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DESIGN AND FEA OF A 3D PRINTED DETECTOR WINDOW FRAME

W. Tizzano*, Diamond Light Source, Didcot, United Kingdom

Abstract

The purpose of the project was to design and simulate a window assembly to be used in GISAX/GIWAX[1] experiments. The window lies between the sample and the WAXS[2] detector, a modified, in-vacuum detector, with modules removed to allow scattered radiation to pass through to a SAXS[3] detector positioned downstream. The window uses 75 µm thick Kapton® HN film and given the size, pressure and the short distance to the sensors, it was necessary to support it on a frame.

To avoid any information loss from shadowing of the detector, a frame was designed so that shadows will be projected into the gaps between the detector modules. The geometry was such that DMLS[4] was an effective way of producing the item. Given the slenderness of the structure and the forces it supports, the material approaches or exceeds its yield point, so a bilinear, isotropic, hardening material model was chosen; moreover, large deflections were enabled. Also, the contacts were modelled with augmented Lagrange frictional formulation. All these assumptions made the analysis strongly non-linear.

INTRODUCTION

I22 is a non-crystalline diffraction beamline for physical and life sciences that records simultaneously both SAXS and WAXS [1]. A recent upgrade project made GISAX/GIWAX experiments possible.

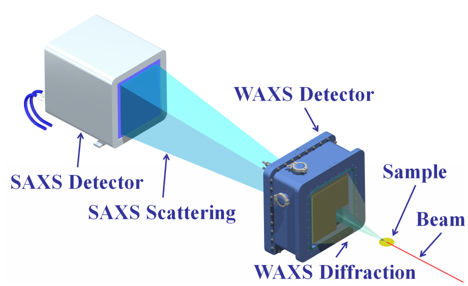

Figure 1: I22 Layout.

I22 is structured as follows (Fig.1): the beam coming from the BCO[5] hits the sample, and the diffracted light goes through a nosecone and is recorded by a 2D in vacuum WAXS detector; the above mentioned detector has some missing modules on the bottom right (Fig.2), allowing part of the radiation to pass through a snout and a camera tube, so the SAXS scattering can be recorded as well, by a detector at a distance that can vary up to 10 m [2] from the sample; three beamstops prevent the direct and reflected beam, and the glare from hitting the detector damaging it.

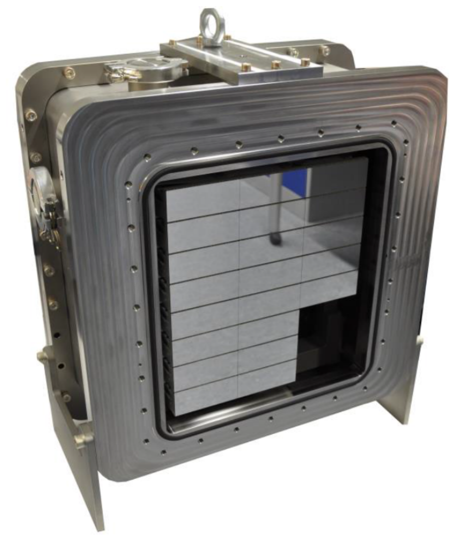

Figure 2: PILATUS3 2M-DLS-L [3].

WINDOW DESIGN

The PILATUS3 2M-DLS-L is an in-vacuum detector, so it was needed to design a window to isolate it from the atmosphere. A 75 µm thick Kapton® HN film was used, because of its transparency to X-ray and low scattering [4]. However, given the area of the window ($\approx 5.8 \times 10^4$ mm^2), the force generated by the differential pressure between the two sides of the film was considerable ($\approx$5.8 kN); for this reason it was necessary to support the Kapton film, or it would have deformed too much, and eventually would have broken.

Nonetheless, any support frame would project a shadow on the detector, and some information would be lost. However, the detector is made up of multiple modules, with gaps between them; the horizontal gaps are 17 pixels tall, and the vertical ones are 7 pixels wide. Since the pixels are square, and have a size of 172 µm^2, the gaps sizes are 2.9 mm and 1.2 mm, respectively. Hence, it was decided to design a support frame consisting in different ribs positioned and angled in such a way that, given a specific relative position between the sample and the detector, the shadow would be projected into the gaps (Fig. 3); in this way no information would be lost.

A rib section was drawn in PTC Creo, and all the necessary constraints were chosen so that in the software the ribs would adapt to the sample position, until this was fixed and the design finalised.

* walter.tizzano@diamond.ac.uk

[1] Grazing Incidence Small/Wide Angle X-ray scattering
[2] Wide Angle X-ray Scattering
[3] Small Angle X-ray Scattering
[4] Digital Metal Laser Sintering
[5] Beam Conditioning Optics

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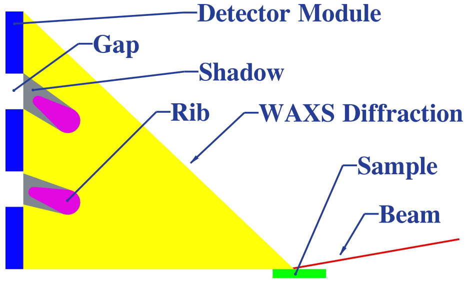

Figure 3: Ribs generation.

Since the resulting geometry was quite complex, and the volume of material was very small compared to the total volume of the part, traditional machining techniques would have been very expensive, so we decided to use an additive manufacturing technique (DMLS).

Among the ones available for this particular manufacturing technique, the material selected was stainless steel 1.4542, due to its mechanical properties (Table 1), and its behaviour in vacuum.

Table 1: SS 1.4542 Mechanical Properties [5]

Property	Unit	Heat Treated
Tensile strength	MPa	1040 ± 60
Yield point (Rp 0.2%)	MPa	430 ± 30
Elongation at break	%	15
E modulus	GPa	170 ± 30

FINITE ELEMENTS ANALYSIS

Given the slenderness of the structure, and the big loads applied to it, it was decided to run an FEA to check before manufacturing that the design was adequate.

Setup

Since the thickness of the Kapton film was very small compared to the other two dimensions, this element was modelled with shell elements and the mechanical properties used are summarised in Table 2:

Table 2: Kapton® HN Mechanical Properties [6]

Property	Unit	Heat Treated
Tensile strength	MPa	231
Yield point at 3%	MPa	69
Elongation at break	%	72
E modulus	GPa	2.5

The contact between the window and the support frame was modelled with an Augmented Lagrange frictional formulation, which reduces the sensitivity of the result to the choice of the contact stiffness, compared to a pure penalty method; in this way, the converged solution will have less penetration, hence being more accurate, at a cost of more iterations to reach convergence [7].

The Kapton film would deform a lot, and the displacements would be large compared to its thickness, so that the force generated by the pressure differential would change direction; for this reason it was necessary to enable the Ansys large deflections option [8].

A preliminary analysis confirmed that both the Kapton film would go beyond the yield point and the steel frame would approach it, so to model these materials as linear elastic was not considered appropriate. To take into account the plastic deformation without increasing too much the complexity of the simulation, a bilinear isotropic hardening model was chosen (Fig. 4).

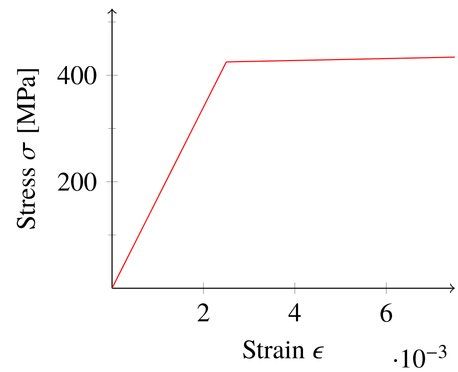

Figure 4: Bilinear Isotropic Hardening.

The Kapton film was meshed using quadrilaters, and the steel structure using tets (Fig. 5). The mesh quality was adequate (Fig. 6). Frictionless supports were used to constrain the Kapton film and the steel structure, and the load was a pressure evenly distributed on the Kapton film.

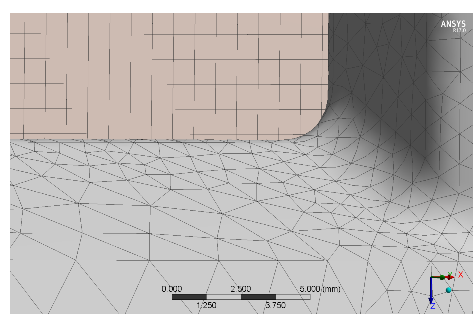

Figure 5: Mesh detail.

Results

The shape of the ribs and the non-linear contact required a fine mesh to reach convergence (minimum size of the elements 1.5 mm), and this was refined even more to 1 mm and then 0.8 mm to check that the solution was not sensitive to the mesh size; neither the stress nor the displacements sensibly changed by modifying the mesh.

The results showed that the support frame would not deform sensibly (Fig. 7); there is a point in the structure where

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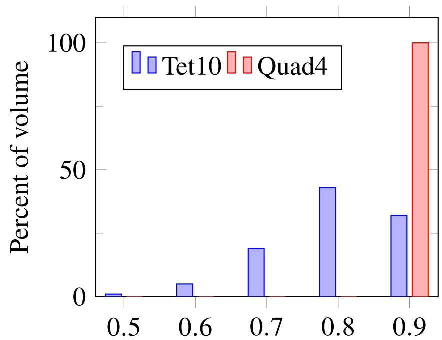

Figure 6: Element quality.

the stress is beyond the yield point, but it is a constrained sharp corner under compressive load, so this is a numerical singularity [9]; other than that, the most stressed point is below the yield point (Fig. 8). The displacements were not excessive for the intended use, as the structure and the Kapton window are far from the detector modules, and the structure does not deform enough to affect the shape of the shadows and make them fall outside the gaps between the modules.

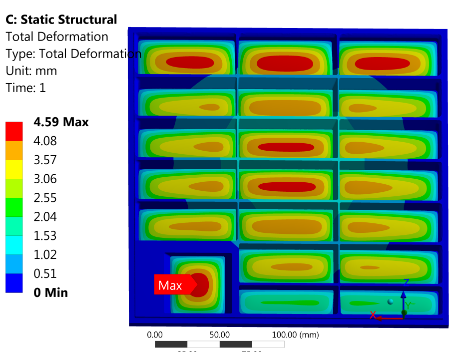

Figure 7: Displacements.

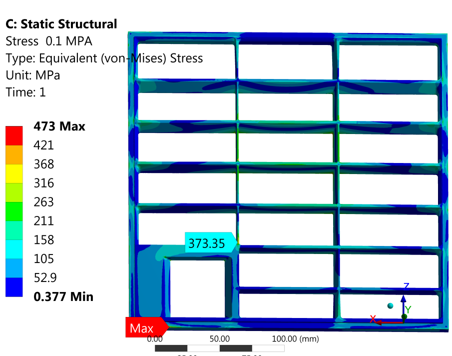

Figure 8: Stress.

FUTURE WORK

The parts were manufactured and assembled (Fig. 9), and they went through a pressure test to check that there were no leaks or visible damage.

A visual examination did not highlight any noticeable permanent deformation so the window is now operative (Fig. 10); a test is planned to measure stress and strain, so the results can be compared to the simulated ones, to validate them.

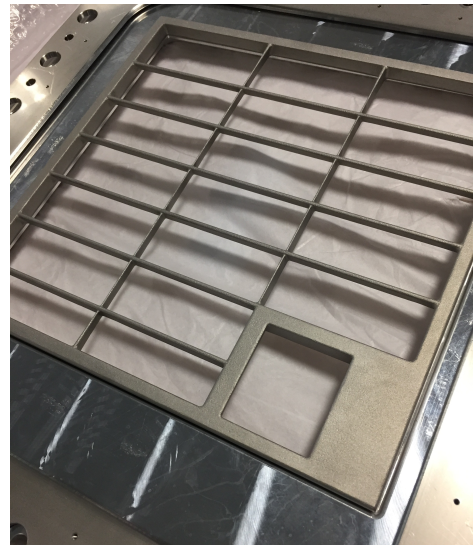

Figure 9: Assembled window (without Kapton film).

Figure 10: Window in operation.

CONCLUSION

A window frame was designed for use in GISAX/GIWAX and manufactured with an additive manufacturing process, only after an FEA confirmed the ability of the design to cope with the loads. It is now in use on the beamline.

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