# BS Final Design Document – T080218-v2

# Joe O'Dell – Jan 2011

# BS Review documentation checklist

| Requirement | Response | Document |
|---|---|---|
| A completed Design Requirements Document (DRD) [by quantifying all "TBD" items and incorporating changes adopted from the DRR] | A new compliance matrix (similar to the E/ITM quad compliance matrix document) specific to the BS | **T080220-00-K** |
| | Updated performance requirement DRD, T010007, based on Peter F.'s recent triple suspension requirements | Awaiting from US |
| | Need to review and then either re-affirm or revise (as appropriate) the generic SUS requirements, T000053 | Awaiting T000053 update |
| A Final Design Document (FDD) which summarizes the design, analysis and prototype testing (and lessons learned) in a single integrated(stand alone) document with pointers to other supporting documents if/as needed | Here we propose a document which point out the key features of the Beamsplitter, and in particular highlights design changes from the quad. This will include images of the Beamsplitter and folding mirror in situ. | **This document** |
| | Checklist | **This document** |
| Design analysis and engineering test data (can be incorporated into the FDD if appropriate) | Tim's FEA documents | **Referenced in this document** |
| | Revised Matlab model/simulation document. | **T040027-03-K** |
| Detailed engineering specifications | Parameter set, and updated values measured from the BS CAD model (showing this is compatible with a current Matlab model) | **T080222-00-K** |
| | plus point to relevant machining specifications | **See drawings** |
| Detailed engineering drawings [mechanical only] | Drawing PDFs | **See drawings** |
| Final parts lists [mechanical only] | Excel parts list document in excel & PDF formats | **T080221-00-K** |
| Final interface control documents [mechanical only] | Combined envelope and assembly drawing | |
| | As we went through the compliance matrix, we noticed that several requirements were not applicable for the BS/FM, and in a few areas where the need was apparent, we looked at the ICDs, to verify that they seemed to | |

| | | |
|---|---|---|
| | us appropriate FM/BS. However, we have not a systematic review of the ICD documents. | |
| Detailed inspection plans/procedures (brief response) | We will use standard RAL procedures, which include that all manufacturing contracts require inspection of parts. In addition we carry out sample checks which can be up to 100 pc depending on results. | |
| Detailed test plans/procedures | A test assembly has been made, and lessons learned applied to the drawings. We do not propose to produce a separate document for this. These plans will be developed further during assembly training and envisaged to include fit checks, weight checks, d-distance setting, stability check, SYS-ID. | |
| Detailed integration plans/procedures | We have carried out an assembly as proof of assembly concept using similar techniques to those of the quad. The assembly is considerably simpler because there are no fibres, and no reaction chain. We don't propose to produce an assembly document for the review; this will be developed in conjunction with the BS assembly training. | **FDD shows how the BS suspension procedures compare favourably in terms of complexity to that of the quad** |
| Written resolution of action items from the DRR/CDR | Relevant actions were incorporated into the E/ITM design which serves as the design heritage for the BS.<br><br>The document that states these actions is T050277-00-R | **This document** |
| Relevant RODA changes and actions completed | A list of relevant RODAs has been included in this document | **This document** |
| Production plans: for acquisition of parts, components, materials needed for fabrication and for assembly & test | We regard this as a "UK problem" and so do not to propose to include it at the review. Separate mechanisms are already in place to ensure compatibility of schedules for training, delivery, etc. | |
| | OK for fabrication and acquisition. However a synopsis of the assembly & test plans especially responsibilities (US vs. UK) for tooling, training, etc. | **M080102-00-K T080223-00-K** |
| Cost/scope compatibility with | We are not aware of any issues. | |

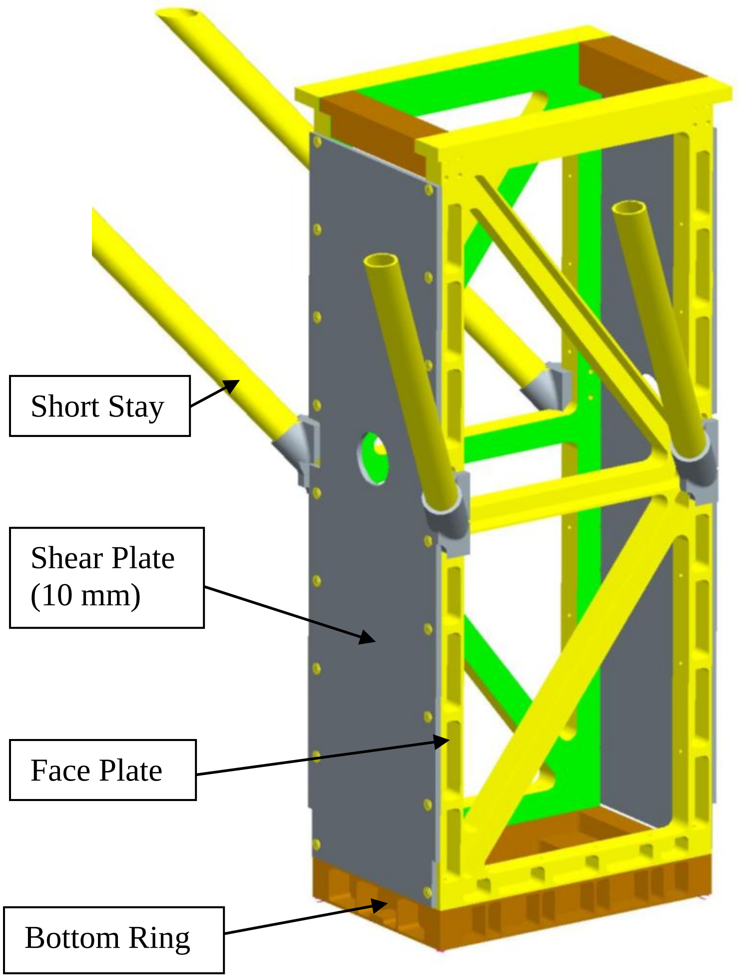
| | | |
|---|---|---|
| RAL work plan (any deviations in scope or quantities noted) | | |
| • updated fabrication, delivery, assembly and test schedule | Delivery/schedule interfaces and assembly & test schedules/plans are incorporated into the Adv. See LIGO project plan and are up to date. | **M080102-00-K** |
| List of problems, risks and concerns | This is included in this document | **This document** |
| | | |

# 1 BS upper structure:

Mass with stays = 100.4 kg
Mass without stays = 90.7 kg

### *1.1 Development Process and FEA*

This Upper structure has gone through an extensive iteration process, through which it has undergone a number of FEA processes in order to optimise the design for the frequency requirements.




In the first instance, a number of different structural concepts were created, with reference to the envelope requirement for the Beamsplitter. These were analysed in the form of beam models, and initial concept was chosen. This concept comprises of two face plates, two shear plates, a bottom ring, and some form of stay design. This process is shown in documents **T070160-00-K** and **T070161-00-K**

The Design then progressed from a beam model, to a solid model, where the conceptual faceplates, shear plates and stays were designed. Document **T080204-00-K** shows the optimisation of the shear plate design, and the justification for the 10mm thickness.

Document **T070033-00-K** shows the FEA for the upper structure with stays, and shows that with the original stay design, although the overall structural frequency is improved, the stays themselves have a low frequency mode, which is relatively high mass.

This has lead to an optimisation process for the stays themselves, resulting in the "short stay" design, labelled in **figure ……** The FEA for this structure is shown in document **T070160-02-K**.

Document **T070161-00-K** also shows in part 6, the rationale for the stay orientations shown in the rendering above. In summary, the stay configuration cannot take the preferred arrangement of symmetrical stays, because the space envelop for the Beamsplitter in the tank does not allow this.

It is evident that the upper structure for the Beamsplitter is very different from that of the Quad. Some of the main differences are as follows:

### *1.2 There are no welds in the BS upper structure*

The welds in the Quad upper structure proved to be problematic, due to the difficulty of producing full penetration welds in aluminium, and for this reason they have been very deliberately avoided in the BS.

### *1.3 The BS upper structure is much longer than that of the Quad*

This is because the BS is a triple, not a quad, and only two masses are housed in the lower structure.

### *1.4 The BS upper structure has stays*

There are a number of reasons why stays are required for the BS upper structure. The reasons for this are shown in the FEA documents mentioned previously, but the following observations can also be made:

- The BS upper structure is much longer than that of the quad, and effectively requires stays as a replacement for the Quad sleeve, even though the quad sleeve supports the lower structure.
- Since the BS is a single chain, the structure is much narrower than that of the quad. This reduced footprint could potentially lower the frequency of the structure considerably, if there were no stays.
- The BS structure uses bolted joints, which are not as effective from a frequency point of view as the welded joints of the Quad upper structure. The bolted joints are however much more effective when supplemented by the stays.

# 2 Lower Structure:

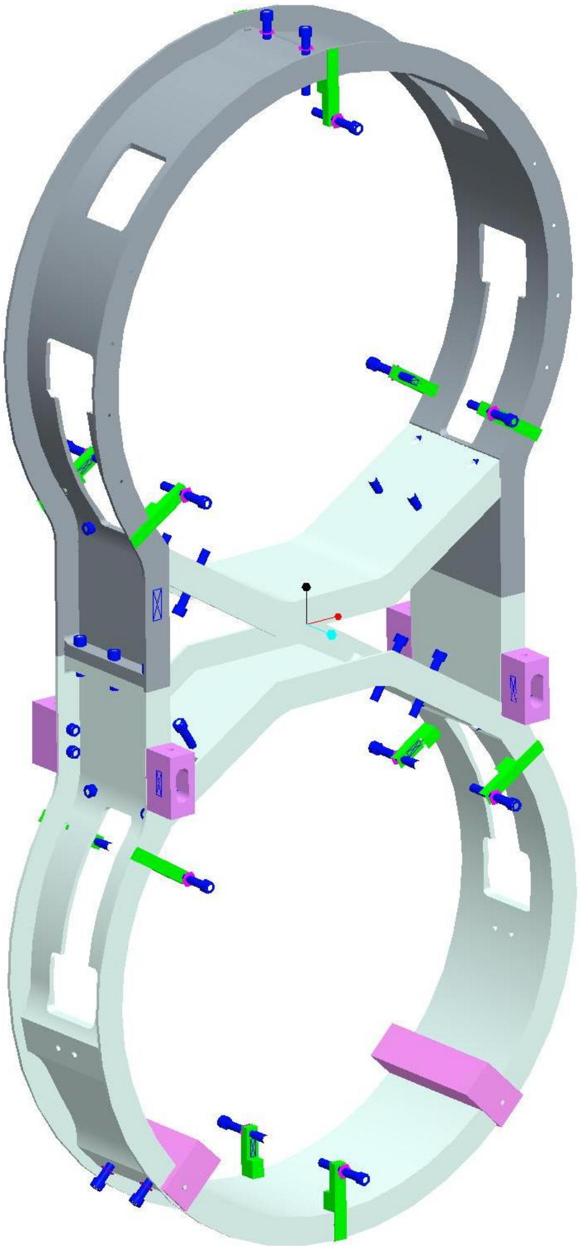
Mass = 6.6 kg

The lower structure for the Beamsplitter is different to that of the quad in a variety of ways, due to a number of factors, many of which relate to each other:

### 2.1 New design principle:

Motivators:

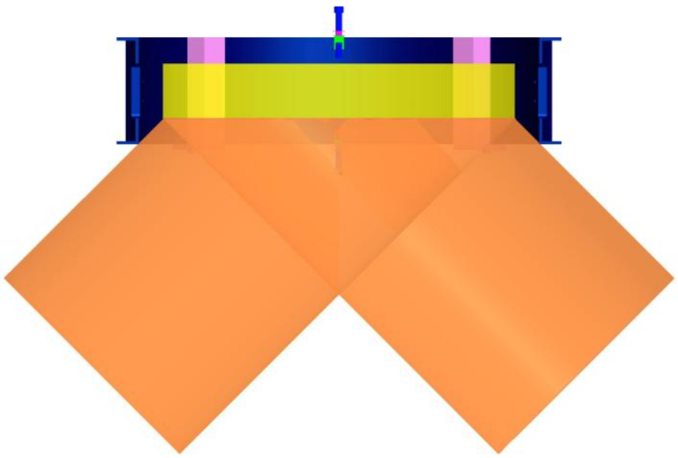
- Importantly, this lower structure only houses two masses, rather than the three masses housed by the quad lower structure. Both the masses housed within this structure are round, and are assembled into the structure before the whole lower structure and masses unit is assembled to the upper structure in a "2 in 1" assembly.



- The masses are much thinner than the round masses of the quad, although they are similar in diameter.
- The beams coming into the BS mirrors come in at 45°, and the structure must not interfere with these.

These factors have lead to the Lower structure design changing from a design with face plates and cross members, to a design where more solid, single members follow the shape of the mass and have many of the earthquake stop positions incorporated.

This structure fits much more closely around the masses, allowing maximum with rigidity, with minimum size and weight, thus allowing an un-obstructed beam path, as shown in the illustration below:



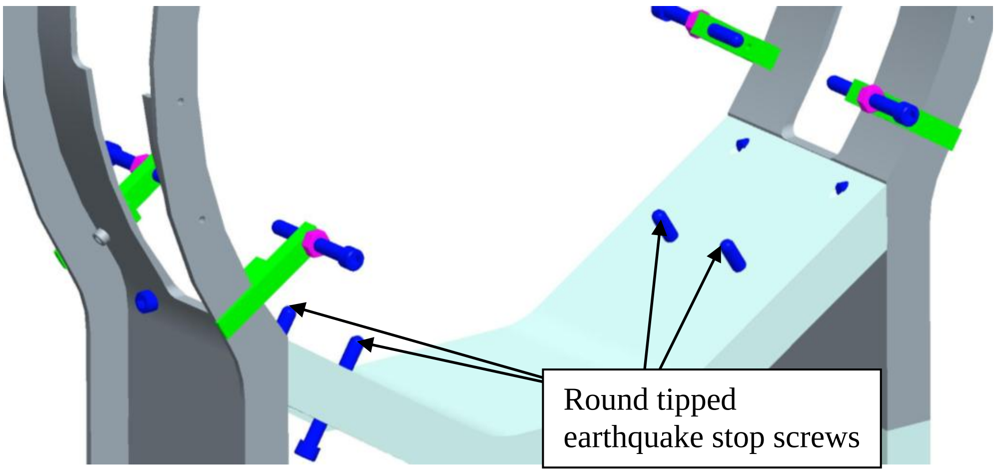
### 2.2 Earthquake stop design:

The designs of the earthquake stops themselves are identical to those of the quad, with a stainless steel, round tipped bolts used for metal masses, and silica tipped Flourel stops used around the silica optic. The exact positioning of the stops for the BS are slightly different to that of the quad, due to the fact that the masses are of different sizes, and the structure design is different. The positions of the earthquake stops are however very comparable to those of the quad, given that the masses for the BS are much lighter.

The stops for the penultimate mass and the test mass are housed in the lower structure, and these are shown in section 3.1 of this document. The stops for the top mass are housed in the upper tablecloth, and these are highlighted in section 8.

### 2.3 No PFA440HP fixed pads for penultimate mass:

Justification: There is no need for soft pads at this stage for two reasons: 1) the penultimate mass in the Beamsplitter is aluminium and not glass, therefore not requiring the protection of soft pads. 2) There are no fibres in the BS, which means that there is no welding, so it is not vital that the penultimate mass be supported at its nominal position during the assembly process. The round tipped earthquake stop screws provide support for the UI mass during assembly.

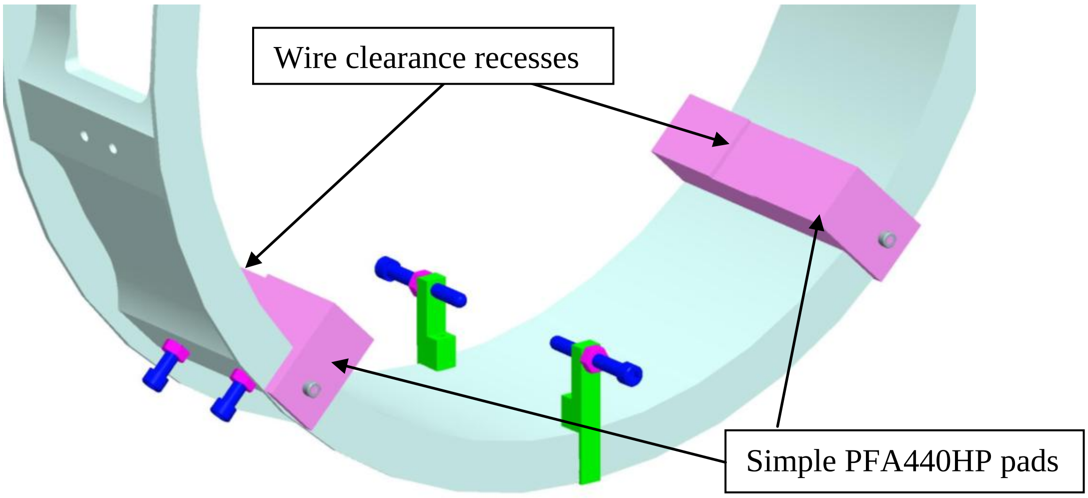


### *2.4 No adjustable pads for the test mass:*

The adjustable pads used in the Quad at the test mass stage have been replaced by simple PFA440HP fixed pads, similar to those used at the penultimate stage of the quad.

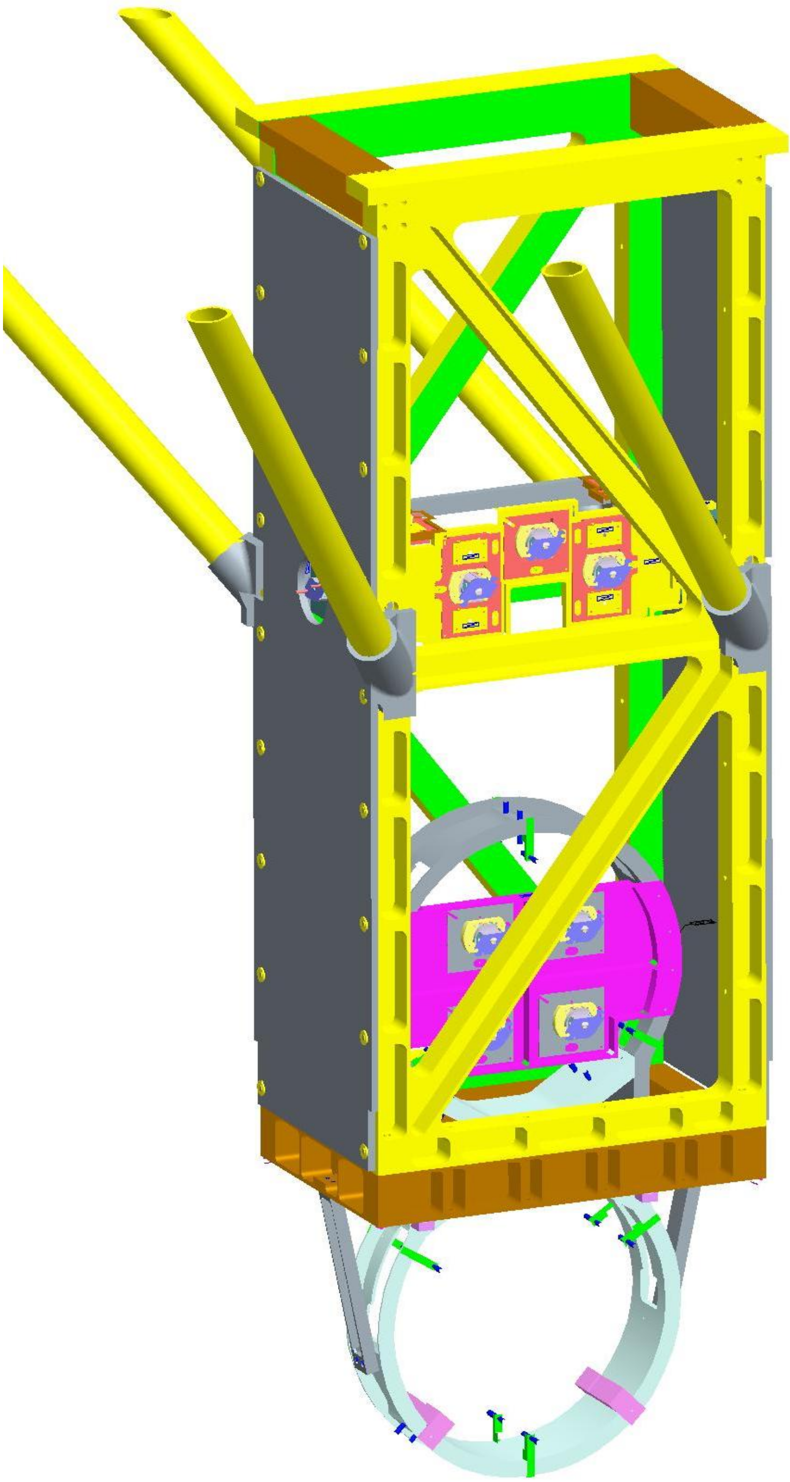
Justification: There is no longer any need for adjustable pads below the test mass, since these were used in the quad to facilitate welding, which is not required on the Beamsplitter.

The job of these pads is simply to provide support and protection for the test mass, and the recesses in the pads allow the wire to pass underneath the mass, without making heavy contact with the glass.



# 3 BS combined upper and lower structures, (with tablecloths for FEA purposes):

As mentioned previously, the aspect ratio between the Upper and lower structures of the Beamsplitter are very different to that of the Quad. Here the structures are shown together.

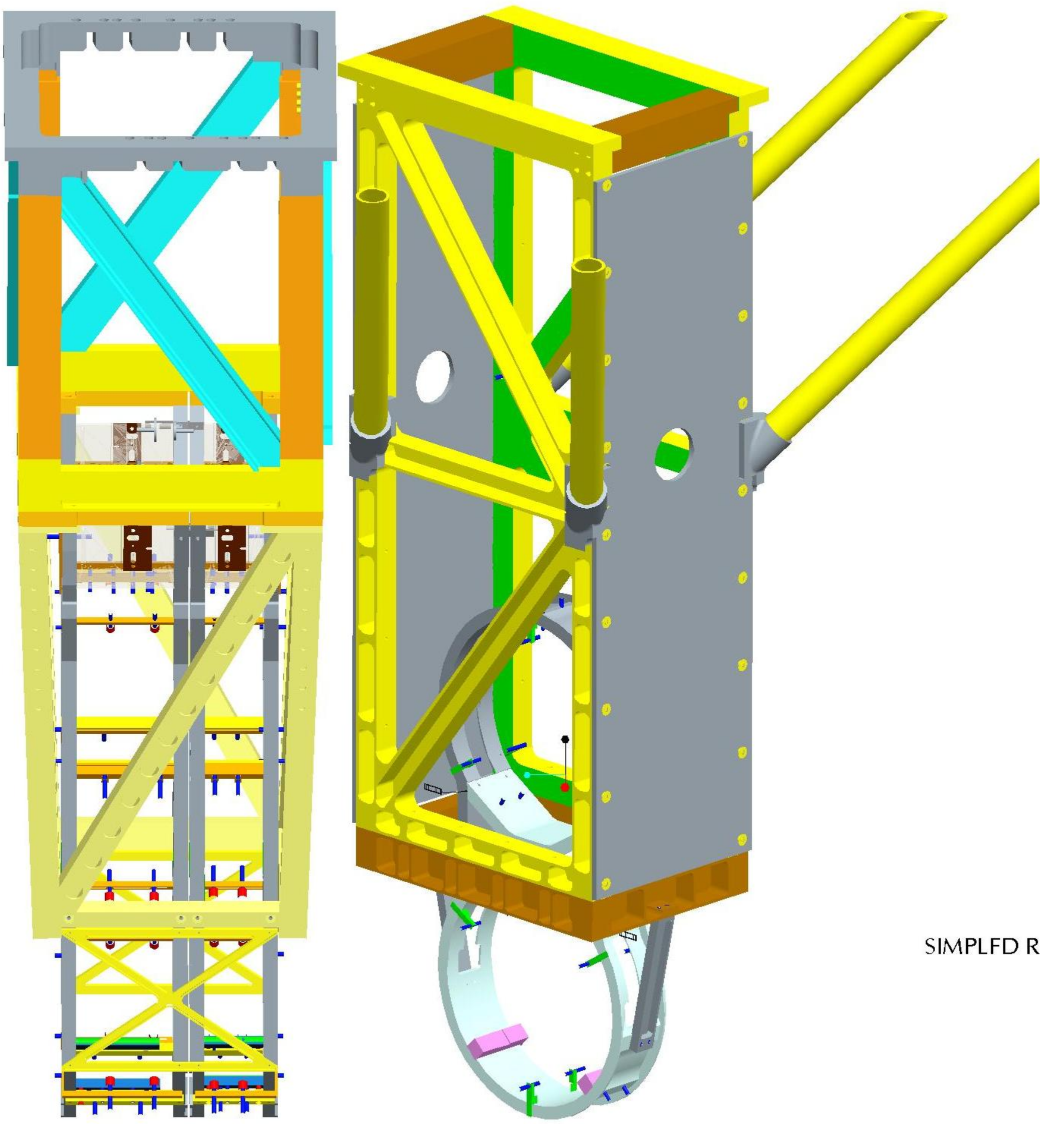


The FEA analysis for this structure is shown in document **T070160-02-K.**

Fig 8 of document **T070160-02-K** shows that the lowest frequency of the earlier structure is only 85 Hz, and this was due to the movement of the lower structure, independently of the upper structure. For this reason, a set of "LS stiffening members" have been added to the structure in order to alleviate this problem. These members have raised the first overall frequency of the structure to 108 Hz as shown in fig 11 of document **T070160-02-K.** The second frequency of the structure is 110 Hz.

# 4 BS and folding mirror

The BS structure combines with Quad structure in the folding mirror configuration. Due to the final optics layout not having been decided on, the folding mirror may or may not have stays.



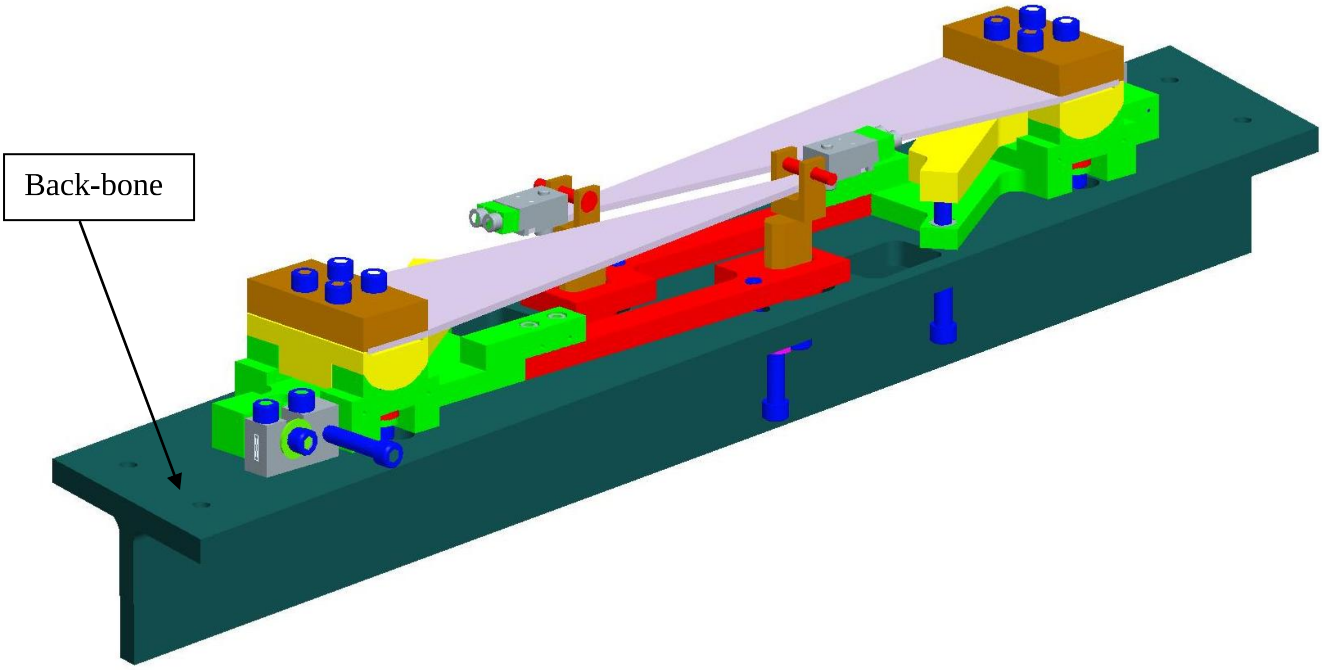

The configuration may well look similar to the one below. If there is not enough space in the area for the stays to be in place, an alternative solution would be to tie the two structures in together so that they reinforce each other.

Articulated stays proposed by Caltech are also a possibility.

# 5 BS top stage:

Mass = 6.3 kg

This is based on a similar "back-bone" concept to that of the quad top stage shown in document **T050233-00-K**, but there are fundamental differences in this configuration.




### 5.1 *Both blades are mounted from the same "back bone"*

This is made necessary by the fact that these two blades are very close together, and is allowed by the fact that: 1) The Beamsplitter blades and blade clamps are smaller than that of the quad, 2) The suspension is well under half the weight of that of the quad, which guarantees that there will be no issues with the deflection of the "back bone" member (see **T050233** figure 6)

It also allows the forces from the blades to be symmetrically distributed through the T bar shaped "back-bone" minimising distortion, and eliminating any twist.

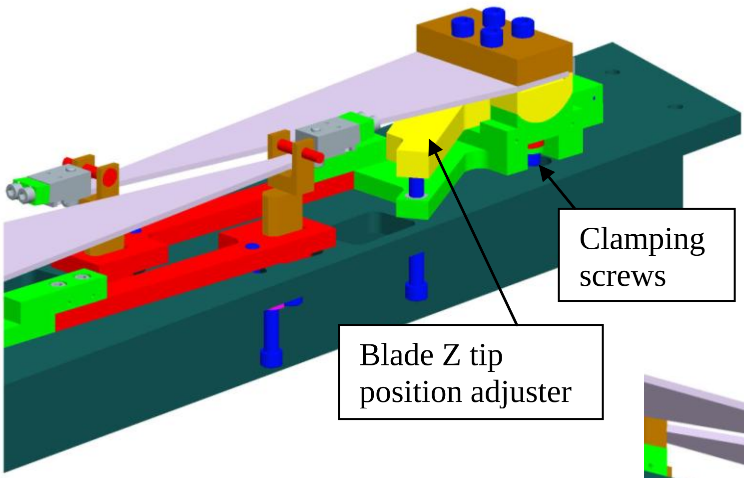
### 5.2 *Blade clamp and backbone arrangement flipped over from quad configuration:*

Motivation: This design change is motivated by a desire incorporate a similar blade tip height adjustment mechanism to that of the Quad top and UI masses, rather than the interchangeable tapered clamp mechanism for tip height adjustment used for the quad top stage, which is a time consuming process, and cannot be done "in situ"

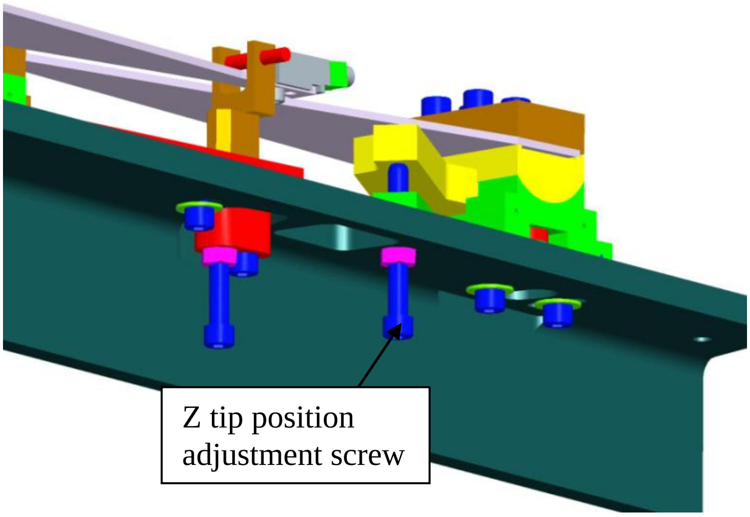
The second motivator for this change is to eliminate the need for blade straightening tooling for the Beamsplitter. Removing the member above the blade, allows the blade to mounted in it's bent position, and pulled down flat with hanging masses, similar to the procedure for the Quad Top and UI mass blades.

### *5.3 Blade tip Z position adjuster mechanism:*

Although in principal this mechanism is similar to that of the blade tip Z position adjusters in the Top and UI masses (**T050188-00-K** paragraph 3.5 and figure 2), it has a fundamental difference in that it is adjusted from below, rather than above.

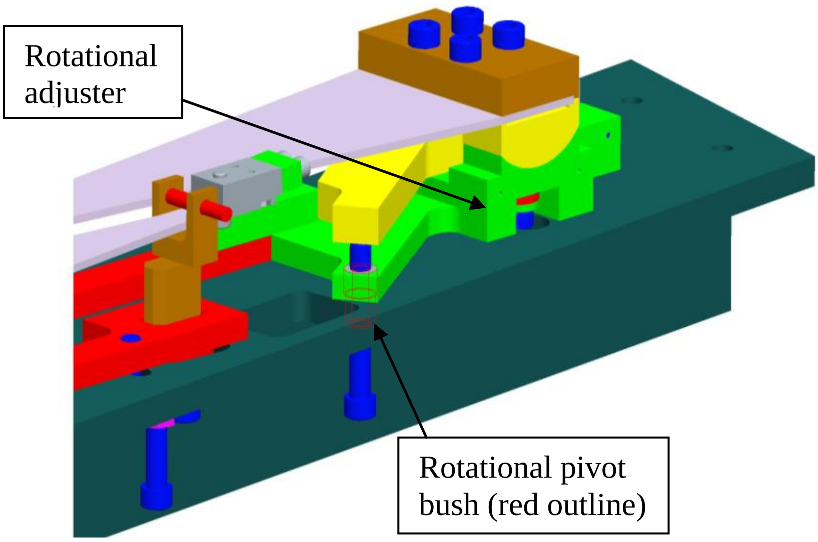



**Motivation:** The reason for this design development in the top stage is that, for the blade tip heights to be adjusted in situ, the tip z position adjustment screws, and the clamping screws, need to be accessible when the optics table is in place above the top stage. The adjustment and clamping screw heads therefore have to protrude from beneath.




### *5.4 Mechanism:*

This mechanism requires the blade Z tip adjuster (yellow piece) to be solid, providing a face which the round tipped screw can push against.




The rotational pivot bush has two purposes. It provides a pivot joint for the rotational adjustment mechanism, but it also provides a jacking screw thread for the Z tip position adjustment screw. The position of this pivot is determined by the concept depicted in **T050233-00-K**, figure 9.

This bush is made from phosphor bronze, and push fitted into the back bone, in order to provide a low-friction pivot joint.

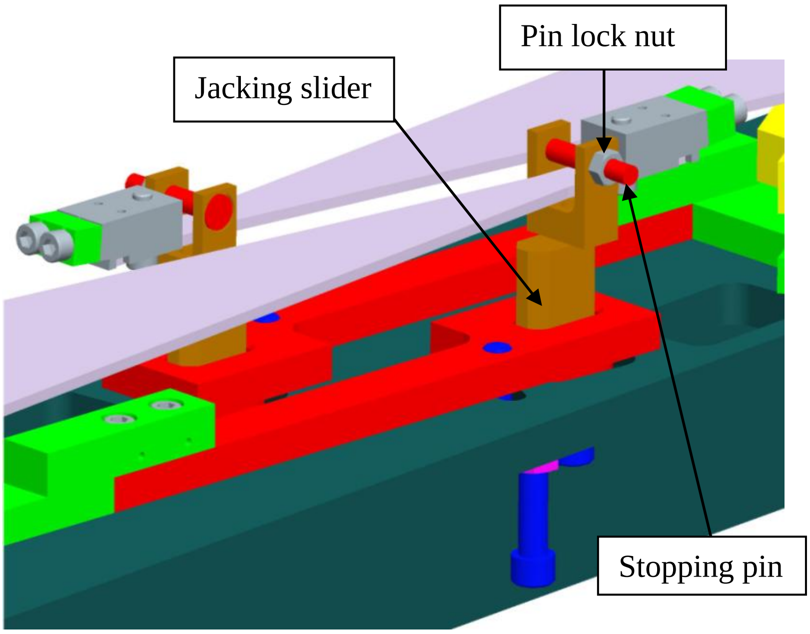
### 5.5 New blade tip stop mechanism:

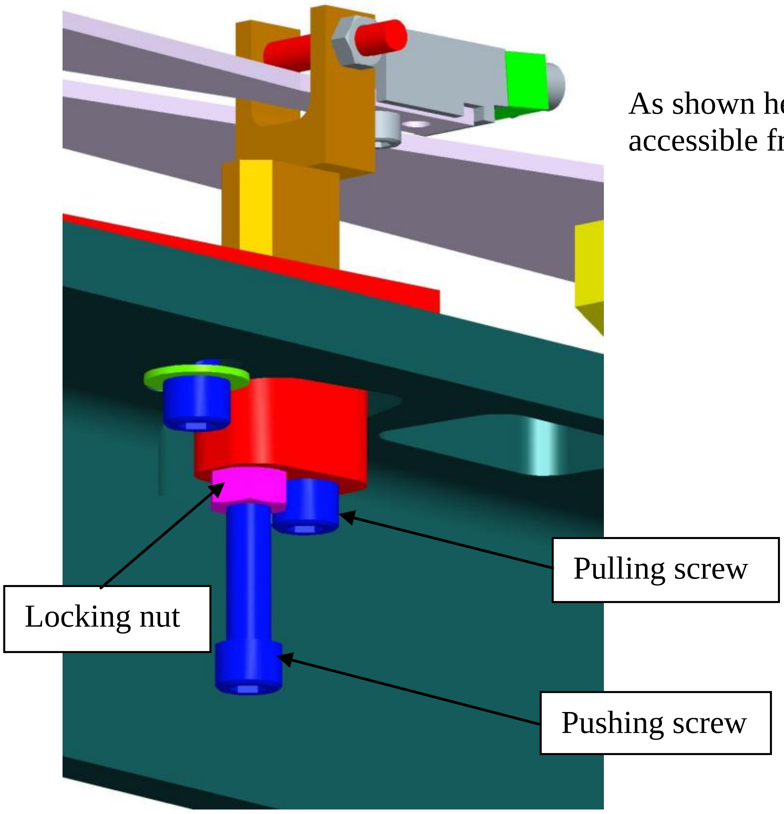
**Motivation:** The change in the orientation of the top stage has lead to a vacant are above the blade. This means that the blade stop must be mounted from below the top stage. It must also be adjustable from below, like all the other mechanisms.

The "jack slider" has forks which protrude either side of the blade, and provide the location for the blade "stopping pin"

The "stopping pin" slides up through the "jacking slider" and is locked in place over the blade by the "pin lock nut". The blade is at this point captivated.

The "Jacking slider" is acted upon by a "pushing screw" and a "pulling screw". The blade can be wound down by the pulling screw, and locked into place by the pushing screw.




As shown here, both of these screws are accessible from below

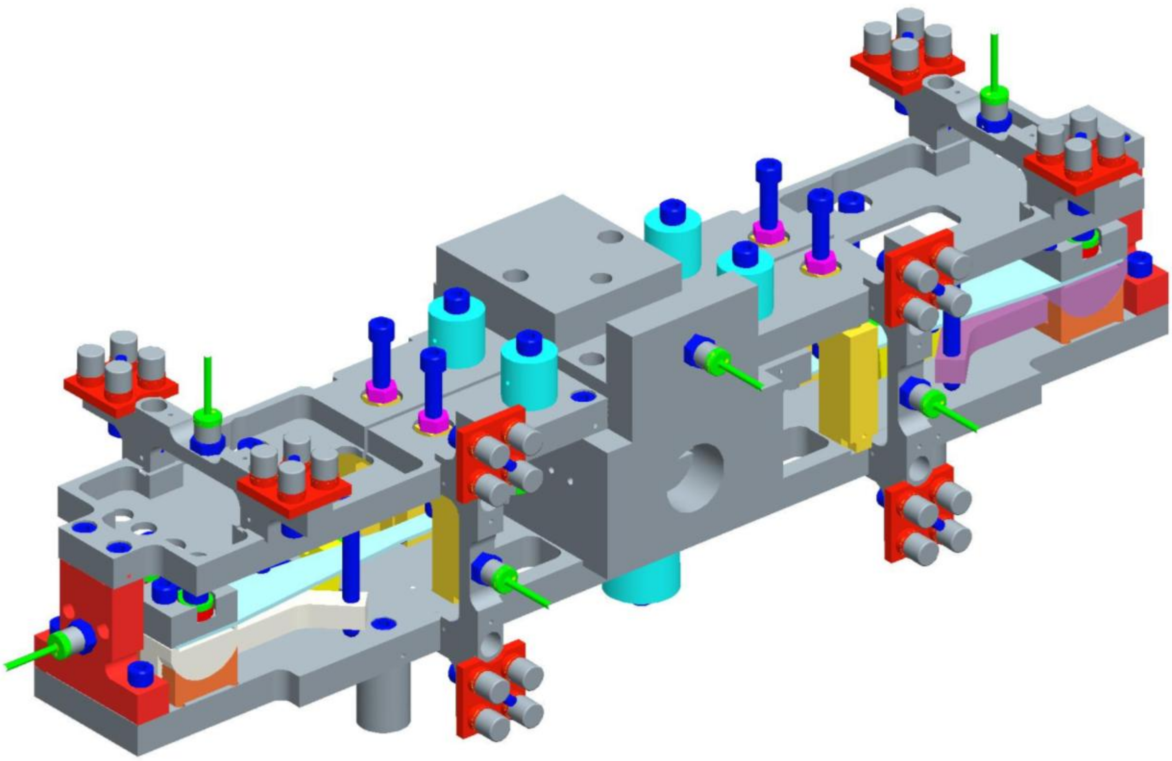
# 6 BS Top Mass:

The top mass is mostly made up of aluminium and stainless steel. The mass has been designed to meet the specified parameters stated in accordance with the Matlab model.

### *6.1 Parameters comparison:*

| Parameter | Value stated in T040027-03-R | Measured value from CAD model |
|---|---|---|
| | | |
| m1 | 1.2627E+01 | **1.2621E+01** |
| Material 1 | Steel' | **Stainless steel, Aluminium** |
| I1x | 1.6350E-01 | **1.6593E-01** |
| I1y | 2.4230E-02 | **2.4732E-02** |
| I1z | 1.6190E-01 | **1.6432E-01** |

There are a number of design features here, that have enabled the parameter set to met, and also to address lessons learned from the quad prototype. These features are pointed out in this document, which focuses on areas where this mass differs from the top mass described in the top mass PDS document **T050188-00-K**.

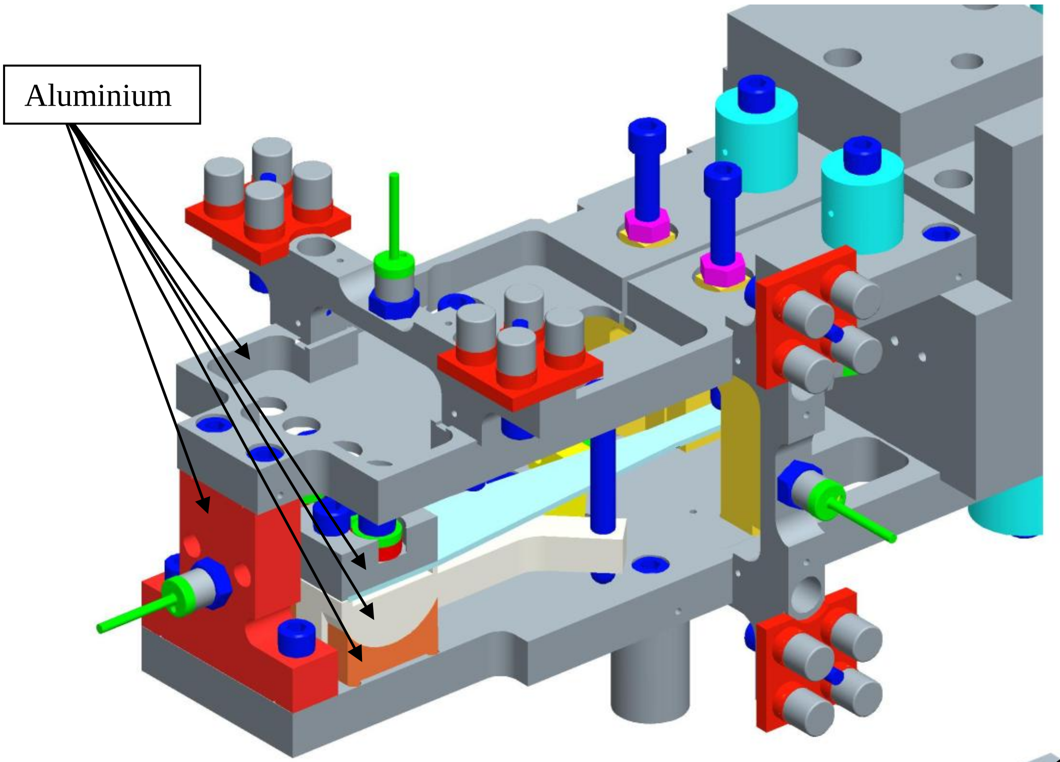


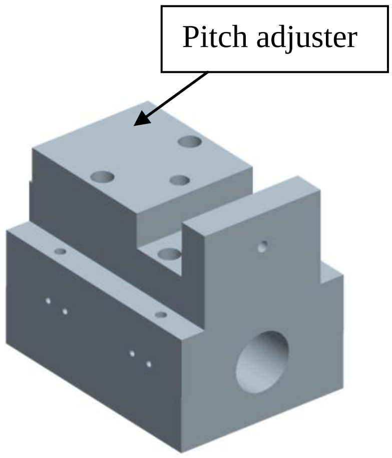
### *6.2 Material changes to blade clamping components from that of the quad:*

Motivation: To reduce the moments of inertia around x and z axis' bringing them into line with the parameter set.

A combination of cut-outs and the use of light weight material (aluminium) for components at a great distance from the centre of mass have been used.

Components made from aluminium for this purpose are highlighted below:



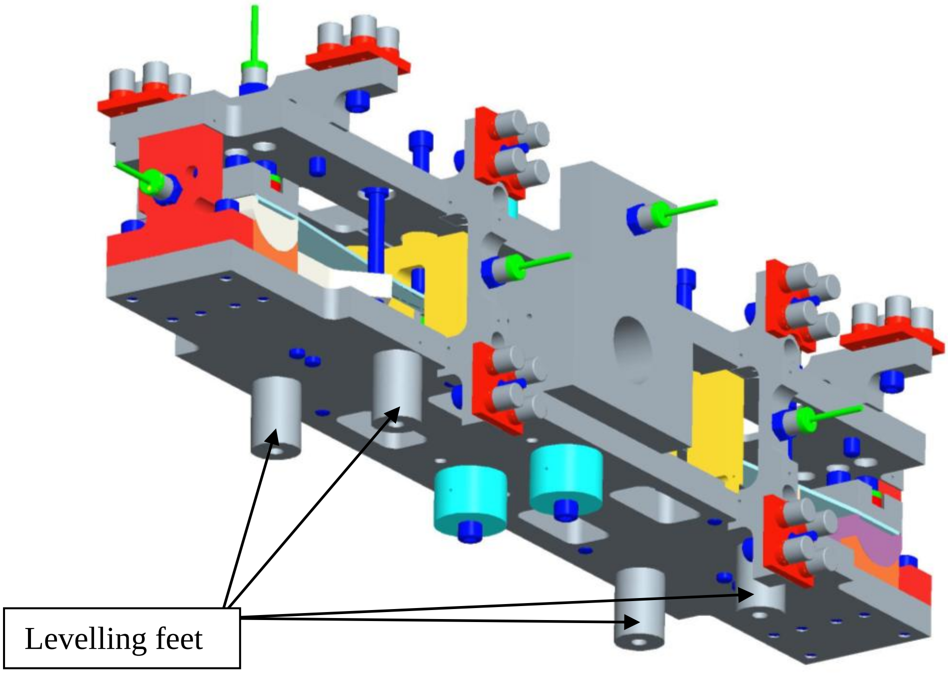




Components which have been changed from Stainless steel on the quad, to aluminium on the Beamsplitter, include the blade clamps (D070418.prt, D070419.prt and D070420.prt)

The pitch adjuster (stainless steel) has been enlarged considerably in order to compensate for the weight lost at the outer parts of the mass, and to increase the mass at the centre, reducing the moment of inertia.

### 6.3 *Inclusion of feet on the BS top mass:*

Motivation: To stabilise the mass when as it sits on a bench for assembly steps such as the pulling down and positioning of the blades. This is a design feature that has been applied directly as a lesson learned from the Quad top mass design.
These levelling feet are highlighted in this view of the underside of the top mass:

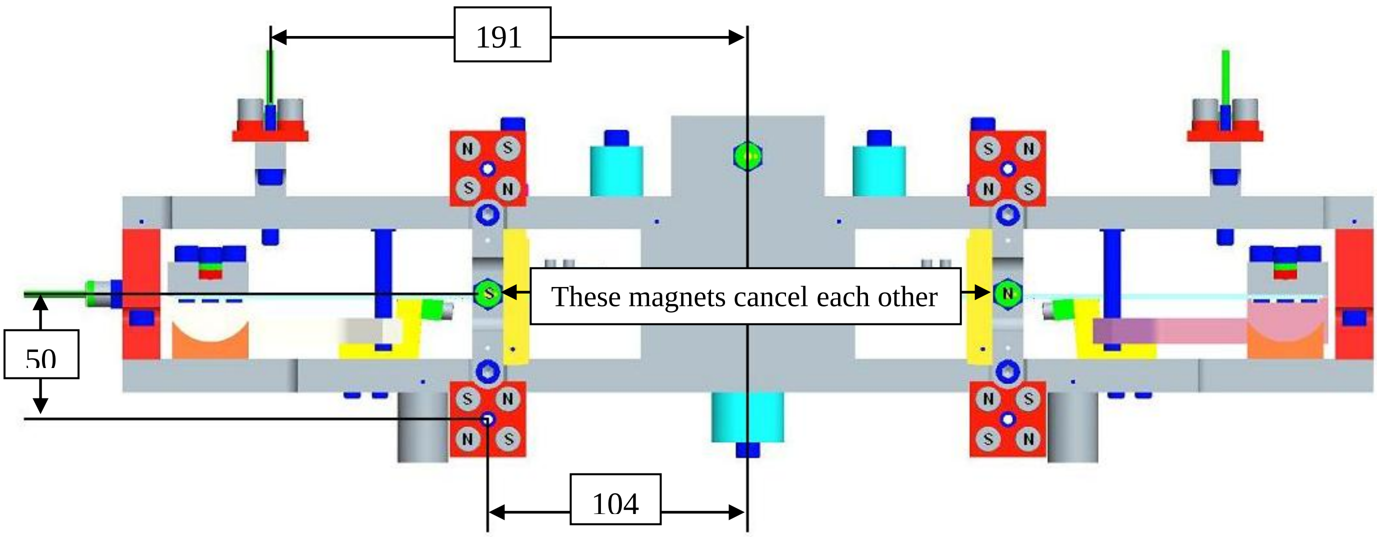



The levelling feet are also made of aluminium, and give the top mass stability, while giving it minimal elevation

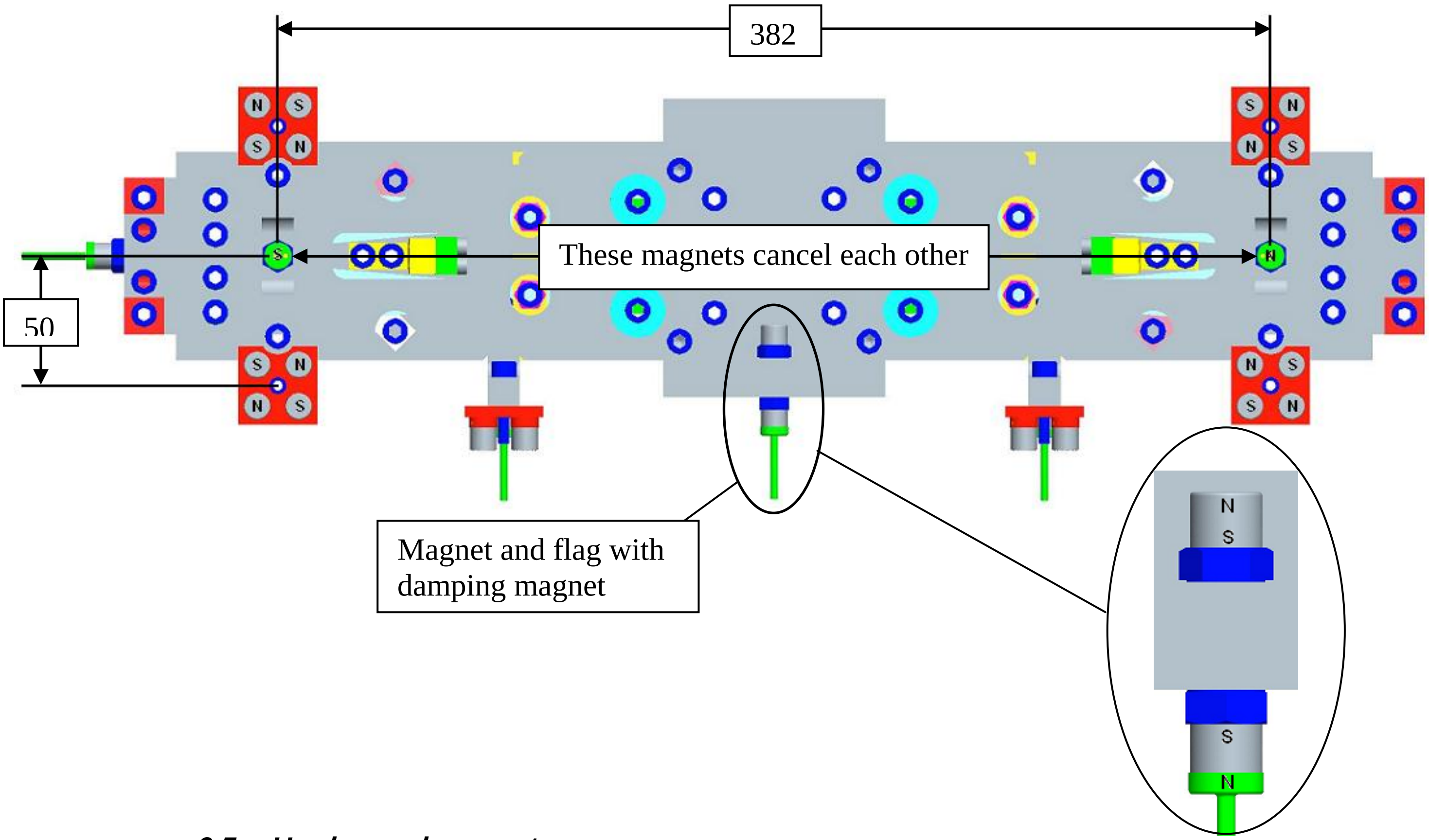
### 6.4 *Changes to ECD magnet positions, relative to centre of mass:*

The ECD magnets and OSEM flags on the front of the top mass have been moved relatively closer together than those on the quad top mass, and the magnets and flags on the top have moved further apart.

**Motivation:** This has been necessary to do in order to allow the OSEM position adjusters on the tablecloth to fit around the mass

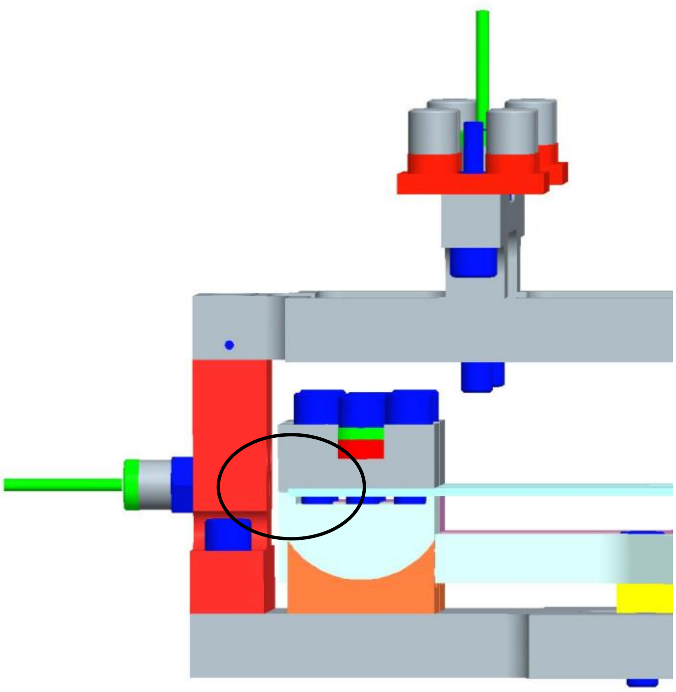


**Affect:** The magnets, as in the quad top mass, are arranged alternately north to south, so that they damp each other. The change of the distance between the ECD units affects the ability of the top magnets to damp each other across from one end of the mass to the other.




### *6.5 Un-damped magnet:*

All magnets except for one on the top mass are to a greater or lesser extent cancelled by another magnet. The one exceptional magnet is the one on the end of the mass, which is shown in the image below:

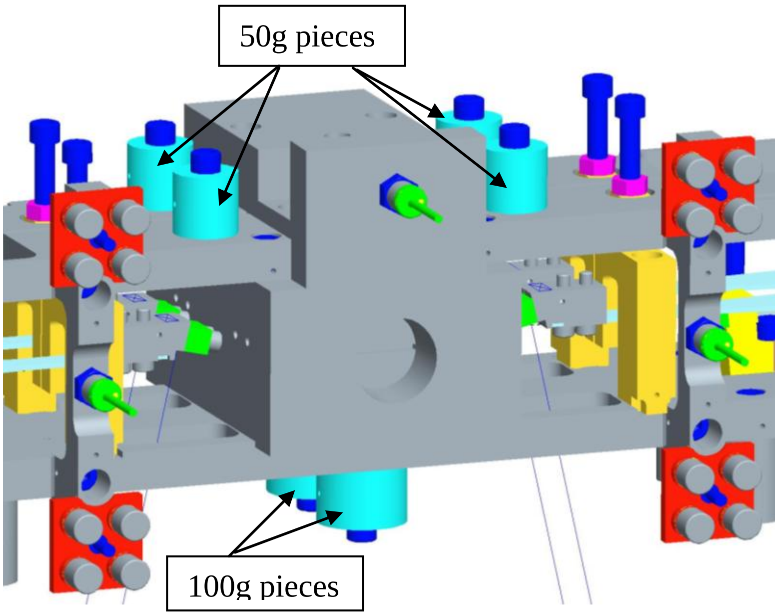


The area circled shows where the cancelling magnet for this magnet would have been, but this area is used for the blade and blade clamps, and is therefore unavailable.

This item is covered in detail in the magnet and flag PDS: - **T060122-00-K**

### 6.6 Addable/removable mass:

This mass has a total of 400g of removable mass in its default configuration. A total of 400g can also be added to this, giving a mass adjustment value of ± 400g. This is less addable/removable mass than the quad top mass, which has ± 800g. This means that the percentage of adjustment per unit of mass in the quad top mass and the BS is very similar, as shown below:




Quad top mass numbers taken from T060149-00-K

BS top mass removable mass = (4 x 50g) + (2 x 100g) = 400g

Quad top mass = 22.1 kg

Therefore (0.8/22.1) x 100 = 3.62% adjustment for quad top mass.

BS top mass = 12.627 kg

Therefore (0.4/12.627) x 100 = 3.17% adjustment for BS top mass.

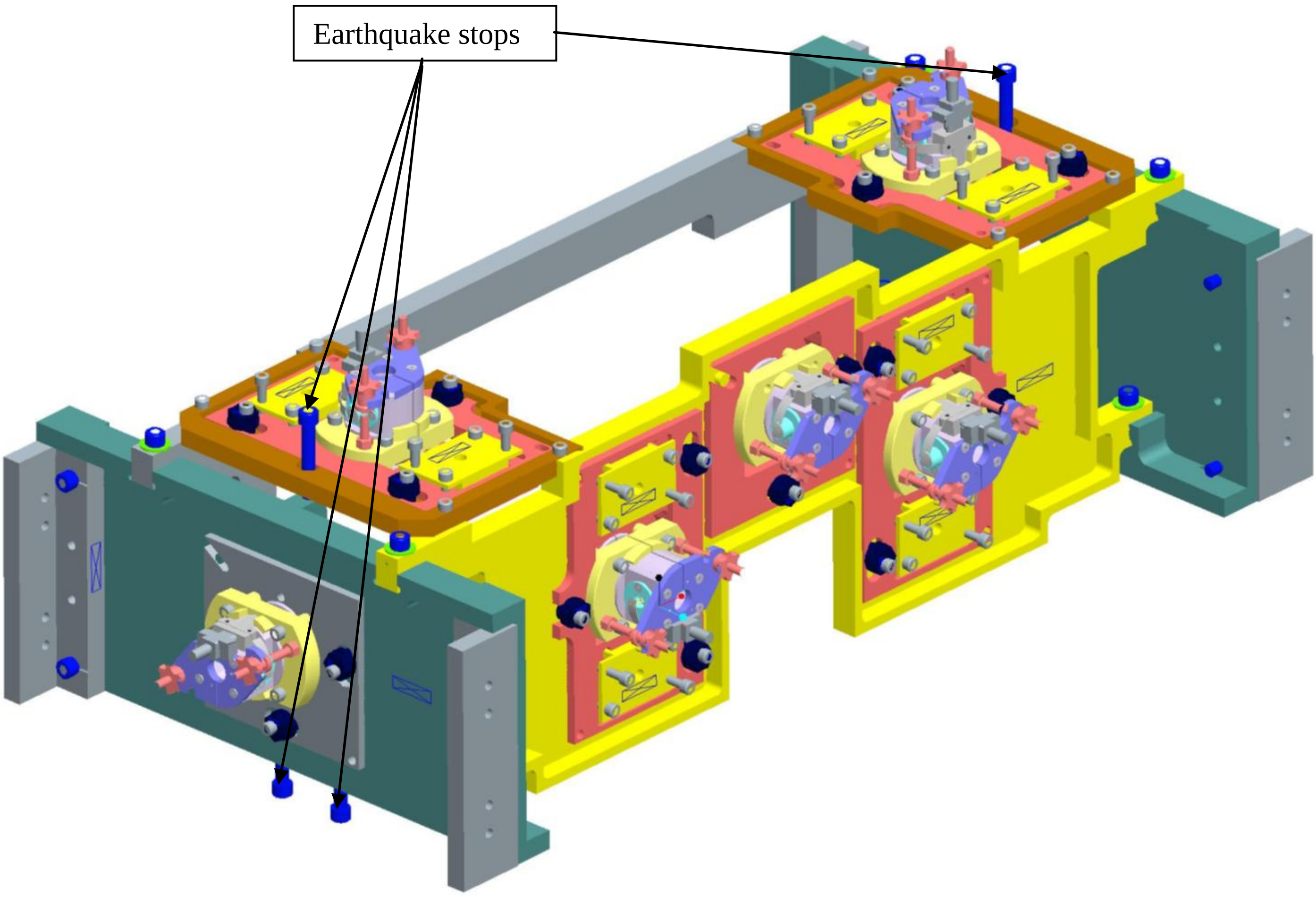
### 6.7 Four blades:

The BS top mass has four blades, unlike the two bladed Quad top mass. This is as specified in the parameter set document: **- T040027-03-K**.

# 7 BS Top Tablecloth:

This design is similar to the Quad tablecloth in that it houses the same OSEM and ECD adjuster mechanisms. The plates are linked together with slotted holes, in the same way as the quad tablecloth, giving each plate a similar independent adjustment range.

Mass = 7.6 kg (including OSEMs)




The features of this design that differ from that of the quad described in document **T050190-00-K** are shown in the following paragraphs:

### *7.1 OSEMs only provided on front, side and top faces:*

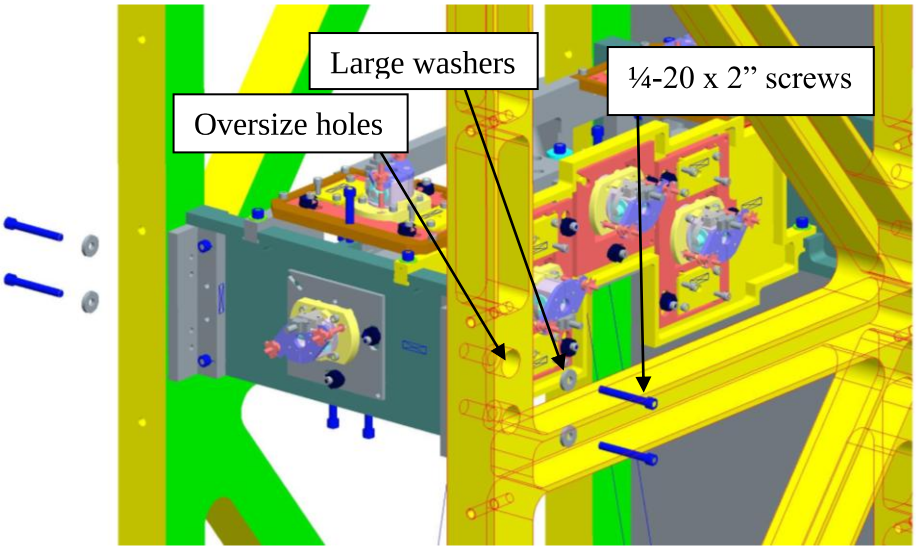
This is due to the fact that the BS tablecloth only houses one mass, which has its flags and ECD magnets on the front face.

The OSEM adjustment mechanisms have been judged to have worked very well in the Quad, and these designs have been incorporated into the Beamsplitter design.

### 7.2 Tablecloth mounting system:

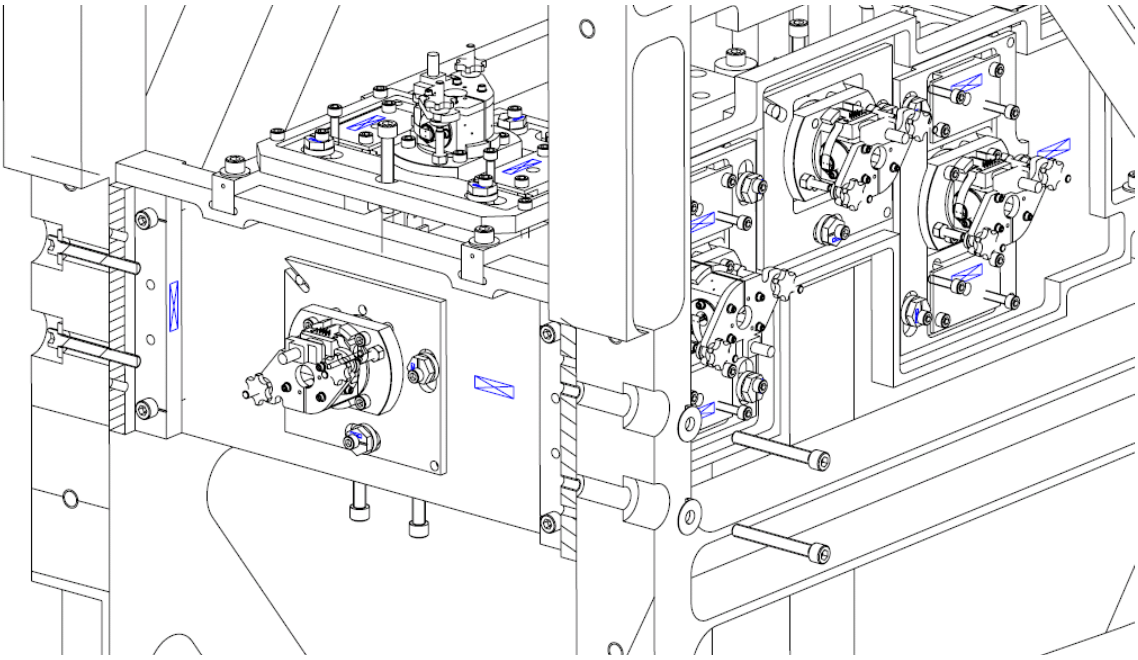
The tablecloth is in the Beamsplitter is mounted in a different way to that of the quad, since it interfaces to member of a different style. Rather than bolting through the tablecloth and into the upper structure, the bolts go through the upper structure, (which is solid), and screw into the tablecloth.

The mounting mechanism is shown below:




The tablecloth panels interface to the inner surface of the face plate, rather than the side. This change has been motivated by the fact that positioning of the cross braces in the face plate do not allow the tablecloth to interface to the inner side.

Oversized holes and large washers in the Beamsplitter replace the large cut-outs and the keep plates used to mount the tablecloth in the Quad. These oversized holes and washers allow a similar amount of tablecloth adjustment to that of the Quad.



The view above has a section through the faceplate of the upper structure, in order to clarify the tablecloth mounting and adjustment system.

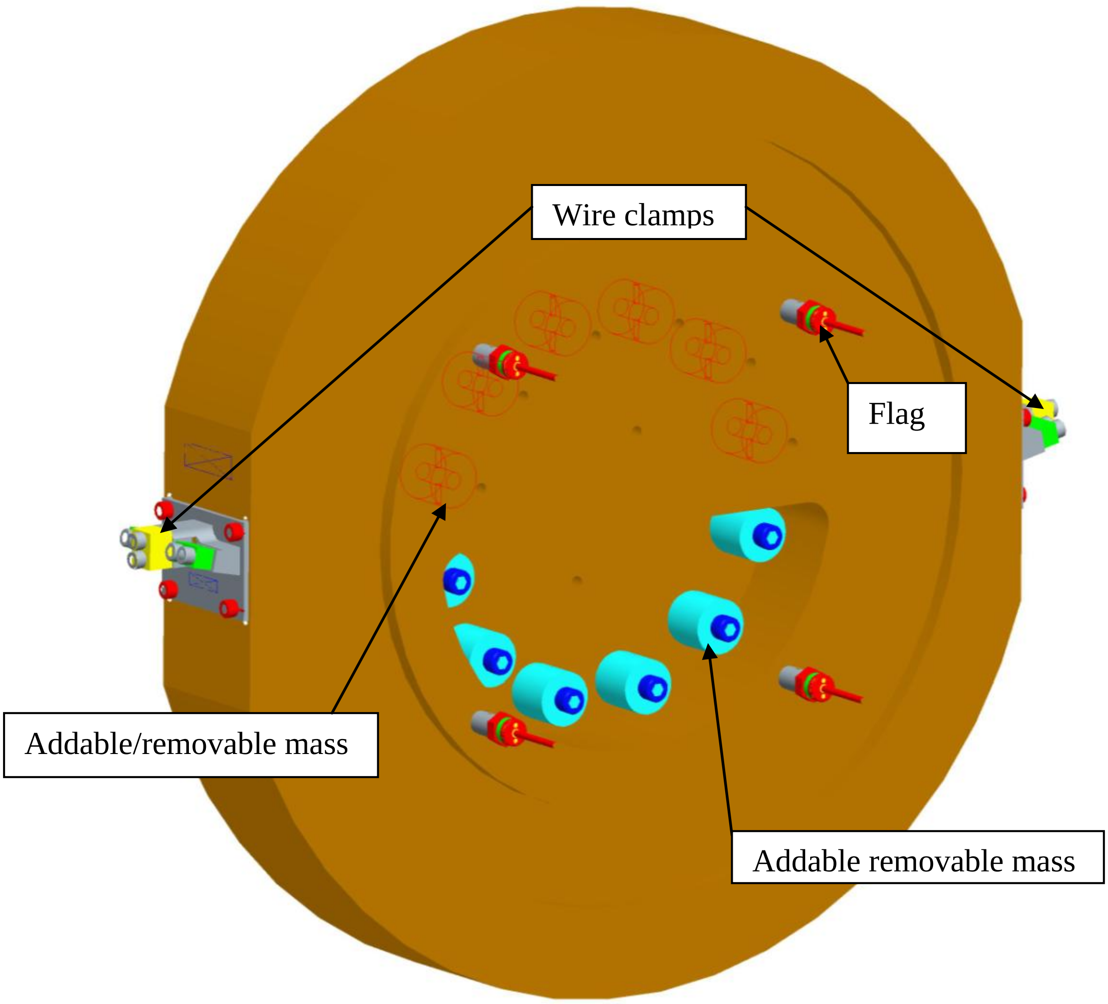
# 8 Penultimate mass:

The penultimate mass is made of aluminium, with stainless steel addable/removable mass and wire clamps.

### 8.1 Parameters comparison:

| Parameter | T040027-03-R | From CAD model |
|---|---|---|
| | | |
| m2 | 1.3575E+01 | **1.3575E+01** |
| Material 2 | silica' | **St. steel** |
| ix | 5.7090E-01 | **5.7090E-01** |
| ir | 1.8500E-01 | **1.8500E-01** |
| I2x | 2.3130E-01 | **2.5644E-01** |
| I2y | 1.1932E-01 | **1.3157E-01** |
| I2z | 1.1932E-01 | **1.3153E-01** |

### 8.2 Main Features:



### 8.3 Wire clamps:

The wire clamps for the BS penultimate mass are a very similar in style to that of the Quad round mass wire clamps.  They perform in exactly the same way, with a set of 8-32 UNC screws and a clamp jaw that hold the wire and place, and are wound up with the wire at its working tension.

Due to the similarity between Quad and BS wire clamps, the BS clamps have not been tested, but are believed to be more than adequate.

### 8.4 Addable removable mass:

This mass has 12 pieces of addable removable mass which are mounted in position on the vertical centre line of the mass, in order to give more mass adjustment options, while keeping the centre of gravity constant.

The nominal weight of each piece of mass is 50g

Therefore there is 50g x 12 = 600 grams of mass in total.

The total mass of the BS penultimate mass is around 13.6kg, so the percentage of adjustment capacity is around 4.4 %, which compares favourably with that of the Quad.

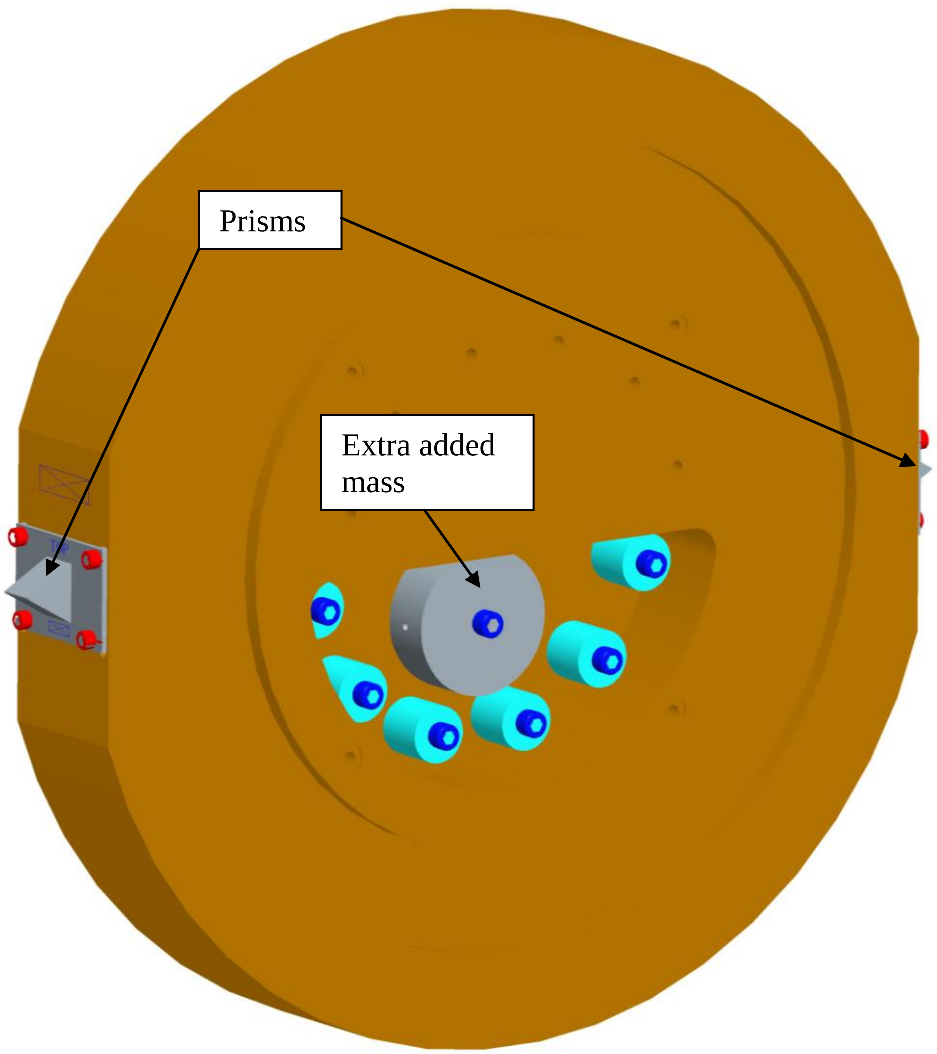
# 9 Test Mass Dummy

## 9.1 Parameters comparison:

| Parameter | T040027-03-R | From CAD model |
|---|---|---|
| | | |
| m3 | 1.4168E+01 | **1.4211E+01** |
| Material 2 | silica' | **St. steel** |
| ix | 5.7090E-01 | **5.7090E-01** |
| ir | 1.8500E-01 | **1.8500E-01** |
| I2x | 2.3130E-01 | **2.5340E-01** |
| I2y | 1.1932E-01 | **1.2770E-01** |
| I2z | 1.1932E-01 | **1.3210E-01** |

## 9.2 Main features

This mass is similar to the penultimate mass except in the features highlighted below:



### 9.3 Prisms

This mass uses Aluminium prisms, in place of the wire clamps used in the stage above. These prisms better simulate the geometry of the BS/FM optic

### 9.4 Extra added mass

The requested mass for the test mass dummy is higher than that of the penultimate mass. In order to reduce the number of unique components, the mass does not have a separate design for the main mass, but has two extra masses bolted to it – one on each side.

### 9.5 No Flags

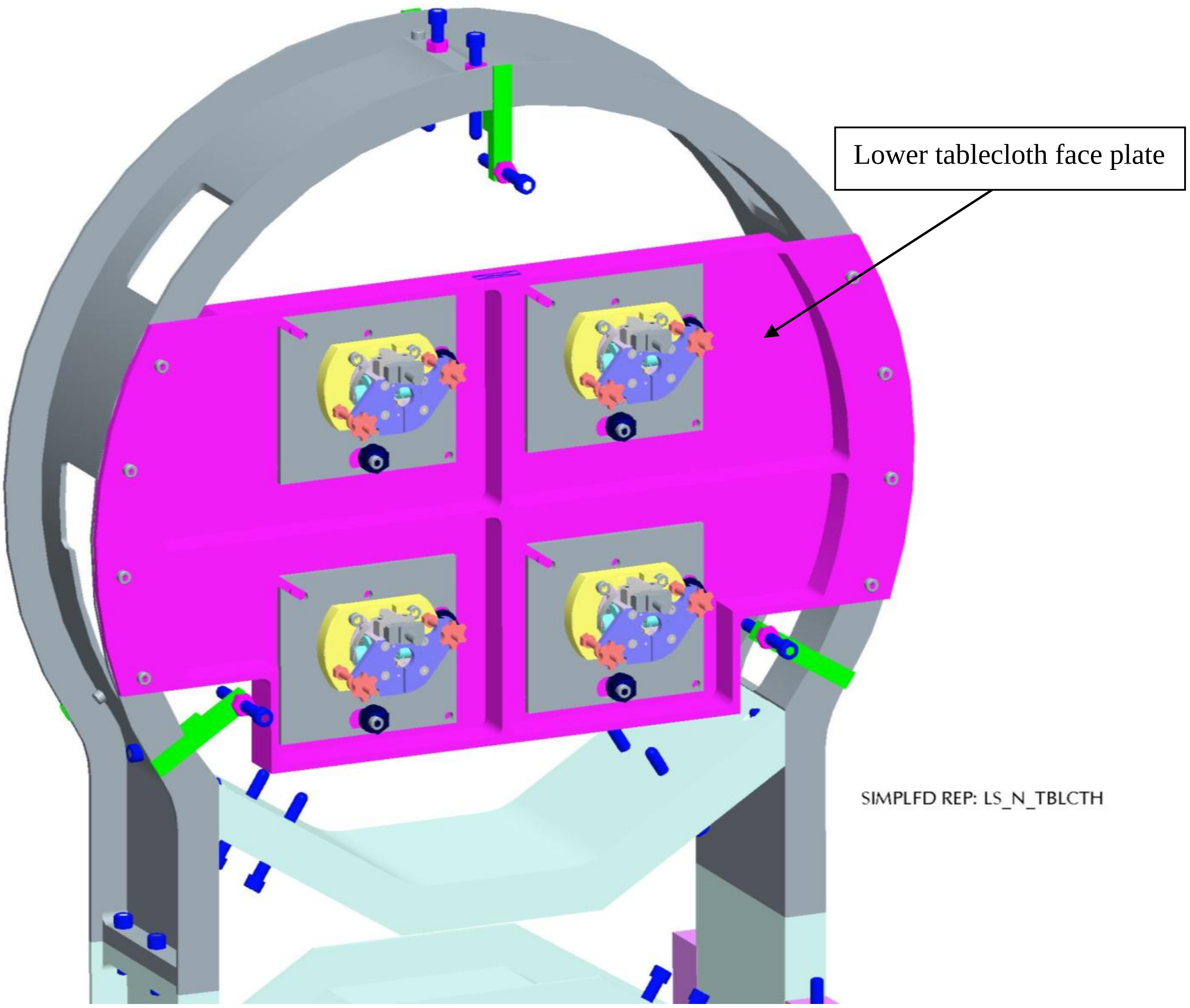
There are no flags at the test ass stage

## *Lower Tablecloth:*

Mass = 2.4 kg (including OSEMs)

The lower tablecloth is a completely new component of the Beamsplitter. No lower tablecloth is used in the Quad because there are two suspension chains, and the OSEM interaction at this stage is between the two chains. In the Beamsplitter however, due to there being only one chain, the interaction at this stage is between the Penultimate mass and the structure. The tablecloth has been designed to provide a simplistic lightweight and stiff mounting point for the BOSEMs.

This tablecloth provides mounting points for exactly the same OSEM adjustment mechanisms as are used in the Tablecloth for the quad, and the top tablecloth for the BS.




This tablecloth interfaces to the Lower Structure with a set of 8-32 UNC screws.

# 10 Problems, risks, concerns:

### *10.1 The structures:*

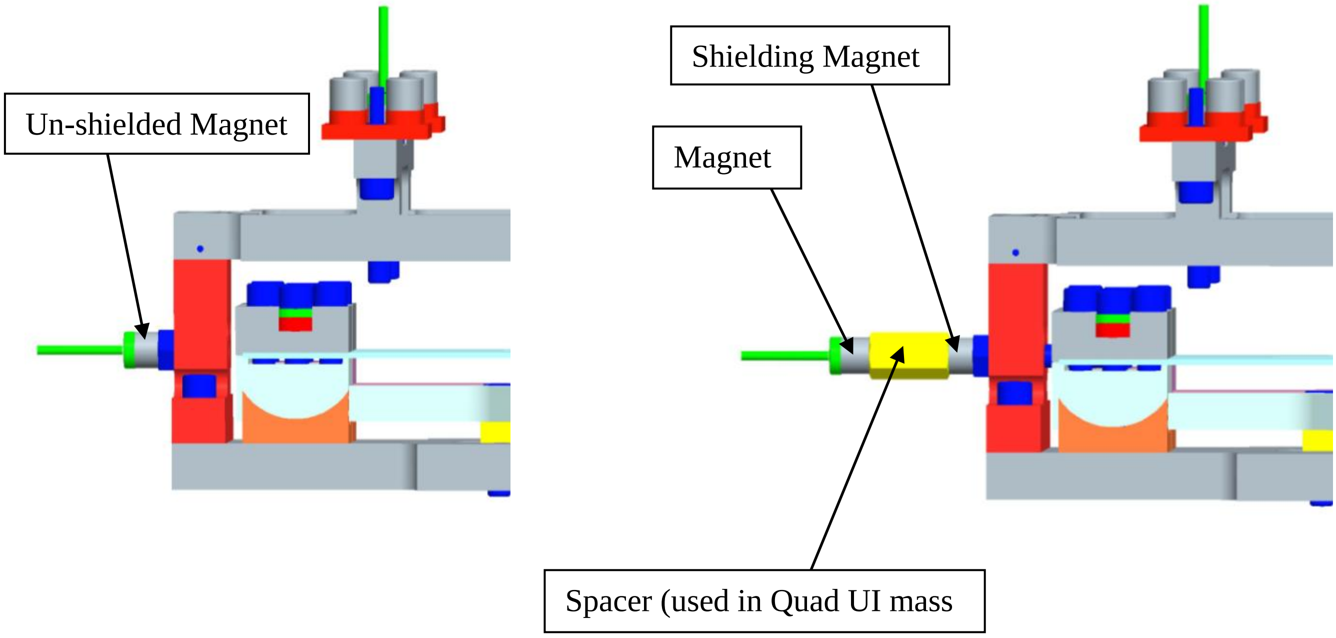
**Resonant frequency:** The FEA for the BS overall structure showed the first two modes to be around 110 Hz. A study conducted for the actual BS upper structure ( ) shows the first measured frequency mode to be within 10% of the FEA result. This may be artificially high, because the method used for measuring the first frequency mode did not include the bolted connection between the structure and the optics table. For this reason, the comparison between the Quad FEA and the actual measured Quad resonant frequency value of 25%

This should give a final frequency of around 80Hz, but there is a small risk that the completed BS structure when suspended from the optics table, will not behave in the way that we expect from past experience.

### *10.2 Top Mass:*

**Shielding magnets:** As mentioned earlier in the document, some of the magnets that shield each other have been moved further apart. There is a risk that these no longer provide adequate shielding.

There is also a magnet that does not have any damping and this may be a problem. This problem could be solved if necessary by adding a magnet and a separation component as shown below:



This option will be avoided if possible, since it would require some considerable re-work to the upper tablecloth, and raise the moment of inertia for the top mass.

**Addable/removable mass:** The quantity of addable/removable mass has been decided based on the numbers from the quad top and UI masses, and it is not expected there will be any shortage of adjustment. There is a very small risk that a combination of maximum deviation from both nominal component dimensions and nominal material densities, could take the top mass outside of its adjustment range. In this case, this can be identified before components are sent, and material removed from components, or extra addable mass mounting positions added in the UK before the components are shipped to the US and cleaned.

# 11 Total mass:

| Sub assembly | Suspended mass (kg) | Non-suspended mass (kg) | Total (kg) |
|---|---|---|---|
| | | | |
| **Upper structure** | | 100.4 | |
| **Lower structure** | | 6.6 | |
| **Top stage** | | 6.3 | |
| **Upper tablecloth** | | 7.6 | |
| **Lower tablecloth** | | 2.4 | |
| | | | |
| **Top mass** | 12.621 | | |
| **Penultimate mass** | 13.575 | | |
| **Test mass** | 14.168 | | |
| | | | |
| **Total (kg)** | **40.364** | **123.3** | **163.664** |

# 12 List of relevant RODAs

| # | Document # - Y | Date | Principal Author | Sub-system(s) | Title | Comments |
|---|---|---|---|---|---|---|
| 17 | M050397-03.pdf | 4 Apr 2008<br>rev. -02 23 Aug 2005 | GariLynn Billingsley | COC, SYS, SUS/UK, SUS/US | Core Optic sizes, including TMs, BS, FM and RM<br>*supersedes M040283-01 and M040387-00*<br>*rev.-03 needed to be consistent with M070120-02 regarding BS thickness* | Note discrepancy on thickness of BS between this document (60 mm) and T040027-03.pdf (57.09mm) |
| 26 | M060300-02.pdf | 29 May 2008 | Justin Greenhalgh | SUS, ISC | BS & FM suspensions: No reaction chains, B-OSEMs and ½ size magnets | Comply |
| 28 | M070120-02.pdf | 11 Jul 2007 | Dennis Coyne | SUS, SYS | BS Optic geometry, Wedge Orientation & Metal Wires | Comply |
| 35 | M080134-00.pdf | 11 Jul 2008 | Norna Robertson | SUS, ISC | E/ITM and BS/FM pitch frequencies and d-values | See comment about D values in section …. Of FDD |