Hector Spectrograph (Spector): Mechanical Engineering Overview

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ABSTRACT

Hector is a multi-integral-field-unit instrument for the Anglo-Australian Telescope (AAT). It simultaneously feeds two spectrographs, the existing AAOmega spectrograph and the new higher-resolution Spector spectrograph. Both are fed with new generation hexabundles. Spector has an all refractive 2- arm design which delivers 1.3A fixed resolution across the full wavelength range has higher resolution in the blue end and R=5000 in the red which makes Spector uniquely powerful spectrograph. The mechanical assembly of the spectrograph is designed to provide specific solutions to the tight spacing between component assemblies with strict tolerance constraints which makes Spector an interesting challenging instrument. The components start with a custom slit assembly providing precise positioning of 855 fibres which forms the interface point for light injection to the spectrograph. This paper presents a detail overview of opto-mechanical component design of Spector spectrograph along with technical specifications. Component fabrication, assembly, testing alignment was completed by early 2021 and received first light in December 2021.

Keywords: Spectrograph, Opto-mechanical design, Fiber Slit, Beamsplitter, VPH Grating, Kinematic Mounts

1. INTRODUCTION

The Hector instrument has two spectrographs, the existing AAOmega spectrograph, and a new higher-resolution fixed-format Hector spectrograph (Spector) built for the Anglo-Australian Telescope (AAT). Spector has an all refractive 2- arm design which delivers 1.3A fixed resolution across the full wavelength range has higher resolution in the blue end and R=5000 in the red. Hector is fed by fibres that are positioned by a robot at the AAT telescope prime focus. There are a total of 855 fibres, which interface with the spectrograph via slit located at the entrance of the spectrograph. Spector contains completely custom optics and mechanical components starting with a fibre slit assembly. The collimator optics reside within individual lens cells that provide tip, tilt, and x, y alignment adjustment.

Spectrograph alignment is accomplished on the AAO lens centering station. The beam from the collimator is split into two bands with the blue arm covering 372 to 591 nm and the red arm covering 571 to 778 nm. The camera, beam splitter and VPH grating assemblies reside in kinematically mounted holder assemblies for alignment and the ability to accurately remove and replace from the spectrograph. Spector consists of semi-custom Spectral Instruments cryostat detectors. Spector has completed its final design and commissioned successfully at AAT after undergoing testing at the AAO office in Sydney. The details of overall mechanical design and assembly of the spectrograph is presented here.

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2. OPTICAL DESIGN

Spector is a 2 arm design with a fibre input slit. The fibre core is reimaged by the spectrograph optics onto the CCD detector, while the fibre far field forms the pupil which is projected by the spectrograph collimator onto a surface after VPH gratings, dispersing the beam into the cameras. The design operates with two semi-custom Spectral Instrument dewar detectors. The red and blue spectrograph cameras provide demagnification of the fibre slit and are therefore a more challenging design when compared to the collimator. Each camera images the spectra on a 4k x 4k E2V detector. The average spectral element of resolution is 0.13 nm wide.

The spectrograph optical design had various stages of development with analysis of trade-offs, performance drivers, and cost minimization. Initially, it was considered to use a microlens array slit which would allow to reduce the numerical aperture of the fiber output and simplify the design of the collimator. Microlens arrays are precision optics lithographically etched to custom requirements, the savings on collimator fabrication would be offset by the relatively high cost of the microlens array. Tolerances of a system with microlens arrays on input and output also degrade the performances.Tolerances of a system with microlens arrays on input and output also degrade the performances

Transparent and semi-transparent types of layout were considered during Spector optical design phase. In the semi-transparent design, all surfaces were aspheric and the design contained large doublets to be bonded or greased. Cost evaluation also showed that the semi-transparent design was more expensive than the transparent design. The transparent design consisted of singlet lenses only in the collimator and cameras. The design featured just 6 mild aspheric surfaces for efficient fabrication. There was no clear pupil stop as compared to the semi-transparent design but this was overcome with the help of a pseudo-stop made of several baffles working together to truncate the peripheral areas of beams. The transparent version was selected for further development in the last stage to yield a hybrid design for the spectrograph. The hybrid design borrowed a number of features from the semi-transparent design. The aspheric departure was increased in pursuit of image quality and lower cost because it permits to reduce the size of the optics for the same performances.[3]

The final design is displayed in Figure 1.

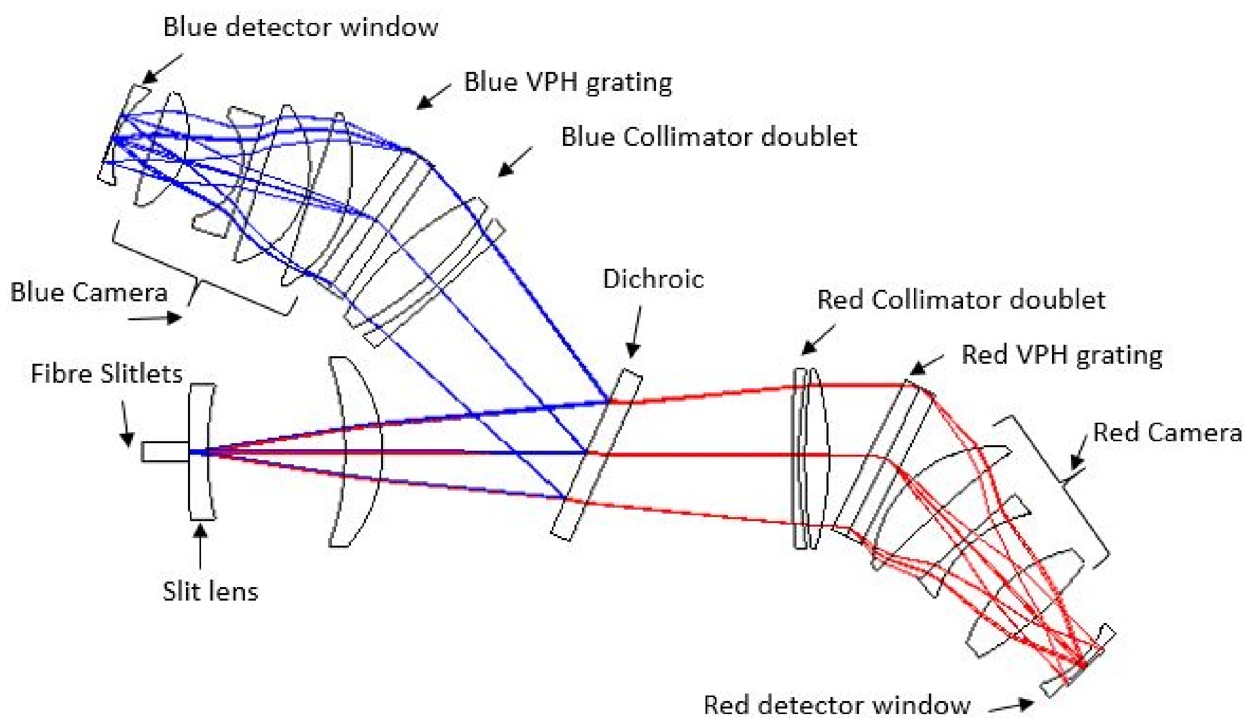

Figure 1. Top view of Spector optical layout

3. MECHANICAL DESIGN - TOLERANCE REQUIREMENTS

The design of Spector was driven by high level science requirements. Table below shows details of Spector optical properties and alignment tolerances.[3]

Table 1. Summary of Spector optical properties

Field of view/Slit length	145.2 mm
Fiber core/cladding/buffer diameter	103/123/250 µm
Number of fibers	855
Number of slitlets	19
Fibers per slitlet	45
Entrance Pupil Diameter	390 mm
Entrance Pupil Position	1270 mm
Spectral arms (Red) Wavelength range	372 - 591 nm
Spectral arms (Blue) Wavelength range	571 - 778 nm
Overlap between arms	571 - 591 nm
Dichroic split	581 nm
Collimator effective focal length	592 mm - 560 mm
Camera effective focal length	235 mm - 223 mm
decenter in spectral direction	8.8mm - 0.45mm
CCD to Camera	
Tilt in spectral directiopn	3.0° - 2.1°
CCD	
pixel size	0.015 mm
number of pixels	4096 x 4096
linear dimensions	61.4 x 61.4 mm

Table 2. Lists Spector alignment tolerances (decenter and focus)

	Horizontal Decenter (mm)	Vertical Decenter (mm)	Focus (mm)
Slit Lens	Reference		
	0.1	0.07	0.1
	Blue and Red Channel		
Beam Splitter	-	-	0.15
Collimator Doublet	0.2	0.1	0.5
VPH Grating	0.7	0	-
Real Stop	0.7	0.7	-
Camera	0.2	0.1	0.5
CCD	0.03	0.03	0.02

Table 3. Lists Spector alignment tolerances (tilt and roll)

-	Horizontal Tilt (mm)	Vertical Tilt(mm)	Roll(mm)
Slit Lens	Reference		
-	10	3	-
	Blue and Red Channel		
Beam Splitter	1	2	-
Collimator Doublet	4	2/3	-
VPH Grating	5/3	10	20/10
Real Stop	-	-	-
Camera	3/2	2	-
CCD	1	1	-

4. SPECTROGRAPH MECHANICAL DESIGN AND SUBSYSTEMS

The main criteria for Spector design was to create a structure that was simple to machine and easy to align all of the optics. The structure supports and position all the optomechanics as per the requirement. The overall construction of spectrograph is made of aluminium and is mounted in a temperature controlled room which has a requirement for the temperature stability to be controlled to +/- 1.5 degrees.

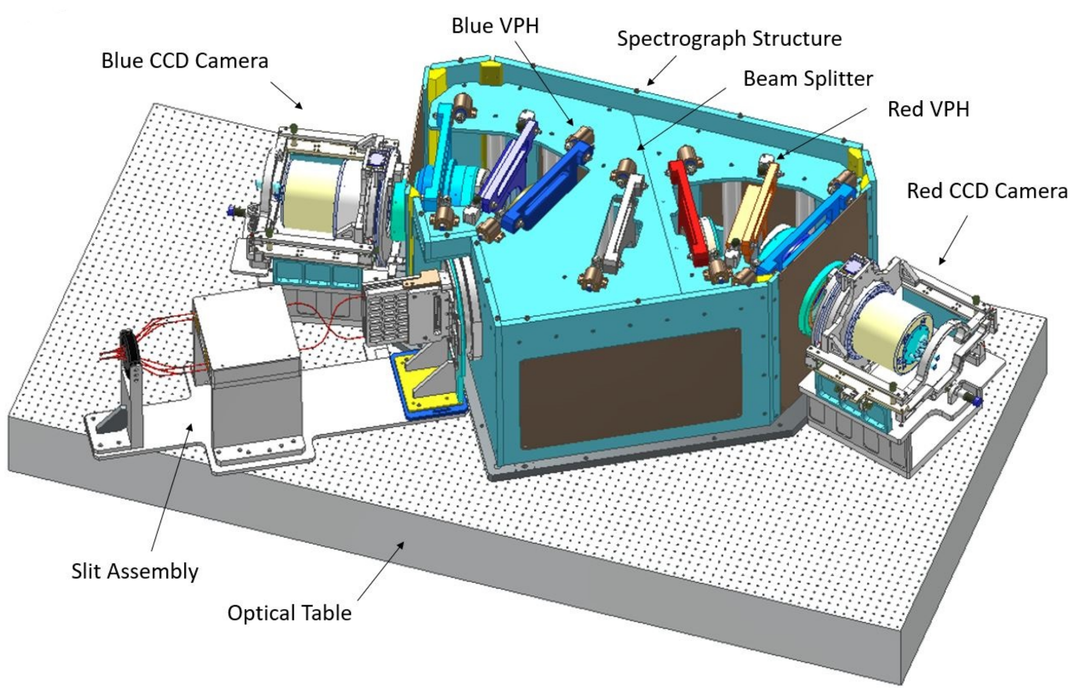

Figure 2. View of Spector spectrograph component subsystems.

All the major component assemblies are shown in Figure 2. Components are mounted on a flat light weighted optical bench. The optical bench for Spector is made of aluminium /steel construction with interfaces to locate structure for 5 axis mount, slit assembly and spectrograph structure. Optical bench offers a high stability of spectrograph optics configuration against temperature variation. All opto-mechanical interfaces, precision machined datum and features ensures accurate and repeatable alignment of optical system. Box type structure is used to install all optical elements in order to prevent stray light (both internal and external) and dust from impacting the optics, hence the performance.

4.1 Spectrograph Structure

The structure is constructed of aluminum cast jig plate which gives stability and precision ground surface. Due to its unique casting process and being fully stress relieved this material provides a high degree of geometric stability post machining. Spector structure frame creates stiff support and positions all the optical components to its position precisely. It will operate in a thermally insulated room that is tightly temperature controlled. The room design and structure design also provides a stable optical alignment.

Figure 3. Optics mounted to spectrograph structure.

Spectrograph structure sets the foundation for the build and alignment of the instrument.The base plate has profile machined to set the required angle of collimator. The collimator plate is located and mounted to the base plate includes a precision bore which establishes the optical axis of the system. The nominal angle of the blue and red channel is set through precision machining of pockets on the intermediate plate. The structure holds kinematic mounts to locate collimators, VPH gratings and cameras. Intermediate plate is used to mount all the optics from top and has various pockets to locate and mount kinematic mounts of all respective assemblies. Top plate is installed to cover the whole assembly from stray light and dust.

4.2 Beam splitter and VPH grating

The beam splitter mount and VPH grating mount follow the same design principle (Figure 4). They are constructed out of Aluminium 6061. The optics are bonded into each mount with RTV and cover is provided to protect the optics from the other side. Each optic is mounted kinematically to the structure. The kinematic mounting arrangement allows highly accurate removal and replacement of optic during alignment.

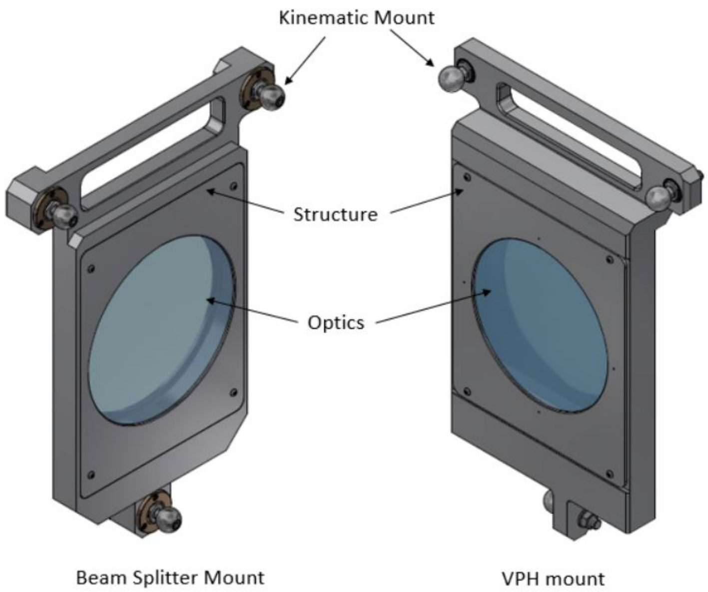

Figure 4. Beam splitter and VPH grating mounts.

4.3 Collimator and Camera

The collimator and camera assemblies (Figure 5) are constructed in aluminium and has number of individual lens sub-assemblies bonded together to make one complete lens assembly. Each lens cell is designed to be aligned on the AAO lens centering station. Each lens is mounted in an individual cell with the optical surface resting on a tangential cell surface. Lens cells are first run out on the precision AB tech air bearing stage to form the opto-mechanical axis of the cell. The lens and cells are then rotated on the air bearing stage while the lens is tilted on the tangential seat. The return beam runout of the lens surfaces as observed by the PSM is minimised thus optical axis is established. Lens is bonded to the lens cell by applying RTV bond on the perimeter of the cell and an axial retaining ring is threaded to securely mount the optics.

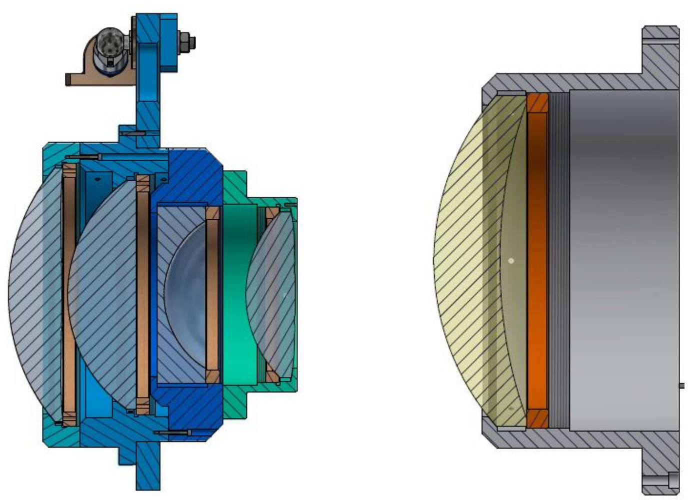

Figure 5. Camera and Collimator mounts.

4.4 Kinematic mounts

Elements on the spectrograph structure are indexed to allow their accurate repositioning to cope with the several mounting and dismounting of the elements and in particular to minimize the activities around the spectrograph during alignment. All the major optics assemblies are mounted to the structure by kinematic mounts. A kinematic mount, which is ideal for optics and optical structure mounting, is a mount in which all six degrees of freedom (three translations and three rotations) of a 3D object are restrained from moving without over constraint. It also allows minute adjustment (tip/tilt, roll translation) to the optic assembly during alignment.

In Spector, the adjustment in kinematic mount is done differently in VPH assemblies and rest of the assemblies. In VPH, the adjustment is done through though shimming (by adding / removing shims from the kinematic mount). This activity requires to remove the whole mount assembly from the structure and adjust the shim as per requirement and refit the mount to the structure which required more time during alignment process. To improve this process a new mechanical design was proposed which deals with the need for modularity and repeatability.

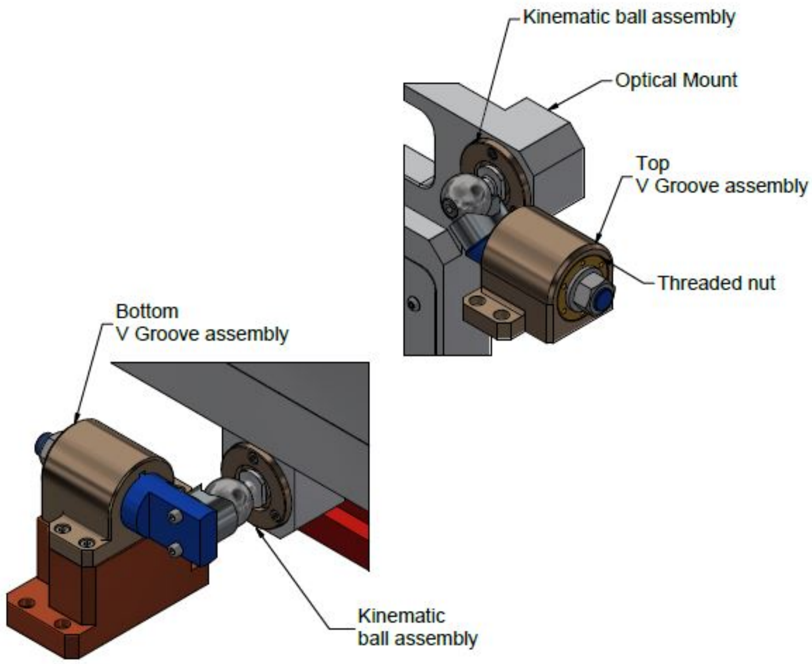

Figure 6. Kinematic mounts.

The new design consists of kinematic ball and V groove mounted on separate casing having an adjustable threaded nut in place. Kinematic ball is fitted to the optics assembly. V groove holders are mounted to the main spectrograph structure which is used to locate and position the optic assembly. During alignment, the threaded nut is rotated which pushes the kinematic ball / V groove to move (± 3 mm) and hence the optic assembly is moved. This process allows minute adjustment of assembly during alignment process without removing optics assembly from spectrograph structure.

4.5 Cryostat mounting

The Spector is configured with semi- custom Dewar detectors (4k-4k) from Spectral instruments. The CCD camera is mounted to a 5 axis mount which has adjustment provision in all 5 axis including tip-tilt, rotation, lateral decentre and focus. Focus adjustment occurs through linear bearings. The Focus travel is motor driven using Maxon motors configured with an integral drive spindle, 29:1 gear head and 500 count per turn encoder. All other axes of travel except focus can be actuated through manual precision adjusters. Height adjustment can be done through shimming. The detector assemblies are face mounted to the structure. Flexures are provided to allow tip tilt rotation adjustment from the surface of the detector.

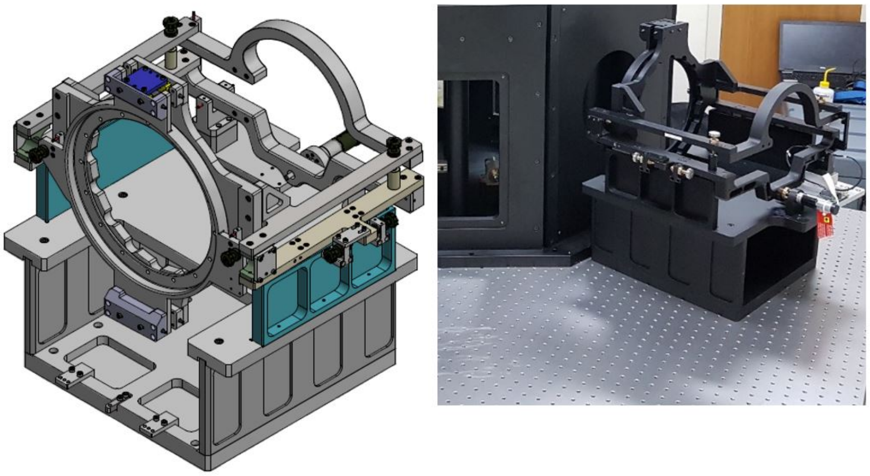

Figure 7. View of Cryostat 5 axis detector mount.

4.6 Spector Slit Assembly

The fibre cable terminates at the spectrograph slit assembly. The slit assembly provides the precise positioning of all the fibres and is the interface for the light injection to the spectrograph. Hector slit assembly consists of 19 slitlets and each carrying 45 fibres. The fibres are terminated in precision fused silica V–groove blocks. The fibre spacing in the V grove blocks is at 160um, pitch as required for the spectrograph performance. Distance between two slilets is around 70 um.

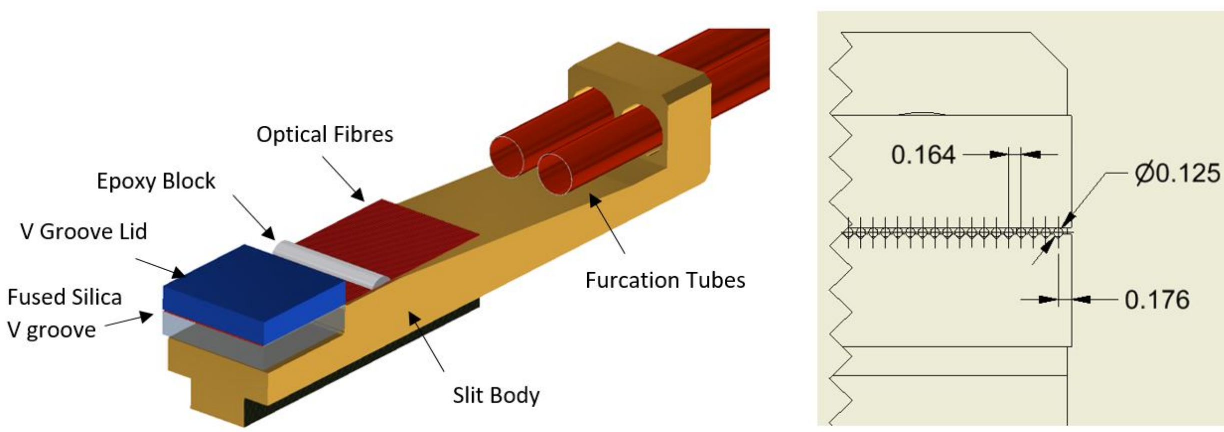

Figure 8. General design of Spector slitlet with fibre placement.

To keep the order of fibres in the bundle correct fibres are glued together before integrating into V-groove. The fibres are then placed in V groove and capped with fused silica lid and glued in place. Slitlet body provides all the assembly interfaces for the slitlet construction and is fabricated from Mirrax as the material is having high corrosion resistance for low maintenance requirements. All the slitlets are assembled to the slit body similarly and then the complete assembly is polished to optical quality. Customise jigs were made to glue and polish the fibres to the slitbody.

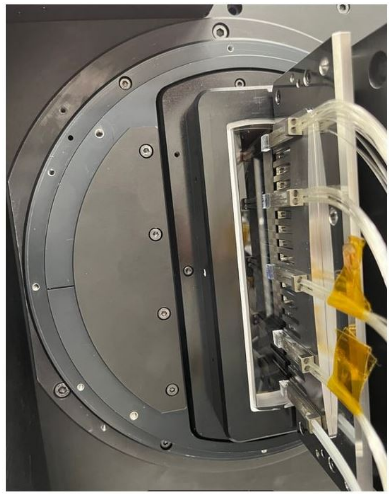

Figure 9. View of Spector test slit assembly

To install complete slit assembly, collimator lens is first installed on its mounting cell and the whole cell unit is installed on spectrograph main structure and aligned with the rest of the spectrograph optics. Slit is mounted on the slitlens structure with axial mounting brackets to prevent structure to damage the slitlens which is already fixed in its mount. The slit body acts as interface to mount all the slitlets precisely and has curved profile machined holds the 855 optical fibres along a curved slit lens.

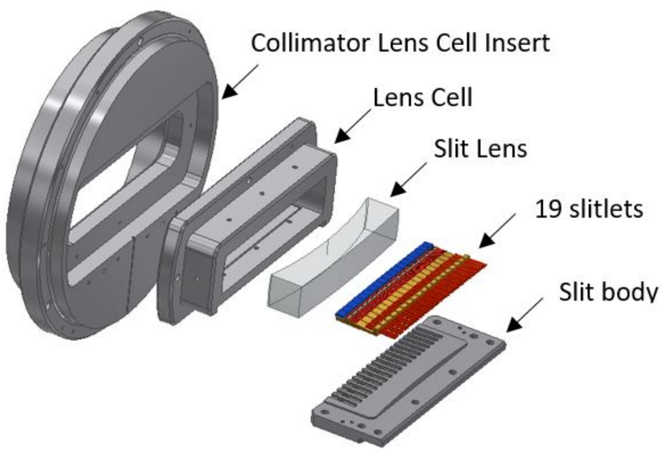

Figure 10. Exploded View of slit assembly design

Fiber cable along with the loop box from the top end is routed to the spectrograph room. The conduit and loop box is clamped to the support structure located on the side of the optical table. Once fiber cable is clamped securely the slitlets are installed on the slit body one by one from the bottom to the top (or reverse). Indexing matching gel is applied to each slitlet surface and carefully slide in the mounting slot and slightly push it against the slit lens. After all slitlets are installed, slit cover is mounted to protect the slitlets.

4.7 Spector Fibre Cable

The purpose of Hector fibre cable is to carry light form Hector positioner to the Spector. 2DF uses fibre optic cables to transmit the light of the science targets from the top end of the telescope to the spectrograph. Hector top end is installed onto the existing 2DF top end. HECTOR top end will utilise two spectrographs (AAOmega and HECTOR) hence the HECTOR optical fibres will also need routing from the 2dF top end to the Spector and the AAOmega spectrograph. Hence two additional fibre optic conduits need to follow the same path as the AAOmega and Hermes fibre conduits starting at the 2DF top end and finishing at the Spectrographs.

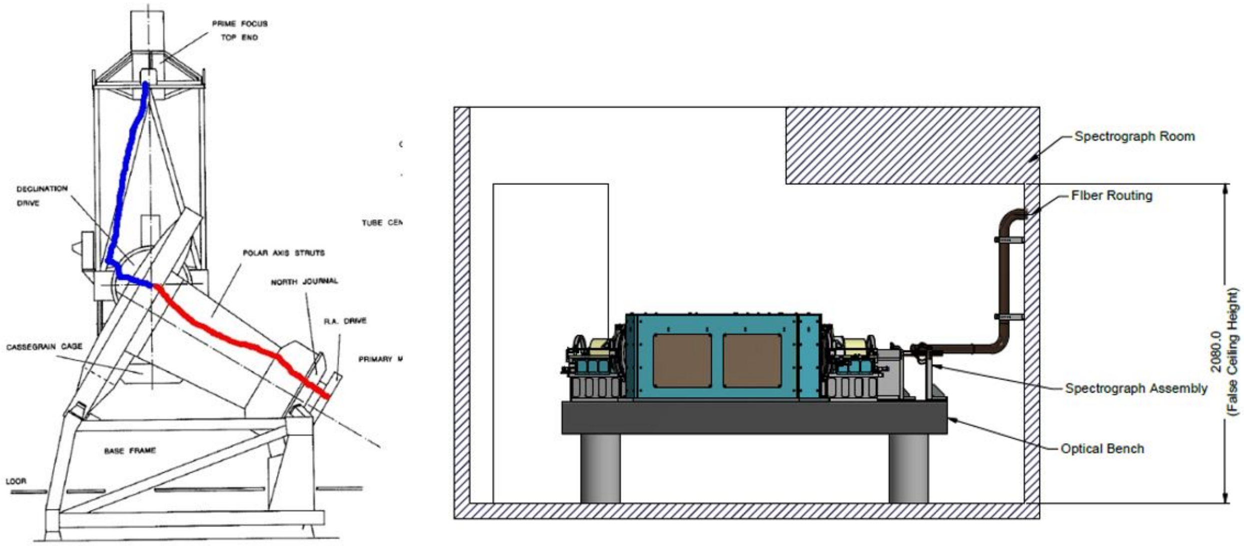

Figure 11. Spector fiber cable routing from telescope top end to spectrograph room.

Spector optic fibre conduit path is as follows: Fibre conduits travels from the Spector room across the corridor into the AAOmega room. From here the two optic fibre conduits leave the AAOmega spectrograph room, traveling through the north journal and into the coude light path. They then proceed to travel up the coude light path, through the declination bearing, through the mirror petals, up the PVC piping and onto the 2dF top end ring. All the necessary modification were made to route new Spector conduit from spectrograph room to telescope top end.

4.8 Mechanical Integration and Testing

All the mechanical parts for Spector was successfully fabricated, integrated and tested at AAO testing labs. CMM inspection of critical parts were carried out to check all important dimensions and tolerances. Once individual parts were checked the complete assembly was also verified to check important features. After operational performance and other testing was done successfully, all part assemblies were shipped to AAT sliding spring for instrument commissioning.

5. CONCLUSION

We have presented here overall mechanical design and installation details of an efficient fibre-fed high-resolution spectrograph. Spector has been commissioned at AAT after testing and meets all of its specifications.Spector has received its first light in December 2021 and other planned science observation is well underway.

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