LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

*LIGO Laboratory / LIGO Scientific Collaboration*

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# FMEA for aLIGO TCS Ring Heater

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# 1 Introduction

This document enumerates the failure modes and hazards associated with the aLIGO TCS ring heater.

# 2 Reference Documents

Advanced LIGO Thermal Compensation System Preliminary Design, LIGO-T0900304-v2.

Delta-Preliminary Design Review Content Relating to the aLIGO TCS Ring Heater, LIGO-T1000252.

aLIGO TCS Electronics and Controls Requirements, LIGO-T0900597-v2.

# 3 Description of the Ring Heater and its Operation

The ring heater is a set of resistive elements employing nichrome wire that encircles the test mass within the suspension structure and radiates heat onto the test mass barrel, thereby thermoelastically changing the HR surface radius of curvature. The heater is surrounded by shields which block the radiated heat from other parts of the suspension structure. The heater elements and shields together form an assembly that is attached to the suspension structure, one assembly above the test mass, one below. Each resistive element contains a temperature sensor.

Electrical cables that supply power to the resistive elements and sense their voltage and temperature run from the ring heaters to outside the vacuum. These cables run up the suspension structure and can be disconnected at the seismic platform and at a point halfway up the suspension structure.

Outside the vacuum are power supplies to provide current to the ring heater elements, and sensors to record the delivered current, voltage, and heater temperature.

During normal operation, the power supplies will heat the ring heater elements to up to 420K by running up to 1.5A of current through them. The voltages required by the ring heaters and their power supplies will not exceed 48VDC. The net power delivered to a single test mass by all the heater elements around it will not exceed 22W. During commissioning, the noise coupling of the ring heaters to the interferometer will periodically be tested by driving a sinusoidal signal to the ring heater elements with 1W power fluctuations.

# 4 Failure Modes

We consider the following set of possible ring heater failures:

1) Failure of the power supply or cabling outside the vacuum
2) Failure of the cabling inside the vacuum
3) Shorting of the ring heater element to the suspension structure
4) Shorting of ring heater current leads to each other
5) Ring heater element open circuit failure

6) Ring heater element mechanical breakage

## 4.1 Failure of Power Supply or Cabling Outside the Vacuum

Should a power supply fail, some ring heater element will no longer deliver power to the test mass, and TCS will deliver a reduced, astigmatic thermal compensation until the power supply is repaired or replaced. This will not damage the interferometer but will impair performance. The voltage and current sense leads to the ring heater element will easily sense such a failure.

Should a current-carrying cable fail, the effect will be the same as for a power supply failure. If the failed cable is one of the voltage sense leads or leads to the temperature sensor, the ring heater will continue to operate, but without full sensing of its performance by CDS.

In either case, the broken component can be replaced without venting the interferometer. Realignment of the interferometer after replacement should not be necessary.

## 4.2 Failure of Cabling Inside the Vacuum

If the cabling fails inside the vacuum, the effects on the interferometer are the same as in Section 4.1 for failure of cabling outside the vacuum. The difference is that a vacuum vent would be necessary to repair or replace the broken cable. At present the manner in which the cable will be routed up the suspension structure has not yet been decided, but it would be desirable that the cable be replaceable without dismantling the suspension structure in any way.

## 4.3 Shorting of the Ring Heater Element to the Suspension Structure

The most likely places where the ring heater would short to ground are within the heater element itself where the bare nichrome wire could make electrical contact with its holder or with the radiative shield, or at the ends of the heater elements where the bare nichrome wire connects to the cabling. In either case, the element would short to ground through the suspension structure and seismic isolation platform.

This path to ground is likely to have high impedance relative to the heater element itself. So, if the power supply to the element has a differential output, the power delivered by the ring heater is unlikely to change, except for a small reduction in delivered power and slight astigmatism in correction due to leakage current through the short. The connection to ground will likely introduce line harmonics into the ring heater current at some level. These could potentially couple 60 Hz line harmonics into the interferometer. The existence of the short would be detected by the voltage sensing circuit, either by a change in the ring heater impedance or by the presence of line harmonics.

The suspension structure and seismic isolation platform can easily handle the leakage current to ground caused by a short. A short might or might not impair the interferometer performance by impairing the thermal compensation pattern- this can be checked by the Hartmann sensors. It also might or might not inject line harmonics into the interferometer- this can be checked by briefly switching off the ring heater element.

If the short does impair the interferometer performance, it would be necessary to vent the vacuum and partially dismantle the suspension to remove and replace the broken ring heater.

## 4.4 Shorting of the Ring Heater Current Leads to Each Other

If the current supply and current return leads short to each other, the ring heater element will be bypassed by a very low impedance path. The power supply will be current-limited to prevent operation of the supply and cabling beyond their rated current levels should this short occur.

The replacement of the failed cables would follow as in Sections 4.1 and 4.2.

## 4.5 Ring Heater Element Open Circuit Failure

If the ring heater element becomes an open circuit (i.e. the nichrome wire breaks), it will cease to deliver power to the test mass and TCS will deliver a reduced, astigmatic thermal compensation until the ring heater element is replaced. This would require a vacuum vent and partial dismantling of the suspension.

It is possible that stresses caused by thermal cycling could induce this failure, by loosening the nichrome wire from its connection to the in-vacuum cabling. Thermal stresses are discussed in the next section.

## 4.6 Ring Heater Element Mechanical Breakage

The ring heater will be very well protected inside the suspension structure and is highly unlikely to suffer any impacts or large mechanical loads once installed. In the event of an earthquake or catastrophic failure of some suspension element that would significantly displace the test mass, the relatively delicate ring heater element will be protected from impact with the test mass by the radiative shield surrounding it and by the earthquake stops.

Thermal cycling is the more likely source of mechanical stress leading to failure, in the author's opinion. No data on this failure mechanism is available for the current ring heater designs. Failure could be the loosening of the nichrome wire from its connection to the current-carrying leads, leading to an open-circuit failure, or the shedding of insulating material from the heater element, or complete fracture of the nichrome wire holder, producing debris.

Shedding or fracture of the nichrome wire holder would certainly contaminate the test mass and compensation plate with particulate debris. It would be necessary to vent the vacuum, partially dismantle the suspension to replace the ring heater, and clean or even potentially replace the test mass and/or compensation plate. This is therefore the most serious failure mechanism.

# 5 Hazard Analysis Severity Table

None of the failure mechanisms described here result in any significant hazards to LIGO site personnel.