize the cavity parameters, trying to exploit the best performance we can reach.
- Glue the optics on the PZT.
- Put the OMC breadboard in the vacuum bake oven
- Characterize the cavity parameters and the performance (~2weeks)

3.4 Step 3: PZT subassembly removal

Basically, we try to remove the entire prism from the breadboard so that we can glue the new PZT subassembly. There are several ideas for the removal process including, soaking the prism in acetone or methylene chloride, heating the CM1 prism above the softening temperature of the UV epoxy, and slicing the UV-epoxy layer by a hot wire (of 5um?).

This step is more invasive to the OMC unit and should be taken if the above step did not help to recover satisfactory performance as an emergency spare, or after preparing another fully functional unit.

Steps to be taken: (~ 3 months)

- Remove CM1 mounting prism from the OMC breadboard.
- Build new PZT sub-assembly.
- Bake the PZT sub-assembly.
- Alignment & gluing of the PZT subassembly with the cavity parameters adjusted/monitored with the optical technique.
- Realignment of the PD/QPD subassemblies.
- Post gluing cavity characterization.

To find out the way to remove prism optics gives us a lot of advantages. We will become able to replace any optics of the OMC, then to repair any prism optics. For example, we can fix L1 OMC that has one of the PZTs broken. Also, this gives us the simplest way to upgrade the OMC cavity optics towards a low optical loss for maximally exploiting the advantage of squeezed vacuum injection.

3.5 Step 4: Salvage plan

If for some reason, the above steps don't work to restore a reasonable performance of the cavity, various components could be salvaged from the OMC for the spare production.

The items that will be salvaged:

- DCPD/QPD housings
- DCPD/QPD cables
- Mass mounting brackets
- Cable harness bracket
- Prism optics (by dissolving the UV epoxy bonding).

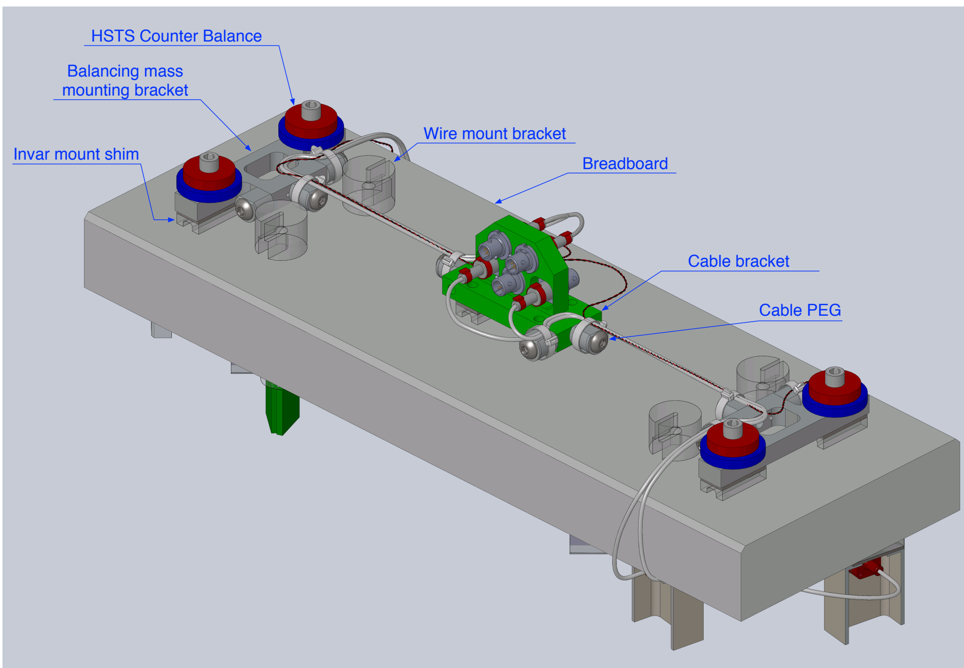

Figure 4 OMC Breadboard - "Top Side"

4 Spare OMC production plan

A completely new unit (Unit 4) will be produced from scratch. The summary of the inventory is found in Table 1 and Table 2. There are important optics for production of this unit[2]. For the

[2] There are just enough coated optics for two OMC units except for the E mirrors. The two missing E mirrors being arranged at SM2 and SM3 can be replaced by commercial mirrors.

mechanical and electrical components, we basically have no spare components. Table 2 lists the missing subassemblies.

Table 1: Optics, ceramic components, and photodiodes

Item	LIGO DCC or P/N	Qty in hand	Required Qty per OMC	Note
Glass breadboard	D1200105	3	1	
Black glass beam dump	D1201286	0	5	Have 16 glass pieces. See also Section 5.2
Noliac PZT	NAC2124	4	2	
Prism Mirror "A"	E1101086	7	2	Flat IO coupler
Prism Mirror "B"	E1101086	6	2	50:50 BS
1/2" Mirror "C"	E1101095	6	2	Curved optic
Prism Mirror "E"	E1101086	6	4	45deg HR mirror
Mouting Prism	E1101087	9	2	
Wire mount	D1102209	13	4	
High QE PD (IGHQE3000X)		>10	2	
QPD (FCI-INGAAS-Q3000)		4	2	

Table 2: Other assemblies

Item	LIGO DCC or P/N	Qty in hand	Required Qty per OMC	Note
Transport Fixture ASSY	D1201515	0	1	
DCPD mount ASSY	D1201273	0	2	Requires Alumina plasma spray on the housing (tends to fail)
QPD mount ASSY	D1201279	0	2	
Cable bracket ASSY	D1300052	0	1	Revised design with PEEK
Mass mounting bracket ASSY	D1300060	0	2	Have D1300060 x1
PEEK cable tie		0	10	
PD Shims	D1201467-x	-	4 ea.	Have -1 x2, -2 x7, -3 x10, -4 x8, -5 x4, -9 x1, and -10 x1.
DCPD Cable A	D1300371	0	1	
DCPD Cable B	D1300372	0	1	
QPD Cable A	D1300374	0	1	One per OMC bread board
QPD Cable B	D1300375	0	1	
PD Mounting Bracket		0	14	See Section 5.1

5 Improvements that could be incorporated

During the assembly and installation of the past OMCs, we identified various issues. Some of them could be incorporated to the new OMCs, taking an advantage of this opportunity.

5.1 Utility mounting brackets

A new method of mounting metal hardware on the glass breadboard is necessary.

We used to have D1102211 “aLIGO OMC Diode Mount Glass Block” to allow metal components to be fastened on this glass block. However, this glass structure was too weak to hold the stress of mounting[3]. In order to mitigate the initial problem, we decided to use a new structure with an invar shim E1300288 “ECR for OMC Invar Shims”. However, the invar shims show delamination of the Epoxy bonding.

The current idea is similar to the one with D1102211, but use stiffer nut bar (like a stain less bar) with recesses around the screw hole in order to avoid stress concentration. For the same purpose a sheet of Kapton is inserted between the nut and the glass. This sound like an idea, and needs testing.

This is a high priority item: We need a new mounting method and stress test of it. This requires an engineering R&D.

5.2 Black-glass beam dump

D1201285 “OMC V Baffle Assembly” tends to have delaminated bonding at the joint between the black glasses and the fused silica base. This can be mitigated by machining V-shaped grooves on the fused silica base. Another idea is to fabricate a prism that touches the black glass pieces at the inside of the v-shape. This enables to use a wider area for black glass gluing.

This is a high priority item: This requires the manufacturing of the new beam dumps. This requires an engineering R&D.

5.3 Cavity mirrors

The current quality of the OMC mirrors gives us only ~97% transmission instead of expected >99%. This can be mitigated by using new optics.

[3]OMC Lab elog 116 (http://nodus.ligo.caltech.edu:8080/OMC_Lab/116)

This has a high impact on the performance: This requires new optics: the prism mirror "A" and curved mirror "C". We will not incorporate these new optics for the (re)production of Unit 1~4.

5.4 Breadboard damping

The frequency of the breadboard bending mode is at around 1kHz[4]. The OMC length noise is dominated by the motion of this mode[5][6]. If we add additional damping of this mode, the RMS motion of the OMC length will be greatly reduced.

This has a high impact on the performance: This requires development of a damping mechanism for the breadboard bending mode.

5.5 Cable electrical isolation

On-board cables on the OMC breadboard are harnessed by D1300052 "Cable Bracket". However, this component is made of aluminum and make the shields of the cables all connected. While it turned out that this is not making significant ground loops, this makes the shield shorting check confusing.

The new design was incorporated to D1300052. The new piece is made of PEEK.

5.6 Cable fastener

On-board cables are held at their ends by the cable brackets on the top side and the corresponding hardware (DCPDs, QPDs, and PZTs) on the bottom side. The cables are free between these two ends and tend to move.

If we have a cable fastener, it will help to make the cables nicely secured.

This requires glass or metal cable fasteners to be designed.

[4] OMC Lab elog 210 (http://nodus.ligo.caltech.edu:8080/OMC_Lab/210)

[5] LLO ALOG 10554 (https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=10554)

[6] LHO ALOG 16089 (https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=16089)

6 Modification history

V1: First release

V2: Incorporated the authors. Reflected the comments in the meeting on Aug 19, 2016, to Sec 2.

V3: Incorporated the comments from P. Fritschel about Section 5.2.

V4: Added Section 2. Reflected the latest updates to Sections 3~5. Revised the tables in Section 4.