BSC suspension Thermal budget

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1 Background

This note sets out the thermal issues involved in the design and operation of the BSC suspensions.

2 Previous work

A previous paper, T050037 looked at the thermal link between the OSEMs and the Seismic table. A separate note[1] mentioned radiative losses from the masses. G060109 took a cursory look at the effect of the ring heaters and concluded that further work was required. This document extends that work.

3 Requirements

E050159, ICD: SIE – SUS/UK gives an expected dissipation of 12W peak from the OSEMs on the basis of heating from the local control OSEMs at 1W each.

4 Heat sources, sinks and limits

4.1 Sources

The heat sources considered here are

- Heat from the OSEM coils. Ideally there would be very little heat from the OSEMs in normal operation, because the required forces to keep the suspension in lock are small. However it is expected that some static correction will need to be done with the local control OSEMs and possibly with the global control OSEMs. The worst case OSEM heating has been estimated at around 800mW[2]. Note however, that the OSEMs on the suspended masses will only be driven at high power during acquisition which lasts of order 10 seconds; in science mode (steady-state) the heat will be significantly less than 800 mW.
- Heat from the OSEM emitters. These will be powered continuously in normal operation. The worst case heat load has been estimated at 100mW[3]
- Heat from the ring heaters. The heat budget of the test mass and the thermal compensator plate are not covered by this paper. However, parasitic heating of the structure by the ring heaters will likely be the major heat source. There is one ring heaters on the ETM and two heaters on the ITM. There may be additional parasitic heating of the structure by the warm masses.

4.2 Sinks

The heat entering the structure from the above sources must be lost by radiation to the wall of the vacuum vessel or by conduction to the seismic platform.

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[1] Email from Ken Strain, Fri 20/02/2004 17:05. Wide circulation: addendum 1 to this document.

[2] Stuart Aston, private communication

[3] As ([2]).

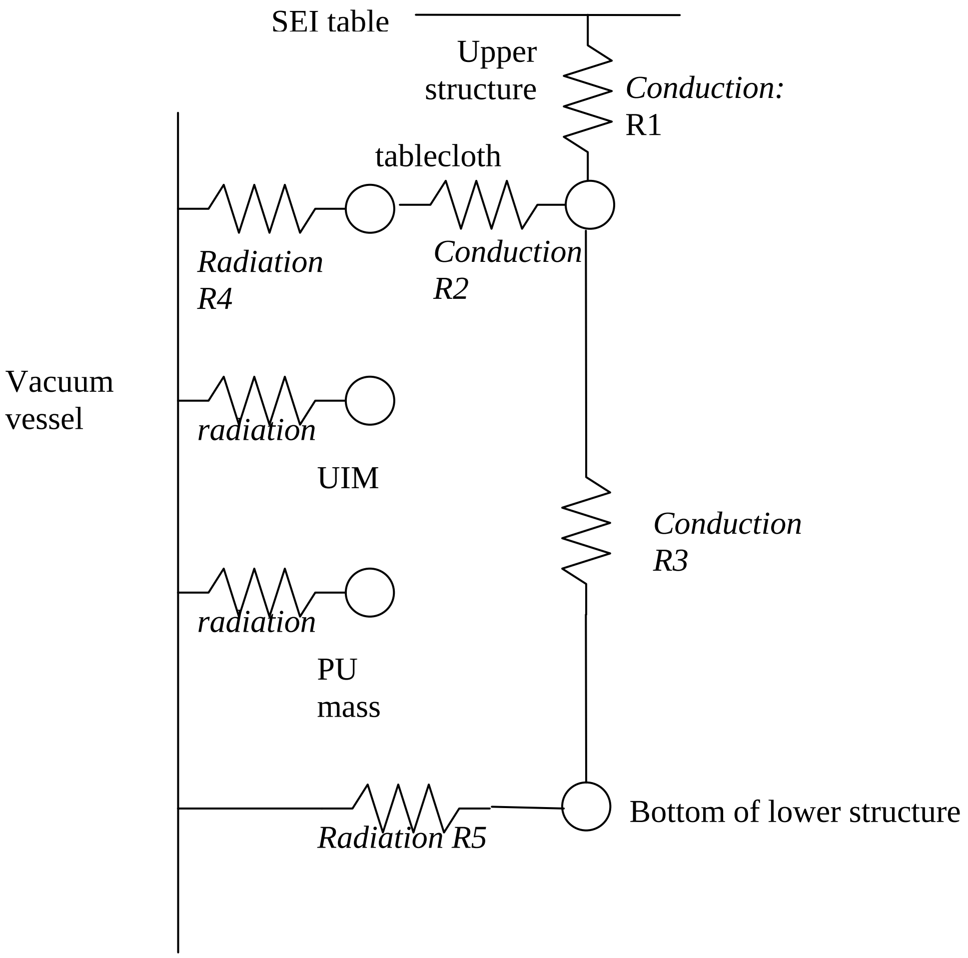
4.3 Limits

The ultimate reasons for doing this work are to check that

- we are not dumping excessive heat to the seismic platform and
- that the temperature of the SUS does not exceed
    - the degradation temperature limit of the magnets (some fraction of the curie point),
    - the operational temperature limit of the emitters and detectors,
    - a temperature in any other parts sufficiently high to generate outgassing concerns, and
- that the temperature change in the structure does not lead to excessive loss of clearance with the earthquake stops and
- that the temperature changes do not give unacceptable effects on the blade springs (through change in modulus with temperature).

5 Thermal model

The work in G060109 showed that a simple conduction-only model of the suspensions would not be adequate. A slightly more sophisticated model is developed here.



The nodes in the model are the points where heat will be injected. The tablecloth and two of the masses in the reaction chain will receive heat from the OSEMs. At the bottom of the structure there will be a heat input from the ring heaters. Radiative links are shown from each of these points to the vacuum vessel walls, and conductive links are shown from the tablecloth to the SEI and from the bottom of the structure to the upper structure/tablecloth area. I assume that the suspension wires have not significant thermal conductivity. I have ignored pro tem radiative heating of the structure by the warmed masses – since the structure obscures of order 25% of the view factor from the masses than it is likely that no more about 25% of the heat load from the masses will go to the structure. If the structure is itself warm, then the heat transfer will be correspondingly lower.

The problem then decouples into three parts. Each suspended mass can be treated on its own, and the structure makes the third part.

5.1 The suspended masses

For the suspended masses, the previous estimates (referred to in section 2 above) varied between 0.5W and 2W to give a temperature rise of 10 degrees for a test-mass (or tablecloth) sized object. Given that the worst-case OSEM heating is around 1W per OSEM in acquisition mode and significantly less in science mode, and there are four OSEMs per mass, then it seems reasonable to conclude that heating will not be a big issue for these masses, with a maximum temperature rise of around 5 degrees. Note also that if 25% of the heat from the mass ends up on the structure, we are looking at much less than 1W from each mass into the structure in the steady state.

5.2 The structure

5.2.1 Conductive paths

From previous work (T050037), the resistances of the links from the upper structure are

R= 2.6 K/W for the path over the tablecloth from an OSEM to the joint with the structure.

R=3 K/W for each of four legs on the upper structure (we ignore, conservatively, conduction along the diagonal cross-braces).

Treating all 12 OSEMs as occupying a single node in the model, the conduction from there to the bottom of the structure consists of 12 paths in parallel (R1 in the diagram):

$$R1 = 2.6/12 = 0.2 \text{ K/W}$$

And taking the four legs in parallel to link the bottom of the upper structure to the SEI (R2 in the diagram)

$$R2 = 3/4 = 0.75 \text{ K/W}$$

The conductive path from the bottom to the top of the structure (R3) in the diagram will involve the lower structure and the sleeve in parallel. The total cross – section may be taken as roughly equivalent to eight members each 50mm square by 5mm wall and 800mm long in aluminum alloy.

The conductivity is

$$R3 = \frac{length}{area * conductivity} = \frac{0.8}{(0.05^2 - 0.04^2) * 170} = 5\,\mathrm{K/W}$$

5.2.2 Radiative paths

In T050037, an estimate was made for radiative linking of the tablecloth to the environment by assuming an area equivalent to a flat sheet 0.3m by 0.3m of

$R4 = 20\,\mathrm{K/W}$ (it was given in that paper as 0.05 W/K)

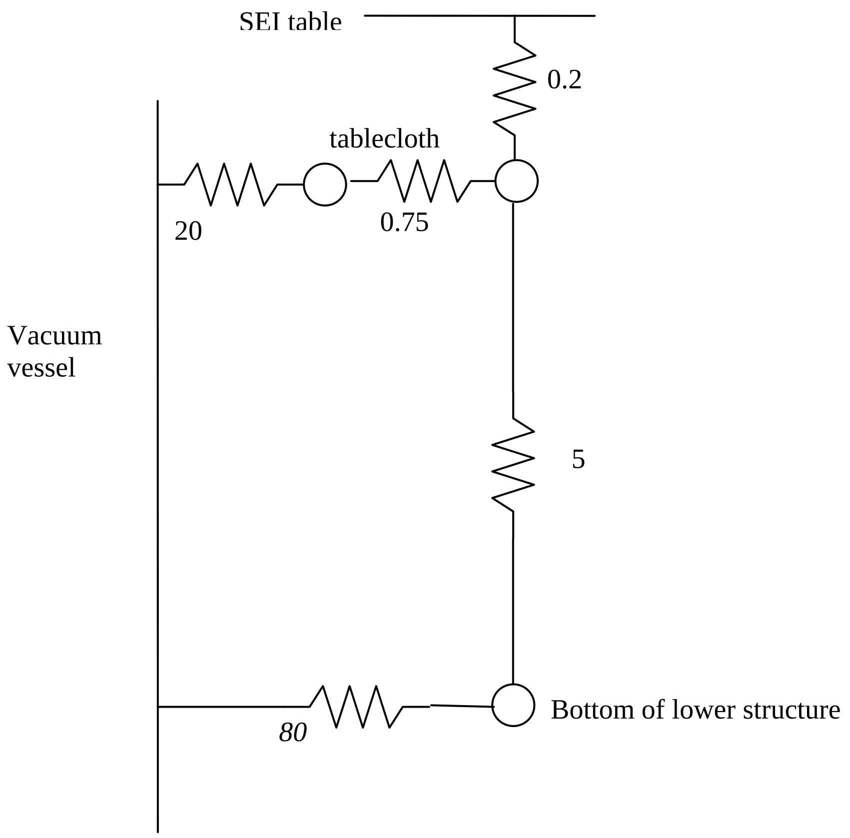
This assumed that the temperature difference between the tablecloth and the wall was small compared to their absolute temperatures.

The total surface area of the lower structure is complex to work out, and in case allowance would need to be made for shadowing of some parts by others. Assume very roughly that the bottom part of the lower structure can be approximated to a flat sheet 150mm by 150mm, with two sides. This would be a quarter of the area used in the tablecloth approximation so the resistance would come to

$R4 = 20 * 4 = 80\ \mathrm{K/W}$

5.2.3 The model, with numbers

Transferring the numbers above to the model gives:



For the results we need, we can ignore the radiative links because they are short-circuited by conductive links.

There are then two largely decoupled issues.

5.2.4 Heating by local control OSEMs

Assume the worst case, that 12 of the OSEMs all dissipate. Ignore heating at the bottom of the structure. The temperature rise is then

$$\Delta T = Q(R1 + R2) = 12\left(0.2 + 0.75\right) \approx 12K$$

(For reference, T050037 had a 5K rise for four energised OSEMs)

5.2.5 Heating by ring heater

Since the resistance of the upper structure is small compared to that of the lower structure, ignore the upper structure and we get simply:

$$\Delta T = QR$$

$$\Delta T = 5Q$$

Where Q is the heat dumped into the structure by the ring heater in Watts, and ΔT is the resulting temperature rise.

6 Effects of temperature rise on OSEMs and magnets

The temperature rises of the locations where OSEMs are fixed are of the order of 10 degrees. This is expected to be small compared to thermal gradients within the OSEMs and so should not have a big effect on the lifetime of the OSEMs.

All of the magnets in the noise prototype design are fixed suspended masses and so will undergo temperature changes smaller than those seen by the OSEMs. This should not pose any problems: the temperature limits on the magnets are at least 80 degrees.

7 Effect of temperature rises on dimensional stability

7.1 Effect on the structure

A rise of 10 degrees at the bottom of the structure would lead to an average temperature rise of ~5 degrees across the whole structure. This would cause an expansion in the aluminium of

$$\Delta l = l\alpha\Delta T$$

Where $\alpha \approx 23$ microns per metre per degree, giving Δl over the 2-metre structure of about 230 microns for a 10 degree temperature rise. The steel wires in the chains will move by about half this amount for a similar temperature change, offsetting the loss of stop clearance but also leading to differences between the chains.

7.2 Effect on the blade springs

The blade springs have a large deflection and so will be sensitive to temperature-induced changes in modulus. The masses that might be heated are the UI reaction mass, which is equipped with OSEMs, and the top masses, which are surrounded by the tablecloth and are probably more efficiently connected to it by radiation than to anything else by conduction down the wires.

The change in modulus with temperature is given in Braccini et al, Meas Sci Tecnol 11 (2000) equation (14) as 2.54E-4 per degree. Blade deflection is proportional to temperature, so the deflection will change by the same factor. With an initial deflection of order 200 mm, a typical blade tip will move by

$$\Delta d = 200 \times 2.54 \times 10^{-4} = 0.05 \text{ mm per degree.}$$

Since there are two sets of blades liable to heating (top mass, UI mass), consider the effect of a change of 5 degrees at each. This would give a total of around $5 \times 0.05 \times 2 =\sim 0.5$ mm. This might give problems with the stops.

8 Summary

- The OSEMs on the tablecloth will dissipate up to ~10W between them and this will raise the temperature of the tablecloth by about 10 degrees. This will raise the temperature of the upper structure where it connects to the tablecloth by about 10 degrees, ramping down to ~zero at the junction with the SEI. The tablecloth will also heat the top mass and its blade springs, which will deflect by about 0.25mm for a 5 degree temperature change.

- The OSEMs on the UIM will raise the temperature of that mass by up to about 5 degrees (main chain only), causing its blade springs to deflect by about 0.25 mm.
- The ring heater will raise the temperature of the bottom of the structure by about 5 degrees per Watt of heat load. Each ten degrees rise at the bottom of the structure will cause the structure to expand by about 0.25mm.

9 Conclusions

1. Most of the heat put into the local control OSEMs, and most of the heat dumped to the structure from the ring heaters, will be passed to the SEI by conduction. Radiation to the walls of the vessel will not be a large contributor (at least, not in the temperature ranges for which the structure is designed). The heat from OSEMs will be no more than about 12W, and that from ring heaters should not exceed about 8W, bringing the total to 20W.
2. The effect on OSEM and magnet performance of heating at this level will be small.
3. However the effect on structural alignment could be troublesome and so
    a. We should do all we can to minimise heating from the OSEMs and the ring heaters
    b. We should discover as much as we can about these effects from the controls prototype
    c. We should test as soon as possible the effects of the various heat sources. This must be done in vacuum and can only practicably be done on the noise prototype at LASTI.
4. Other options include
    a. Partially compensating for the known expansions by adjusting the stop positions in the “cold” state to allow (approximately) for anticipated movements
    b. Fitting a small heater to the bottom of the structure to actively control the temperature.
5. It would be worth checking the conductivity paths using the extant FEA model converted to thermal form.

10 Addendum – email from Ken Strain.

From: k.strain [mailto:k.strain@physics.gla.ac.uk]
Sent: 20 February 2004 17:05
To: Alberto Vecchio
Cc: J.Greenhalgh@rl.ac.uk; nick@phys.strath.ac.uk; (cut)
Subject: Re: AdvLIGO OSEM/Electronics Telecons and meetings

Dear All,

(cut)

I have done a few rough estimates of allowed heat in the reaction pendulum. Conduction through the suspension wires seems to be too small to help, leaving radiation. It is quite uncertain what emissivity and effective area we'll have from the various masses (especially the metal ones, as the surface finish is important). My best guess is that ~ 2 W is about as much as we can allow for of order 10K increase.

(cut)

Cheers,
Ken