Harmonic Analysis of SPT4 Cryostat Preliminary Millikelvin Stage Designs

SPT4

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Overview

This document presents the preliminary designs for the millikelvin stage standoff for the SPT4 Cryostat design and the initial analysis evaluating them. The different designs are evaluated relative to each other by performing a Harmonic Frequency Finite Element Analysis (FEA). The ultimate goal for the designs is to push the resonant frequencies high enough to weaken coupling to the modes of other cryostat components. This document is meant to be informational and the work it presents is not set in stone, but rather could change as the design process progresses.

Preliminary Designs

This section contains snapshots of all the designs considered. The two materials present in these designs are the cryogenic Titanium 15-3-3-3 alloy and the more traditional carbon fiber. Titanium 15-3-3-3 has a similar thermal conductivity to carbon fiber below 1K and even surpasses carbon fiber below about 0.5K. This titanium alloy can also be pattern cut from thin sheets using EDM fabrication techniques, giving the huge advantage of being able to mechanically secure the members with bolts rather than relying on glued joints as is the case with carbon fiber.

Titanium 15-3-3-3 Designs

The cross sectional geometry of all the designs is chosen such that the cumulative thermal load from the 1K mount to the 100mK wafer mount is 0.5 uW to be in conjunction with thermal requirements.

[1] **Truss** is in quotation marks because this design is not really a truss. A truss structure's members are only allowed to deform axially under an arbitrary load, meaning there should be no flexure or torsion which this design does not protect from either.

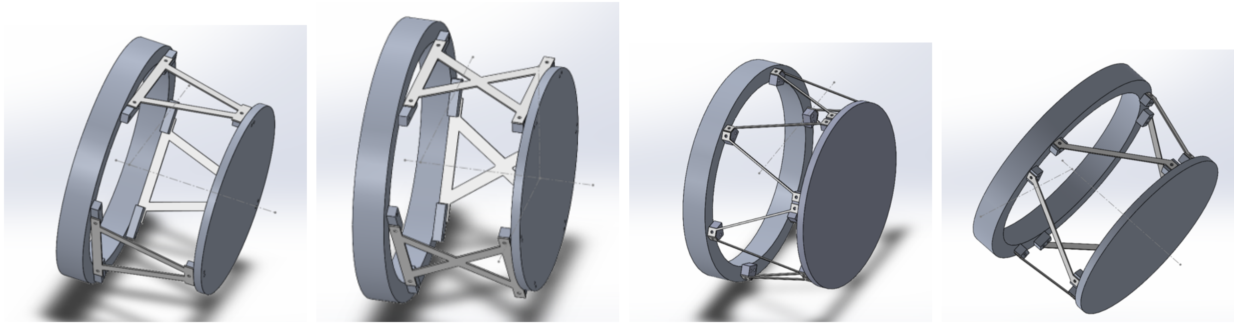

Figure 1: The names of these designs will be referred to now on as (left to right): Triangular Ti, X Ti, 'Truss' Ti[1]*, and Hexapod Ti. The thickness of the titanium members is constrained by the availability of the Ti 15-3-3-3 alloy and what is possible with EDM fabrication techniques. The two thicknesses that are available for this alloy are 1 mm (0.04") and 1.5 mm (0.06") thick. The thinner option is chosen for this analysis in order to be conservative.*

Model Setup

This section details the setup of the FEA model. First the assembly is created, as snapshots shown in the previous section. Since Solidworks maps the mating relationships in assemblies to it's best guesses for simulation connectors, careful consideration had to be taken here so as not to introduce inaccurate connections between elements. The mounts that interface the members to the 1K aluminum mount and the 100mK detector wafer mount are standard mating relationships to mimic a rigid connection (1 coincident mate between faces and 2 concentric relations between bolt holes). For the members, the parts are first aligned using standard mating relationships. Then those mating relationships are deleted and replaced with one coincident relationship between the inner edge of the titanium member and the outer edge of the connection hole at the mount such that the holes are coaxial but are still allowed to rotate. In the simulation interface, this coaxial connection is defined to be a pin connection with a very high rotaional stiffness (1000 Nm/rad) to mimic a strong bolt connection.

The structure is then fixed at the 1K mount to the optics tube to eliminate rigid body modes and to assume this connection is rigid to the optics tube. A 5kg distributed mass is defined on the 100mK detector mount to mimic the detector module that will be connected to the back. 5kg is chosen to be at the heavier end of the possible detector module design in order to be conservative.

There isn't much problem in meshing using the blended curvature based mesher, so the model

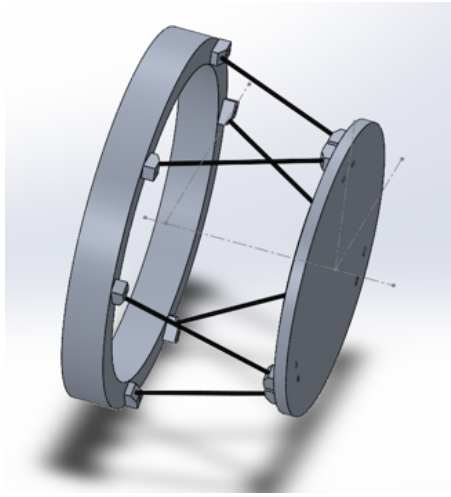

Figure 2: The radius of the carbon fiber members is 0.75mm. The mounting mechanism being an aluminum glue joint as is the only option for this material.

is not simplified past what is seen in previous sections. An example of one of the meshes is shown below for one of the titanium designs. The smallest element size was decreased based on how the holes were meshed as well as to get decent discretization along the axis of each member.

The FEA solver then calculates the first five modes (usually taking about 10-15 minutes to complete).

Resonant Modes

Natural Frequencies

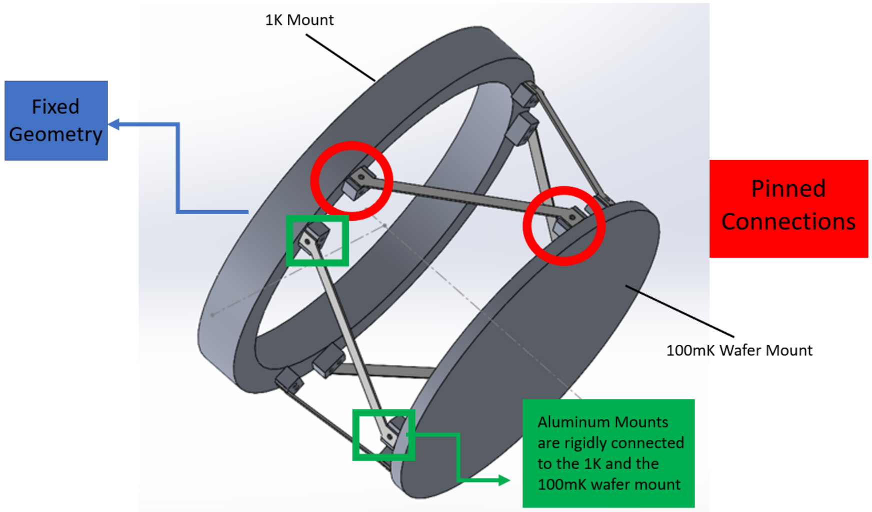

Figure 3: A visual example of how the FEA's are set up for all the models.

Table 1: The table below summarizes the first five eigenvalues of the above analysis. All units are in Hertz and have an indicator of the mode shape in () where relevant.

Preliminary Design	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Triangular Ti	72 (Flexure)	72 (Flexure)	143 (Torsion)	272 (Buckling)	381
X Ti	96 (Flexure)	96 (Flexure)	189 (Torsion)	220	305
'Truss' Ti	89 (Flexure)	89 (Flexure)	179 (Torsion)	270	380
Hexapod Ti	144 (Flexure)	144 (Flexure)	255 (Buckling)	299 (Torsion)	372
Hexapod Carbon Fiber	82 (Flexure)	82 (Flexure)	152 (Torsion)	210	275

Mode Shapes

here will go snapshots of the mode shapes

Concluding Remarks

Based on this analysis it would seem the best design according to natural frequencies would be the Hexapod Ti design. This seems to give a good balance between the flexure and torsional modes, and the buckling mode. One can imagine there is a trade-off here with the angle of the Ti members where one becomes dominant over the other and vice versa. Note: This is just a preliminary analysis and the designs in this document are subject to change

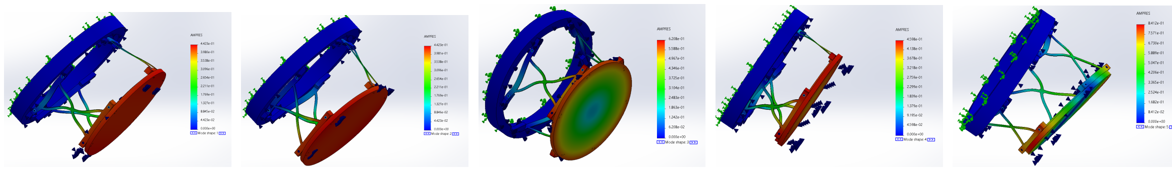

Figure 4: X Ti

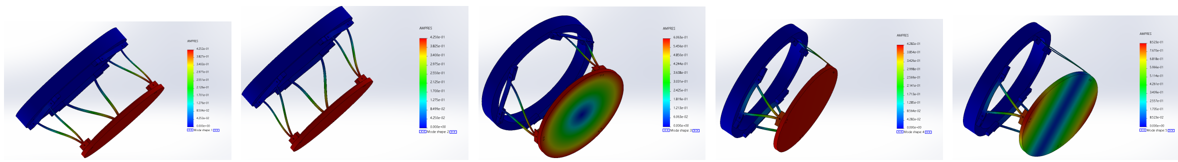

Figure 5: Triangular Ti

later on as the design process progresses.

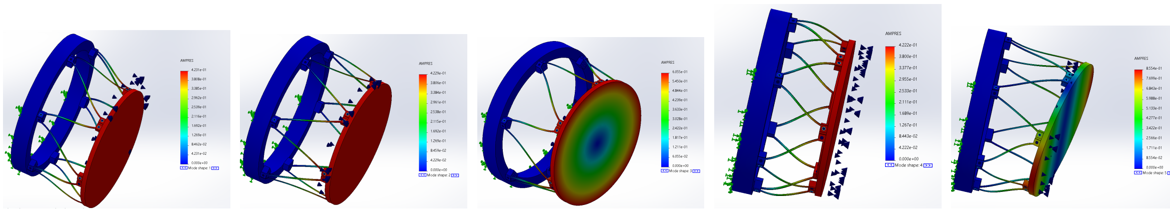

Figure 6: 'Truss' Ti

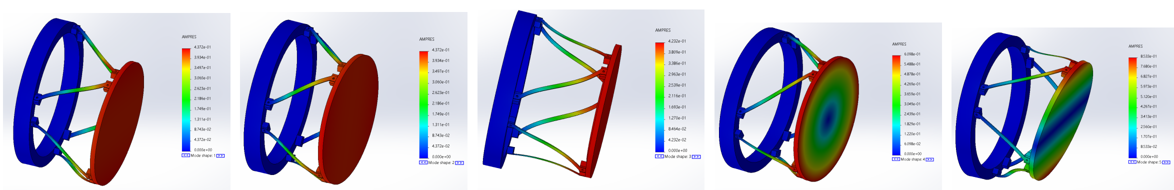

Figure 7: Hexapod Ti

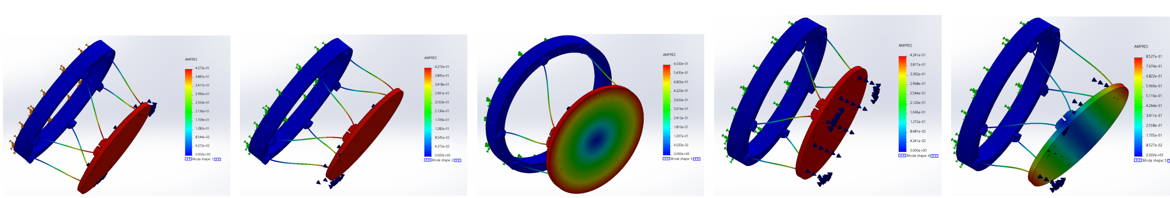

Figure 8: Hexapod Carbon Fiber