# Section 10

# Appendix 3A: Dynamic Analysis Of The BSM

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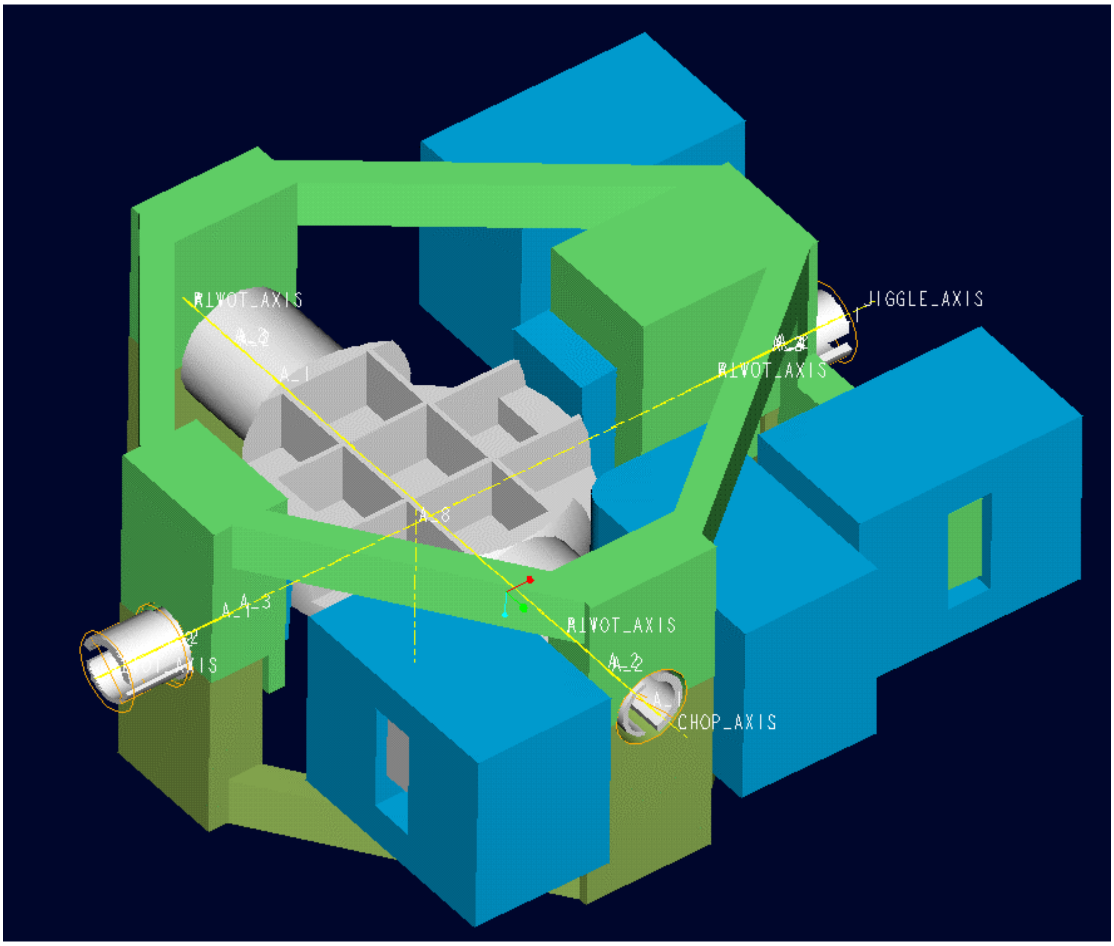
| Document No: | spire-bsm-001-tdn-001.doc.133 |
| | |
| Status: | Draft |
| Version: | 10 |
| Modified by: | Richard Bennett |
| Modified date: | 4 May 2000 7:30 PM |
| | |
| Author: | Richard Bennett |
| Created date: | 4 May 2000 5:04 PM |
| | |
| Category: | Technical Design Note |
| Type: | |
| Generated with: | Microsoft Word 8.0 |

# 1 BSM Design

The SPIRE Beam Steering Mirror has been modelled for finite element analysis as a simplified representation of the Pro/E solid model shown below.

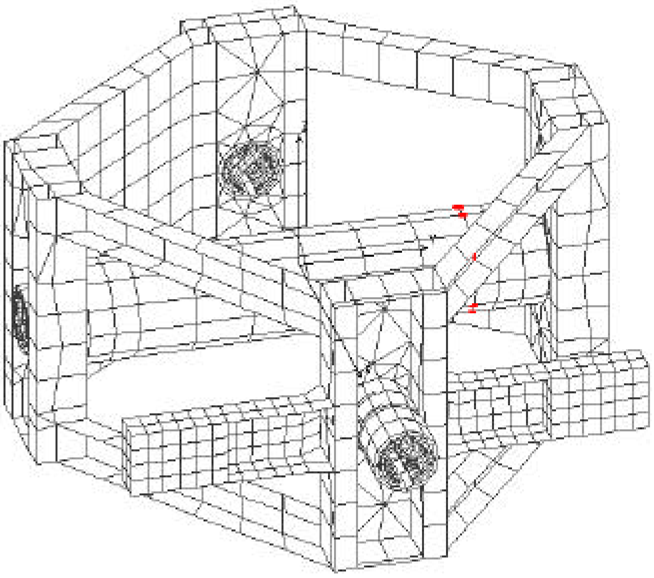



- The chop stage is monolithic. The underside of the mirror is lightweighted and has pockets for the iron plates for the sensors.
- The jiggle stage is split and clamps together around the flex pivots.
- Space envelopes for the coils and sensors (potted) are shown in blue.
- The outer rings of the flex-pivots are not shown for clarity.
- In this revision Lucas 5010-600 pivots have been used for the jiggle axis and 5010-800 for the chop axis. These have torsional stiffnesses of 0.0286 and 0.0036 lb.in/degree respectively.

# 2 FEA Model

## 2.1 Modelling

- The jiggle stage structure has been represented by thin shell elements;
- The chop stage has been represented by a tube of solid elements together with lumped masses (shown red in the illustration below) to give the same mass and moments of inertia as the solid model;
- The flex pivots have been modelled using a combination of solid and shell elements.



- The jiggle stage framework between the flex-pivot housings has been modelled as 5mm x 5mm x 0.5mm channel section.
- The pivots have been moved as far as reasonably practical towards the mirror to minimise the inertia and maximise the stiffness. To clear the coils this leads to an asymmetric arrangement.
- To balance the jiggle stage the framework in the opposite corner to the coils has been made solid. This also increases the stiffness of the structure. Due to the use of lumped masses which do not give the correct products of inertia and also because the jiggle stage has not been dynamically balanced their will be some inaccuracy in modelling coupling of the stages.

## 2.2 Load cases

The follwing analyses have been made:

50 g static load in X,Y and Z directions

Frequency response analysis for excitation of the chop and jiggle stages by couples of 1 Newton forces at the centre of the drive magnets (equivalent forces for the chop stage.)

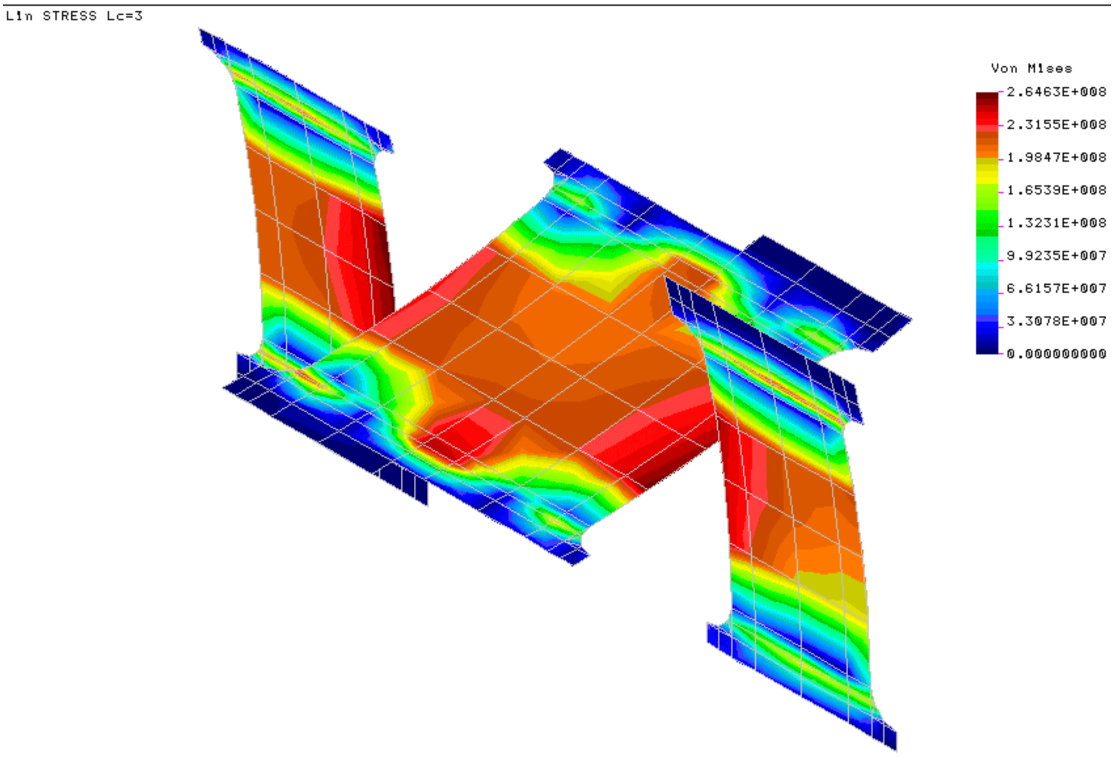
# 3 Results

## 3.1 Static stress analysis

The three load cases (50g in X, Y and Z) lead to stresses in the flexures of similar magnitude.

The highest stress, 265 MPa, occurs in the jiggle axis flex-pivots. The 0.2% proof and ultimate tensile stresses and of 420S29 equivalent to the stainless steel used for these items are 555 MPa and 755 MPa respectively so the design appears relatively safe. <u>It should be noted however that the model is a simplified representation for dynamic analysis and would need refinement for accurate stress calculation.</u>

The load capacity of each of the pivots is 245 N (55 lb) and the weight of the jiggle and chop stages at 50g is 27 N.



## 3.2 Dynamic Analysis

### 3.2.1 Frequency analysis

The model was analysed to obtain the first 50 natural frequencies. The resonant frequencies of the chop and jiggle stages are 23 and 18 Hz respectively.

The first parasitic resonance occurs at 729 Hz.

| FREQUENCY NUMBER | FREQUENCY (RAD/SEC) | FREQUENCY (CYCLES/SEC) | PERIOD (SECONDS) |
|---|---|---|---|
| 1 | .1142200E+03 | .1817867E+02 | .5500952E-01 |
| 2 | .1454493E+03 | .2314898E+02 | .4319844E-01 |
| 3 | .4577739E+04 | .7285698E+03 | .1372552E-02 |
| 4 | .5822649E+04 | .9267033E+03 | .1079094E-02 |
| 5 | .7800567E+04 | .1241499E+04 | .8054781E-03 |
| 6 | .9250813E+04 | .1472313E+04 | .6792036E-03 |
| 7 | .1019618E+05 | .1622772E+04 | .6162294E-03 |
| 8 | .1030486E+05 | .1640069E+04 | .6097305E-03 |
| 9 | .1129106E+05 | .1797028E+04 | .5564743E-03 |
| 10 | .1459196E+05 | .2322382E+04 | .4305923E-03 |

### 3.2.2 Damping

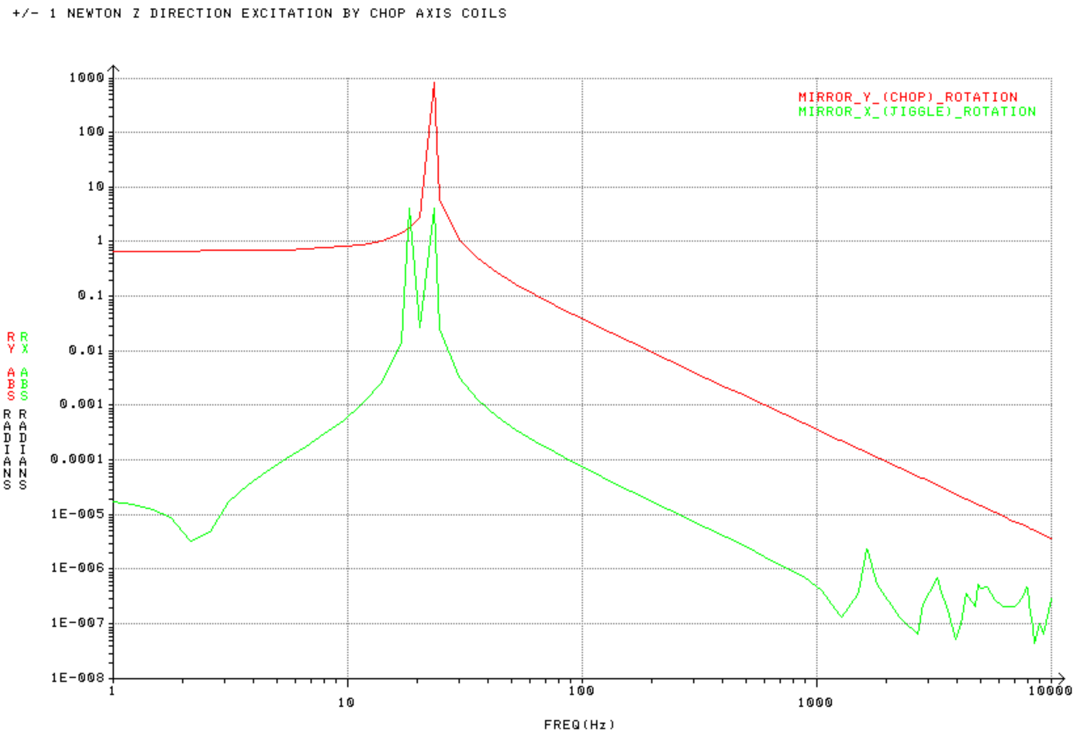
The damping ratio for the near rigid-body modes (chop and jiggle) were set to 0.0004 based on data in the Lucas flex-pivot catalogue. For the higher frequency where the flexure of the jiggle-stage framework is significant the ratio was set to 0.02 which is typical of a well engineered bolted structure.

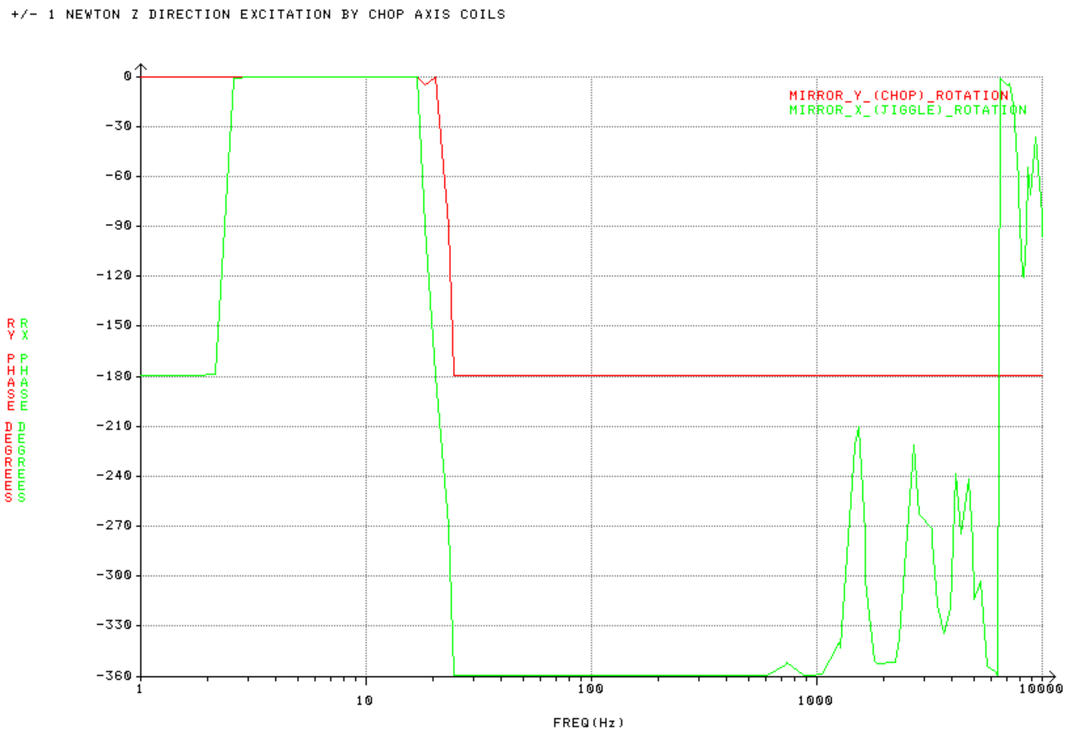
| Set no. | First Mode | Last Mode | Damping Ratio |
|---|---|---|---|
| 1 | 1 | 2 | .4000E-03 |
| 2 | 3 | 50 | .2000E-01 |

### 3.2.3 Chop axis excitation

Forces were applied equivalent to a couple of 1Newton forces acting at the chop magnet radius (15mm from the axis).

Below the resonance the response tends to the static case; a rotation of 0.086 radian.

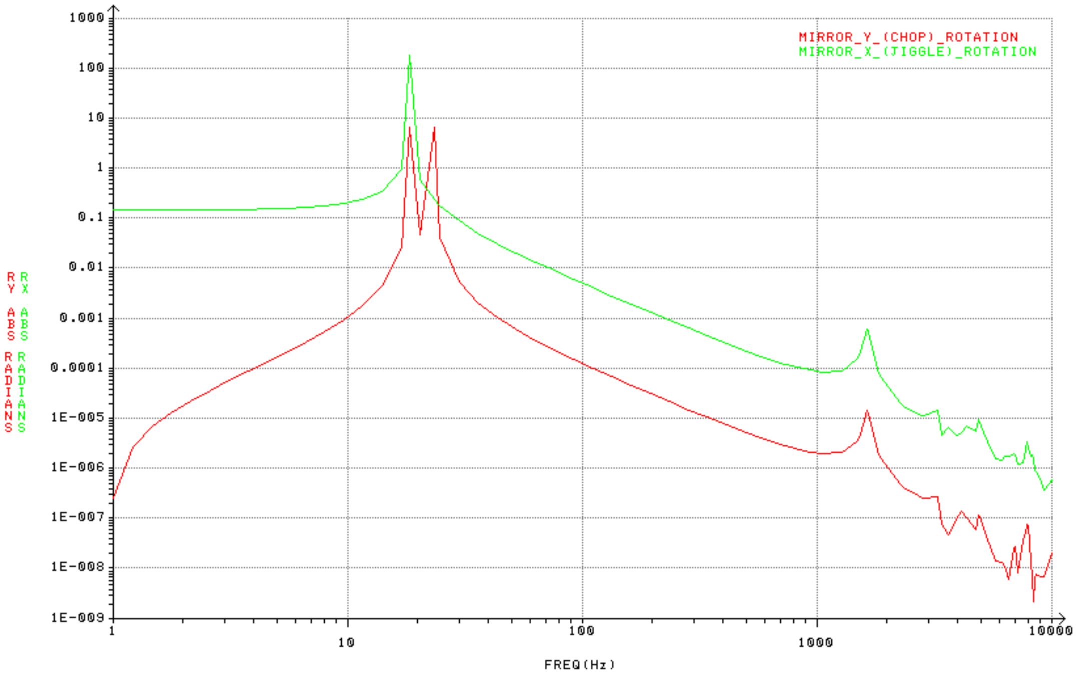



+/- 1 NEWTON Z DIRECTION EXCITATION BY CHOP AXIS COILS
MIRROR_Y_(CHOP)_ROTATION
MIRROR_X_(JIGGLE)_ROTATION
RY PHASE DEGREES
RX PHASE DEGREES
0
-30
-60
-90
-120
-150
-180
-210
-240
-270
-300
-330
-360
1
10
100
1000
10000
FREQ(Hz)

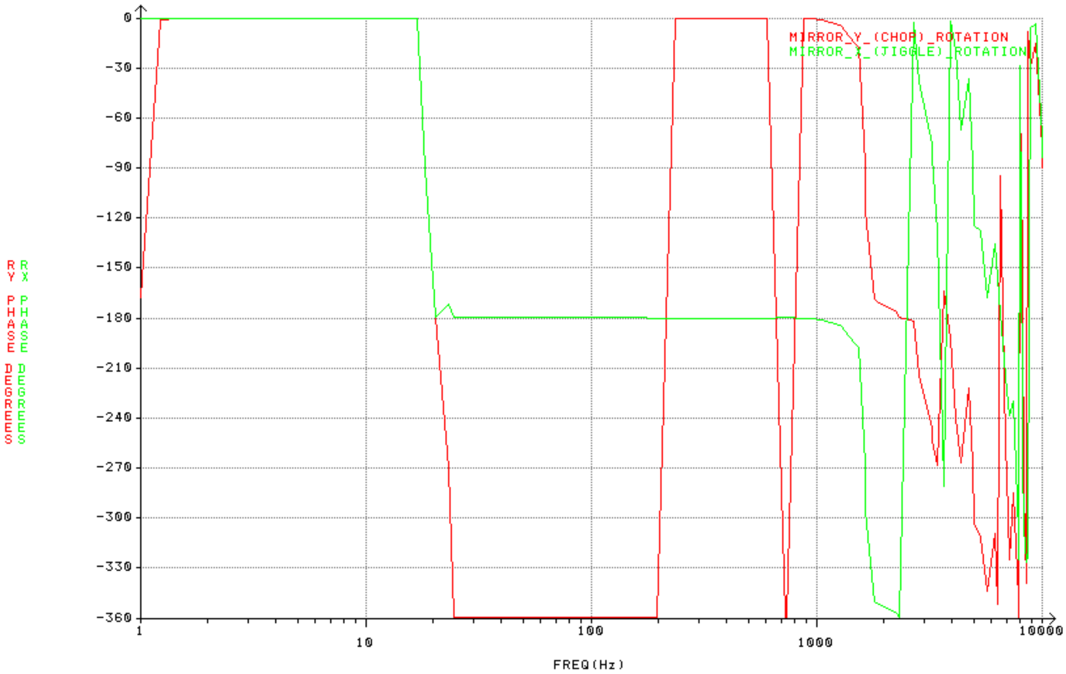
### *3.2.4 Jiggle axis excitation*

A couple of 1Newton forces acting at the centre of the jiggle magnets. Below the resonance the response tends to the static case; a rotation of 0.14 radian.

+/- 1 NEWTON Z DIRECTION EXCITATION BY JIGGLE AXIS COILS




+/- 1 NEWTON Z DIRECTION EXCITATION BY JIGGLE AXIS COILS



# 4 reference

## 4.1 Mass properties

The following parameters are derived from the FEA model. The section dimensions used will be fed back into the solid model and more accurate values obtained in due course.

| Stage | Parameter | Value |
|---|---|---|
| | | |
| Chop | Mass | 0.018 Kg |
| | Moment of Inertia | 2.1 $Kg.mm^2$ |
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| Jiggle | Mass | 0.054 Kg |
| | Moment of Inertia | 27 $Kg.mm^2$ |
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