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Violin Mode Frequency Summary

Mark Barton

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| **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](mailto: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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# Introduction

## Purpose and Scope

This is a summary of estimated violin mode frequencies and Qs for all wires in all suspensions.

## References

LLO alog entries [4470](https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=4470), [4472](https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=4472), [5097](https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=5097), [5280](https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=5280)

G. Cagnoli et al., Phys. Lett. A 255 (1999), p230

[T0900415](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=5084): Upper Limit to Suspension Thermal Noise from LIGO 1 and Implications for Wire Suspensions in Advanced LIGO

T070101: [Dissipation Dilution](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=27812)

T080096: [Wire Attachment Points and Flexure Corrections](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=10955)

LIGO-T0900435: [HAM Small Triple Suspension (HSTS) Final Design Document](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=5424)

LIGO-D020700: [HSTS Overall Assembly](https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=6873)

Cumming et al., Design and development of the advanced LIGO monolithic fused silica suspension, Class. Quantum Grav. 29 (2012) 035003.

T1200418: [LLO MC2 Violin Mode Q](https://dcc.ligo.org/LIGO-T1200418)

## Version history

10/24/13: -v1.

3/6/14: -v2. Added damping theory, calculated Qs and associated parameters. Used updated models for BS, TMTS First Article and Production, HAUX and HTTS.

9/10/14: -v3 with renumbering of equations and fix to Eq. 1.11 ( should have been ).

3/9/15: -v4 with correction of fibre modes (had used neck thickness rather than centre section thickness, so modes too low by about √2), and update of model from 20120601TMproductionTM to .

# Theory

The following theory is borrowed from T1200418 (LLO MC2 Violin Mode Q).

## Mode Frequencies

Per Eq. 2.67 of Fletcher and Rossing, to second order in small quantities, the frequency of a violin mode is



(Their  has been renamed to avoid confusion with the thermodynamic material property used below.)



Here is the mode number, and



,



is the frequency of a wire without bending stiffness but the same length , tension and mass per length .



The dimensionless quantity (formerly) is



where is the radius of gyration of the wire, is the Young’s Modulus, and is the cross-sectional area, but it is closely related to the usual flexure length, defined (T080096) as



Here, is the second moment of area of the wire in the bending direction, equal to in any direction for a wire of circular cross-section. (The moments of area of the bottom wires in the longitudinal and transverse directions are called M31 and M32 in the model code.)



It is convenient and instructive to put the above formula in terms of :



This makes it obvious that to first order in  (≈ 0.00248 for the HSTS) the effect is simply to shorten the wire by one flexure length  at each end for all harmonics. This is consistent with the fact that a wire of non-zero bending stiffness does not bend sharply at the clamp point but along a curve that for most purposes gives the effect of a pivot away from the attachment point. In addition, there is also a tiny shortening second order in both and mode number . The plain term disappears because it turns out to be an artifact of doing the expansion in the numerator rather than the denominator, i.e.,



In a practical suspension with multiple wires which may not be exactly vertical, the tension is given by



where m is the net mass supported by a set of wires, g is local gravity (taken to be 9.81 m/s2), is the number of wires sharing the load, and is the angle of the wires to the vertical. The cross-sectional area and moment of area are



where r is the radius.

## Damping

The  of the violin mode depends on the material damping factor  and the dissipation dilution factor . The damping factor is modeled as a frequency-independent structural term  (Cagnoli et al. 1999; also T0900415) plus a thermoelastic term:

 

where (e.g., Cumming et al.)



is a time constant for heat diffusion across the wire ( is heat capacity,  is heat conductivity and  is diameter), and



is twice the thermoelastic damping at the peak frequency  ( is temperature,  is linear expansion, , and  is stress). The magic number 0.0732 is a geometrical factor for wires of cylindrical shape, equal to  where  is the first zero of the derivative of the first Bessel function of the first kind:



Because the energy in a violin mode is stored in second-order stress changes of the elastic material, dissipation dilution is applicable (T070101) and the quality factor  is not just  for the material, but  where



Again there is a higher order term proportional to , which turns out to be significant.

# Results

The data used to calculate the modes in the following tables were extracted from the indicated Mathematica model/case pairs (specified by location in the SUS SVN relative to ^/trunk/Common/MathematicaModels/). In each case, the notebook used to generate the numbers lives in the mark.barton calculation directory and has a name like XXXXXXXViolinModes.nb. So for example, the Quad Monolithic notebook is

^/trunk/Common/MathematicaModels/QuadLite2Lateral/mark.barton/20120601TMproductionTM/mark.barton/ASUS4XLLateralModelCalcViolinModes.nb

Note that in the above it’s not a mistake that there two levels called mark.barton. The first is a directory of related cases (the production quad model really should be moved out of that personal directory to the top level and will be the next time there’s a pretext to do an update), and the second is a directory of customized calculations for a particular case.

## Monolithic QUAD

For main chain of standard QUAD (ITM or ETM).

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| QUAD fibre: QuadLite2Lateral/mark.barton/20140304TMproductionTM | | | | | | | | | | | | |
| Top Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 123.3 | 2 | 0.9344 | 7800. | 2.12E11 | 0.55 | 449. | 4.534 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 336. | n=2 | 673. | n=3 | 1012. | n=4 | 1354. |  |  |  |  |
| Q | n=1 | 1.46E5 | n=2 | 1.9E5 | n=3 | 1.872E5 | n=4 | 1.663E5 |  |  |  |  |
| UIM Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 101.3 | 4 | 0.891 | 7800. | 2.12E11 | 0.3555 | 308.4 | 2.752 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 495.5 | n=2 | 992.1 | n=3 | 1491. | n=4 | 1994. |  |  |  |  |
| Q | n=1 | 1.125E5 | n=2 | 1.586E5 | n=3 | 1.657E5 | n=4 | 1.538E5 |  |  |  |  |
| PUM Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 79.26 | 4 | 0.9939 | 7800. | 2.12E11 | 0.3175 | 339.9 | 2.923 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 421.3 | n=2 | 843.6 | n=3 | 1268. | n=4 | 1695. |  |  |  |  |
| Q | n=1 | 97700. | n=2 | 1.458E5 | n=3 | 1.609E5 | n=4 | 1.565E5 |  |  |  |  |
| Fibres | | | | | | | | | | | | |
| A more accurate calculation of the fibre f's and Q's can be found in Cumming et al., Class. Quantum Grav. 29 (2012) 035003 | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 39.63 | 4 | 1. | 2200. | 7.27E10 | 0.2 (centre),  0.4 (neck) | 594.6 | 3.859 | 6.191E-8 | 3.9E-7 | 0.000152 | 772. | 1.38 |
| f (Hz) | n=1 | 505.3 | n=2 | 1011. | n=3 | 1518. | n=4 | 2028. |  |  |  |  |
| Q | n=1 | 1.205E9 | n=2 | 1.103E9 | n=3 | 9.658E8 | n=4 | 8.226E8 |  |  |  |  |

## Rehung QUAD

For the ITMy at LHO, rehung on wires after the fibre break incident; slightly different from pilot hang.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| QUAD rehang: QuadLite2Lateral/mark.barton/20120831TMproductionTMrehang | | | | | | | | | | | | |
| Top Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 123.9 | 2 | 0.9344 | 7800. | 2.12E11 | 0.55 | 449.2 | 4.522 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 336.7 | n=2 | 674.5 | n=3 | 1014. | n=4 | 1357. |  |  |  |  |
| Q | n=1 | 1.458E5 | n=2 | 1.901E5 | n=3 | 1.875E5 | n=4 | 1.667E5 |  |  |  |  |
| UIM Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 101.9 | 4 | 0.8912 | 7800. | 2.12E11 | 0.3555 | 308.6 | 2.744 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 496.7 | n=2 | 994.6 | n=3 | 1495. | n=4 | 1999. |  |  |  |  |
| Q | n=1 | 1.119E5 | n=2 | 1.581E5 | n=3 | 1.654E5 | n=4 | 1.538E5 |  |  |  |  |
| PUM Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 79.95 | 4 | 0.9953 | 7800. | 2.12E11 | 0.3175 | 330.8 | 2.917 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 434.7 | n=2 | 870.4 | n=3 | 1308. | n=4 | 1749. |  |  |  |  |
| Q | n=1 | 97550. | n=2 | 1.448E5 | n=3 | 1.59E5 | n=4 | 1.538E5 |  |  |  |  |
| Wires (yes, wires) | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 39.56 | 4 | 1. | 7800. | 2.12E11 | 0.2285 | 604.3 | 2.163 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 229.5 | n=2 | 459.1 | n=3 | 688.9 | n=4 | 918.9 |  |  |  |  |
| Q | n=1 | 1.03E5 | n=2 | 1.49E5 | n=3 | 1.874E5 | n=4 | 2.117E5 |  |  |  |  |

## Pilot Hang QUAD

For the new-style metal build with a wire loop, and also various wire-hung pilot optics.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| QUAD rehang: QuadLite2Lateral/20120831TMproductionTMrehang | | | | | | | | | | | | |
| Top Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 124.3 | 2 | 0.9331 | 7800. | 2.12E11 | 0.55 | 445. | 4.507 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 340.6 | n=2 | 682.3 | n=3 | 1026. | n=4 | 1373. |  |  |  |  |
| Q | n=1 | 1.465E5 | n=2 | 1.903E5 | n=3 | 1.871E5 | n=4 | 1.66E5 |  |  |  |  |
| UIM Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 102.3 | 4 | 0.8929 | 7800. | 2.12E11 | 0.355 | 311. | 2.739 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 493.9 | n=2 | 989. | n=3 | 1486. | n=4 | 1987. |  |  |  |  |
| Q | n=1 | 1.137E5 | n=2 | 1.607E5 | n=3 | 1.684E5 | n=4 | 1.567E5 |  |  |  |  |
| PUM Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 79.99 | 4 | 0.9943 | 7800. | 2.12E11 | 0.3175 | 339. | 2.912 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 424.3 | n=2 | 849.5 | n=3 | 1277. | n=4 | 1707. |  |  |  |  |
| Q | n=1 | 98330. | n=2 | 1.467E5 | n=3 | 1.618E5 | n=4 | 1.573E5 |  |  |  |  |
| Wires (yes, wires) | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 39.6 | 4 | 1. | 7800. | 2.12E11 | 0.2285 | 604. | 2.162 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 229.7 | n=2 | 459.5 | n=3 | 689.5 | n=4 | 919.8 |  |  |  |  |
| Q | n=1 | 3.943E8 | n=2 | 5.718E8 | n=3 | 6.407E8 | n=4 | 6.479E8 |  |  |  |  |

## QUAD CP

For the Compensation Plate (reaction chain of ITM QUAD).

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| QUAD CP: QuadLite2Lateral/mark.barton/20120831TMproductionCP | | | | | | | | | | | | |
| Top Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 122.8 | 2 | 0.9344 | 7800. | 2.12E11 | 0.55 | 449.2 | 4.543 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 335.2 | n=2 | 671.4 | n=3 | 1010. | n=4 | 1351. |  |  |  |  |
| Q | n=1 | 1.448E5 | n=2 | 1.887E5 | n=3 | 1.861E5 | n=4 | 1.654E5 |  |  |  |  |
| UIM Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 100.8 | 4 | 0.8912 | 7800. | 2.12E11 | 0.355 | 308.6 | 2.752 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 494.6 | n=2 | 990.5 | n=3 | 1489. | n=4 | 1990. |  |  |  |  |
| Q | n=1 | 1.111E5 | n=2 | 1.57E5 | n=3 | 1.643E5 | n=4 | 1.528E5 |  |  |  |  |
| PRM Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 79.27 | 4 | 0.994 | 7800. | 2.12E11 | 0.3175 | 330.8 | 2.924 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 433.1 | n=2 | 867.3 | n=3 | 1304. | n=4 | 1743. |  |  |  |  |
| Q | n=1 | 96980. | n=2 | 1.44E5 | n=3 | 1.58E5 | n=4 | 1.528E5 |  |  |  |  |
| CP Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 20.04 | 4 | 1. | 7800. | 2.12E11 | 0.2285 | 604.1 | 3.039 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 163.9 | n=2 | 327.9 | n=3 | 492.2 | n=4 | 656.8 |  |  |  |  |
| Q | n=1 | 69620. | n=2 | 86140. | n=3 | 1.025E5 | n=4 | 1.117E5 |  |  |  |  |

## ERM

For the End Reaction Mass (reaction chain of ETM QUAD).

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| QUAD ERM: QuadLite2Lateral/mark.barton/20120831TMproductionERM | | | | | | | | | | | | |
| Top Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 122.7 | 2 | 0.9344 | 7800. | 2.12E11 | 0.55 | 449.2 | 4.545 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 335. | n=2 | 671.1 | n=3 | 1009. | n=4 | 1351. |  |  |  |  |
| Q | n=1 | 1.446E5 | n=2 | 1.886E5 | n=3 | 1.859E5 | n=4 | 1.653E5 |  |  |  |  |
| UIM Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 100.7 | 4 | 0.8912 | 7800. | 2.12E11 | 0.355 | 308.6 | 2.753 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 494.3 | n=2 | 989.8 | n=3 | 1488. | n=4 | 1989. |  |  |  |  |
| Q | n=1 | 1.11E5 | n=2 | 1.568E5 | n=3 | 1.641E5 | n=4 | 1.526E5 |  |  |  |  |
| PRM Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 79.13 | 4 | 0.994 | 7800. | 2.12E11 | 0.3175 | 330.8 | 2.926 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 432.8 | n=2 | 866.6 | n=3 | 1302. | n=4 | 1741. |  |  |  |  |
| Q | n=1 | 96840. | n=2 | 1.437E5 | n=3 | 1.577E5 | n=4 | 1.526E5 |  |  |  |  |
| ERM Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 25.99 | 4 | 1. | 7800. | 2.12E11 | 0.2285 | 604.1 | 2.668 | 0.0001 | 1.2E-5 | -0.00025 | 460. | 49. |
| f (Hz) | n=1 | 186.4 | n=2 | 373. | n=3 | 559.7 | n=4 | 746.8 |  |  |  |  |
| Q | n=1 | 80280. | n=2 | 1.062E5 | n=3 | 1.295E5 | n=4 | 1.434E5 |  |  |  |  |

## BS

Note the BS has a horizontal wedge, so in reality the left and right wires will have slightly different tensions and thus frequencies.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| BSFM: TripleLite2/mark.barton/20120120bsNW | | | | | | | | | | | | |
| Upper Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 40.42 | 2 | 0.9962 | 7800. | 2.119E11 | 0.3125 | 612. | 2.814 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 237.8 | n=2 | 475.8 | n=3 | 714. | n=4 | 952.7 |  |  |  |  |
| Q | n=1 | 1.142E5 | n=2 | 1.689E5 | n=3 | 1.948E5 | n=4 | 2.001E5 |  |  |  |  |
| Intermediate Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 27.79 | 4 | 0.9747 | 7800. | 2.119E11 | 0.2 | 596. | 1.902 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 225.5 | n=2 | 451.1 | n=3 | 676.8 | n=4 | 902.7 |  |  |  |  |
| Q | n=1 | 1.032E5 | n=2 | 1.336E5 | n=3 | 1.611E5 | n=4 | 1.775E5 |  |  |  |  |
| Optic Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 14.21 | 4 | 1. | 7800. | 2.119E11 | 0.125 | 500. | 1.08 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 303. | n=2 | 606.1 | n=3 | 909.2 | n=4 | 1212. |  |  |  |  |
| Q | n=1 | 1.589E5 | n=2 | 1.505E5 | n=3 | 1.681E5 | n=4 | 1.855E5 |  |  |  |  |

## HLTS

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HLTS: TripleLite2/mark.barton/20120120hlts | | | | | | | | | | | | |
| Upper Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 36.46 | 2 | 0.9651 | 7800. | 2.119E11 | 0.3048 | 202.5 | 2.687 | 0.0002 | 1.2E-5 | -0.00025 | 486. | \ |
| f (Hz) | n=1 | 724.2 | n=2 | 1452. | n=3 | 2188. | n=4 | 2936. |  |  |  |  |
| Q | n=1 | 72420. | n=2 | 85170. | n=3 | 77780. | n=4 | 65220. |  |  |  |  |
| Intermediate Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 24.37 | 4 | 0.9433 | 7800. | 2.119E11 | 0.1702 | 203.6 | 1.4 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 744.2 | n=2 | 1489. | n=3 | 2237. | n=4 | 2987. |  |  |  |  |
| Q | n=1 | 67510. | n=2 | 96720. | n=3 | 1.071E5 | n=4 | 1.053E5 |  |  |  |  |
| Optic Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 12.14 | 4 | 1. | 7800. | 2.119E11 | 0.1346 | 255. | 1.355 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 513.3 | n=2 | 1027. | n=3 | 1542. | n=4 | 2057. |  |  |  |  |
| Q | n=1 | 63750. | n=2 | 81280. | n=3 | 94420. | n=4 | 99490. |  |  |  |  |

## HSTS

Note that some HSTS have a horizontal wedge, so in reality the left and right wires will have slightly different tensions and thus frequencies.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HSTS: TripleLite2/mark.barton/20120120hsts | | | | | | | | | | | | |
| Upper Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 8.987 | 2 | 0.997 | 7800. | 2.119E11 | 0.178 | 295. | 1.938 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 409.9 | n=2 | 820.4 | n=3 | 1232. | n=4 | 1645. |  |  |  |  |
| Q | n=1 | 58340. | n=2 | 80280. | n=3 | 91680. | n=4 | 93430. |  |  |  |  |
| Intermediate Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 5.872 | 4 | 0.9745 | 7800. | 2.119E11 | 0.1 | 167. | 1.034 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 744.6 | n=2 | 1490. | n=3 | 2237. | n=4 | 2987. |  |  |  |  |
| Q | n=1 | 51730. | n=2 | 59200. | n=3 | 66270. | n=4 | 68430. |  |  |  |  |
| Optic Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 2.889 | 4 | 1. | 7800. | 2.119E11 | 0.0597 | 220. | 0.5462 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 650.6 | n=2 | 1301. | n=3 | 1952. | n=4 | 2604. |  |  |  |  |
| Q | n=1 | 2.012E5 | n=2 | 1.357E5 | n=3 | 1.196E5 | n=4 | 1.149E5 |  |  |  |  |

## OMCS

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| OMCS: DualLite2/20130612OMCSmetal4904 | | | | | | | | | | | | |
| Upper Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 10.02 | 2 | 1. | 7800. | 2.12E11 | 0.178 | 249.6 | 1.843 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 511.8 | n=2 | 1024. | n=3 | 1539. | n=4 | 2056. |  |  |  |  |
| Q | n=1 | 57710. | n=2 | 81240. | n=3 | 91050. | n=4 | 90640. |  |  |  |  |
| OMC Bench Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 7.124 | 4 | 1. | 7800. | 2.12E11 | 0.1005 | 220. | 0.986 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 609.4 | n=2 | 1219. | n=3 | 1830. | n=4 | 2441. |  |  |  |  |
| Q | n=1 | 73380. | n=2 | 78070. | n=3 | 88000. | n=4 | 93680. |  |  |  |  |

## TMTS First Article

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TMTS: DualLite2DBLateral/20131224TMTS\_FirstArticle | | | | | | | | | | | | |
| Upper Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 123. | 2 | 0.933 | 7800. | 2.119E11 | 0.55 | 456.2 | 4.529 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 330.4 | n=2 | 661.7 | n=3 | 995.1 | n=4 | 1331. |  |  |  |  |
| Q | n=1 | 1.157E5 | n=2 | 1.325E5 | n=3 | 1.218E5 | n=4 | 1.037E5 |  |  |  |  |
| TransMon Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 78.6 | 4 | 0.9891 | 7800. | 2.119E11 | 0.55 | 801.9 | 8.743 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 103.4 | n=2 | 207.2 | n=3 | 311.8 | n=4 | 417.5 |  |  |  |  |
| Q | n=1 | 59790. | n=2 | 79430. | n=3 | 80120. | n=4 | 72440. |  |  |  |  |

## TMTS Production

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TMTS: DualLite2DBLateral/20131224TMTS\_Production | | | | | | | | | | | | |
| Upper Mass Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 123.9 | 2 | 0.933 | 7800. | 2.119E11 | 0.55 | 456.2 | 4.511 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 331.7 | n=2 | 664.3 | n=3 | 998.9 | n=4 | 1336. |  |  |  |  |
| Q | n=1 | 1.164E5 | n=2 | 1.332E5 | n=3 | 1.225E5 | n=4 | 1.043E5 |  |  |  |  |
| TransMon Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 79.86 | 4 | 0.9889 | 7800. | 2.119E11 | 0.55 | 801.9 | 8.671 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 104.2 | n=2 | 208.9 | n=3 | 314.2 | n=4 | 420.7 |  |  |  |  |
| Q | n=1 | 60580. | n=2 | 80520. | n=3 | 81260. | n=4 | 73500. |  |  |  |  |

## HAUX

Note this model has not had much validation against installed suspensions.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HAUX: TwoWireSimpleBlades/20131231HAUXdamp | | | | | | | | | | | | |
| Optic Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 0.3738 | 2 | 0.986 | 7800. | 1.65E11 | 0.0762 | 253.8 | 1.705 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 228.3 | n=2 | 456.9 | n=3 | 686.1 | n=4 | 916.3 |  |  |  |  |
| Q | n=1 | 1.316E5 | n=2 | 79260. | n=3 | 56340. | n=4 | 43490. |  |  |  |  |

## HTTS (Tip-Tilt)

Note: to match observed pendulum frequencies, this model has fitted values of the MOIs which were very different (an order of magnitude) from those in the source document P1100090. Very likely the mass is off as well, in which case the tension and VM frequencies could be wrong too.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| HTTS: TwoWireSimpleBlades/20140123HTTSdamp | | | | | | | | | | | | |
| Optic Wires | | | | | | | | | | | | |
| m (kg) | cos | nw | (kg/m3) | Y (Pa) | r (mm) | l (mm) | a (mm) |  | (K-1) | (K-1) | C (J/(kg.K)) | (W/(m.K)) |
| 0.0885 | 2 | 0.9867 | 7800. | 1.65E11 | 0.0635 | 141.9 | 2.447 | 0.0002 | 1.2E-5 | -0.00025 | 486. | 49. |
| f (Hz) | n=1 | 243.9 | n=2 | 490.1 | n=3 | 740.7 | n=4 | 998.4 |  |  |  |  |
| Q | n=1 | 58300. | n=2 | 31380. | n=3 | 18720. | n=4 | 12130. |  |  |  |  |