LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO-T1200416-v1 *ADVANCED LIGO* 27 August 2012

First Contact and its Effect on Pitch of Optics

Mark Barton

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of the LIGO Laboratory.

California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

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1 Introduction

1.1 Purpose and Scope

A quick compilation of calculations of the amount a film of First Contact on a hanging optic perturbs its pitch. QUAD (monolithic, CP, and ERM), HSTS, HLTS and BSFM are considered.

1.2 Version history

8/27/12: -v1.

2 Background

It is desirable to leave a film of First Contact on optics as long as possible during installation and initial alignment, to protect the optics and keep them clean. However the pitch offset on a hanging optic due to the weight of the film is significant compared to the precision the pitch needs to be measured and set.

To help set requirements, Mathematica models of the major types of suspension, QUAD (monolithic, CP, and ERM), HLTS, HSTS, and BSFM, were used to calculate the effect of added mass on the surface of optics.

3 Theory

The compliance of the optic in pitch can be calculated as the real part of the DC value of the transfer function from pitch torque at the optic to pitch displacement of the optic, by the Mathematica command

```
Re[calcTFf[eom2, makefinputvector[pitch3], makeoutputvector[pitch3], 0]]
```

The torque due to a mass `m` on the surface is

```
m*g*tx/2
```

where `g` is gravity and `tx` is the thickness of the optic. The mass of a layer of thickness `t` is

```
rho*t*Pi*tr^2
```

where `rho` is the mass-volume density of the dried First Contact, and `tr` is the optic radius (assuming First Contact applied over the whole face). The product `rho*t` can also be considered jointly as a mass-area density.

Since it might be convenient to do further calculations in any of torque, mass and areal density, the pitch compliance w.r.t. all three were all calculated and are presented in Table 1. For ease of scaling, a hopefully representative reference area density of 1000 kg/m^3 * 0.0001 m = 0.1 kg/m^2 was chosen.

Table 1

Quantity	Monolithic	CP	ERM[1]	BSFM	HLTS	HSTS
pitch compliance rad/(N.m)	0.116	0.108	0.107	0.784	0.609	2.92
mass compliance rad/kg, or mrad/g	0.113	0.0532	0.0528	0.220	0.299	1.06
areal density compliance mrad/(0.1 kg/m^2)	1.03	0.484	0.479	2.36	1.65	1.88

4 Conclusion

The effect on pitch of a layer of fixed areal density of First Contact is moderately clustered - plus or minus a bit over a factor of two. The most sensitive is the BSFM and the least sensitive is the CP (as noted in a footnote to Table 1, the value for the ERM is an underestimate).

5 Appendix

In the PDF version of this report, printouts of the Mathematica notebooks with the calculations will be appended, to serve as documentation of the exact cases used.

[1] In the course of the calculations for this document, a non-trivial error was noticed in the ERM case based on the Matlab parameter set ^/trunk/QUAD/Common/MatlabTools/QuadModel_Production/quadopt_erm.m r2731 in the SUS SVN: the optic thickness was 100 mm (as for the CP) rather than 130 mm. The main effect is to reduce the lever arm converting mass to torque, so that the mass and area density numbers above are underestimates. This will be corrected as soon as possible.

Standard calculation of QuadLite2Lateral model with First Contact calculation

Setup

Switches to enable loading of previously saved results instead of recalculating from scratch

In[1]:=
```
useprecomputed = True; (* set to True to use saved results from precomputed subdirectory *)
If[useprecomputed,
    exceptdamping = False, (* False by default, True to recalculate just damping-dependent stuff*)
    exceptdamping = True (* DON"T CHANGE *)
];
```

In[3]:=
```
loadcasefromuser["ASUS4XLLateralCaseDefn.m"];
```

In[4]:=
```
modelcase
```

Out[4]=
```
{mark.barton, 20120601TMproductionTM}
```

In[5]:=
```
modelcasecomment
```

Out[5]=
```
20120601TMproductionTM, equivalent to
  ^trunk/QUAD/Common/MatlabTools/QuadModel_Production/quadopt_fiber.m r2731 of 6/1/12
```

In[6]:=
```
Calculate[Stage2]
```

First Contact calculation

Pitch compliance at optic in rad/(N.m)

In[7]:=
```
comp = Re[calcTFf[eom2, makefinputvector[pitch3], makeoutputvector[pitch3], 0]]
```

Out[7]=
```
0.115664
```

Effect of First Contact or other mass on surface of optic, in rad/kg or mrad/g

In[8]:=
```
comp * g * tx / 2 /. constval
```

Out[8]=
```
0.113466
```

Effect of layer of First Contact of density*thickness product 0.1kg/m^2 (e.g., 1000 kg/m^3 times 0.0001 m), in mrad

In[9]:=
```
1000 * 0.1 * Pi * tr^2 * comp * g * tx / 2 /. constval
```

Out[9]=
```
1.03018
```

Standard calculation of QuadLite2Lateral model with First Contact calculation

Setup

Switches to enable loading of previously saved results instead of recalculating from scratch

In[1]:=
```
useprecomputed = True; (* set to True to use saved results from precomputed subdirectory *)
If[useprecomputed,
    exceptdamping = False, (* False by default, True to recalculate just damping-dependent stuff*)
    exceptdamping = True (* DON"T CHANGE *)
];
```

In[3]:=
```
loadcasefromuser["ASUS4XLLateralCaseDefn.m"];
```

In[4]:=
```
modelcase
```

Out[4]=
```
{mark.barton, 20120601TMproductionCP}
```

In[5]:=
```
modelcasecomment
```

Out[5]=
```
Corresponds to ^/trunk/QUAD/Common/MatlabTools/QuadModel_Production/quadopt_thincp.m
  r2731 of 6/1/12. Some minor errors in r2731 (MOIs of mass 1) have been reproduced.
```

In[6]:=
```
Calculate[Stage2]
```

First Contact calculation

Pitch compliance at optic in rad/(N.m)

In[7]:=
```
comp = Re[calcTFf[eom2, makefinputvector[pitch3], makeoutputvector[pitch3], 0]]
```

Out[7]=
```
0.108211
```

Effect of First Contact or other mass on surface of optic, in rad/kg or mrad/g

In[8]:=
```
comp * g * tx / 2 /. constval
```

Out[8]=
```
0.0532471
```

Effect of layer of First Contact of density*thickness product 0.1kg/m^2 (e.g., 1000 kg/m^3 times 0.0001 m), in mrad

In[9]:=
```
1000 * 0.1 * Pi * tr^2 * comp * g * tx / 2 /. constval
```

Out[9]=
```
0.483754
```

Standard calculation of QuadLite2Lateral model with First Contact calculation

Setup

Switches to enable loading of previously saved results instead of recalculating from scratch

```
useprecomputed = True; (* set to True to use saved results from precomputed subdirectory *)
If[useprecomputed,
    exceptdamping = False, (* False by default, True to recalculate just damping-dependent stuff*)
    exceptdamping = True (* DON"T CHANGE *)
];
```

```
loadcasefromuser["ASUS4XLLateralCaseDefn.m"];
```

```
modelcase
```

```
{mark.barton, 20120601TMproductionERM}
```

```
modelcasecomment
```

```
Corresponds to ^/trunk/QUAD/Common/MatlabTools/QuadModel_Production/quadopt_erm.m r2731
  of 6/1/12. Known errors in r2731 (in tx and MOIs for UIM and ERM) have been reproduced.
```

```
Calculate[Stage2]
```

First Contact calculation

Pitch compliance at optic in rad/(N.m)

```
comp = Re[calcTFf[eom2, makefinputvector[pitch3], makeoutputvector[pitch3], 0]]
```

```
0.107202
```

Effect of First Contact or other mass on surface of optic, in rad/kg or mrad/g

```
comp * g * tx / 2 /. constval
```

```
0.0527509
```

Effect of layer of First Contact of density*thickness product 0.1kg/m^2 (e.g., 1000 kg/m^3 times 0.0001 m), in mrad

```
1000 * 0.1 * Pi * tr^2 * comp * g * tx / 2 /. constval
```

```
0.479246
```

Calculation of TripleLite2 model with First Contact calculation

Setup

Switches to enable loading of previously saved results instead of recalculating from scratch

In[1]:=
```
useprecomputed = True; (* set to True to use saved results from precomputed subdirectory *)
If[useprecomputed,
    exceptdamping = False, (* False by default, True to recalculate just damping-dependent stuff*)
    exceptdamping = True (* DON"T CHANGE *)
];
```

In[3]:=
```
loadcasefromuser["ASUS3L2ModelCaseDefn.m"];
```

In[4]:=
```
modelcase
```

Out[4]=
```
{mark.barton, 20120120bsNW}
```

In[5]:=
```
modelcasecomment
```

Out[5]=
```
Same as Jeff K's Matlab model bsfmopt_metal.m Rev 2005 of 1/19/12 (no wedge)
```

In[6]:=
```
Calculate[Stage2]
```

First Contact calculation

Pitch compliance at optic in rad/(N.m)

In[7]:=
```
comp = Re[calcTFf[eom2, makefinputvector[pitch3], makeoutputvector[pitch3], 0]]
```

Out[7]=
```
0.784482
```

Effect of First Contact or other mass on surface of optic, in rad/kg or mrad/g

In[8]:=
```
comp * g * tx / 2 /. constval
```

Out[8]=
```
0.219676
```

Effect of layer of First Contact of density*thickness product 0.1kg/m^2 (e.g., 1000 kg/m^3 times 0.0001 m), in mrad

In[10]:=
```
1000 * 0.1 * Pi * tr^2 * comp * g * tx / 2 /. constval
```

Out[10]=
```
2.36198
```

Calculation of TripleLite2 model with with First Contact calculation

Setup

Switches to enable loading of previously saved results instead of recalculating from scratch

In[1]:=
```
useprecomputed = True; (* set to True to use saved results from precomputed subdirectory *)
If[useprecomputed,
    exceptdamping = False, (* False by default, True to recalculate just damping-dependent stuff*)
    exceptdamping = True (* DON"T CHANGE *)
];
```

In[3]:=
```
loadcasefromuser["ASUS3L2ModelCaseDefn.m"];
```

In[4]:=
```
modelcase
```

Out[4]=
```
{mark.barton, 20120120hlts}
```

In[5]:=
```
modelcasecomment
```

Out[5]=
```
Equivalent to Jeff K's hltsopt_metal.m revision 2034 of 1/24/12 for PR metal build.
```

In[6]:=
```
Calculate[Stage2]
```

First Contact calculation

Pitch compliance at optic in rad/(N.m)

In[7]:=
```
comp = Re[calcTFf[eom2, makefinputvector[pitch3], makeoutputvector[pitch3], 0]]
```

Out[7]=
```
0.608859
```

Effect of First Contact or other mass on surface of optic, in rad/kg or mrad/g

In[8]:=
```
comp * g * tx / 2 /. constval
```

Out[8]=
```
0.298645
```

Effect of layer of First Contact of density*thickness product 0.1kg/m^2 (e.g., 1000 kg/m^3 times 0.0001 m), in mrad

In[9]:=
```
1000 * 0.1 * Pi * tr^2 * comp * g * tx / 2 /. constval
```

Out[9]=
```
1.64716
```

Calculation of TripleLite2 model with with First Contact calculation

Setup

Switches to enable loading of previously saved results instead of recalculating from scratch

In[1]:=
```
useprecomputed = True; (* set to True to use saved results from precomputed subdirectory *)
If[useprecomputed,
    exceptdamping = False, (* False by default, True to recalculate just damping-dependent stuff*)
    exceptdamping = True (* DON"T CHANGE *)
];
```

In[3]:=
```
loadcasefromuser["ASUS3L2ModelCaseDefn.m"];
```

In[4]:=
```
modelcase
```

Out[4]=
```
{mark.barton, 20120120hsts}
```

In[5]:=
```
modelcasecomment
```

Out[5]=
```
Equivalent to Jeff K's hstsopt_metal.m revision 2007 of 1/19/12.
```

In[6]:=
```
Calculate[Stage2]
```

First Contact calculation

Pitch compliance at optic in rad/(N.m)

In[7]:=
```
comp = Re[calcTFf[eom2, makefinputvector[pitch3], makeoutputvector[pitch3], 0]]
```

Out[7]=
```
2.91721
```

Effect of First Contact or other mass on surface of optic, in rad/kg or mrad/g

In[8]:=
```
comp * g * tx / 2 /. constval
```

Out[8]=
```
1.06387
```

Effect of layer of First Contact of density*thickness product 0.1kg/m^2 (e.g., 1000 kg/m^3 times 0.0001 m), in mrad

In[9]:=
```
1000 * 0.1 * Pi * tr^2 * comp * g * tx / 2 /. constval
```

Out[9]=
```
1.88001
```