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NIRSPEC Cryomechanics Design Note 11.01
Echelle mechanism

1 Introduction

The echelle mechanism must perform two functions: scanning the echelle over a range of a few degrees, and replacing the echelle with a flat mirror for the low-resolution mode. The required accuracy and stability are very high, and the total mass of material to be moved is larger than in any of our other mechanisms. A big factor in the difficulty of the design is the fact that space is constrained on one side by other mechanisms, so the moving part of the mechanism, carrying the optical components, has to overhang from the side providing the support.

Over the last few months I have come up with two designs for this mechanism. The simpler mechanism is what we refer to as the 1-axis design. This has the echelle and the low-res flat mirror mounted back to back. When we want to change from one to the other we simply rotate it into place. The full details of this design are given in a later section.

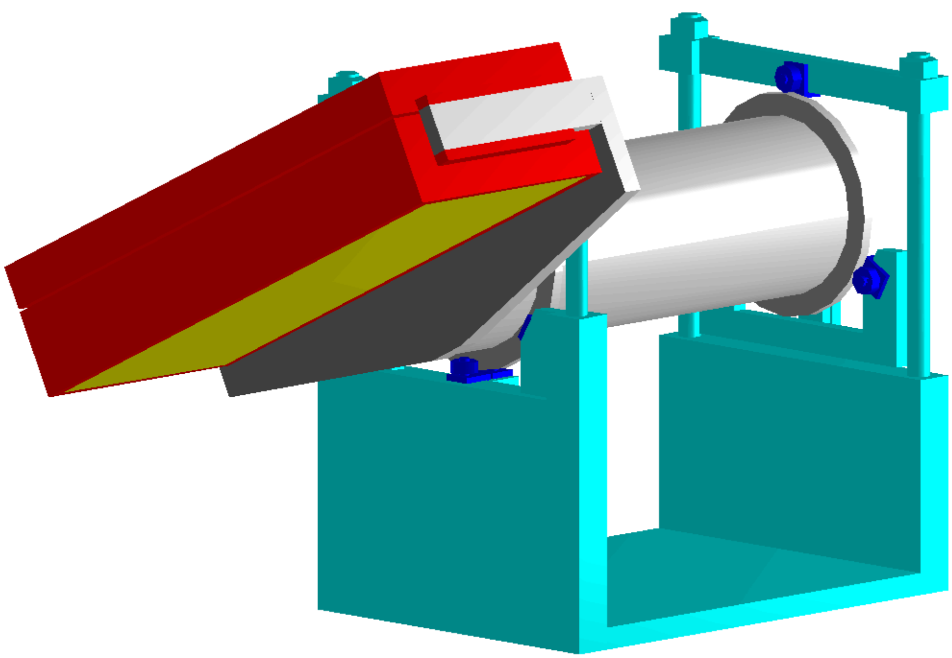

Figure 1: The one-axis version of the echelle mechanism

One factor that complicates matters is that we may want to add a second echelle with a different groove density at a later date. The second echelle would be a custom ruling, making it much more expensive than the primary one, so it's hard to say whether or not it will ever be purchased. Nevertheless, I tried to accommodate it in another version of the mechanism design. This is what we call the 2-axis design, since the scanning axis is not used to change between optical elements. The changeover is accomplished by having a second axis of motion, with the three optical elements mounted as a triangular prism which rotates about its long axis.

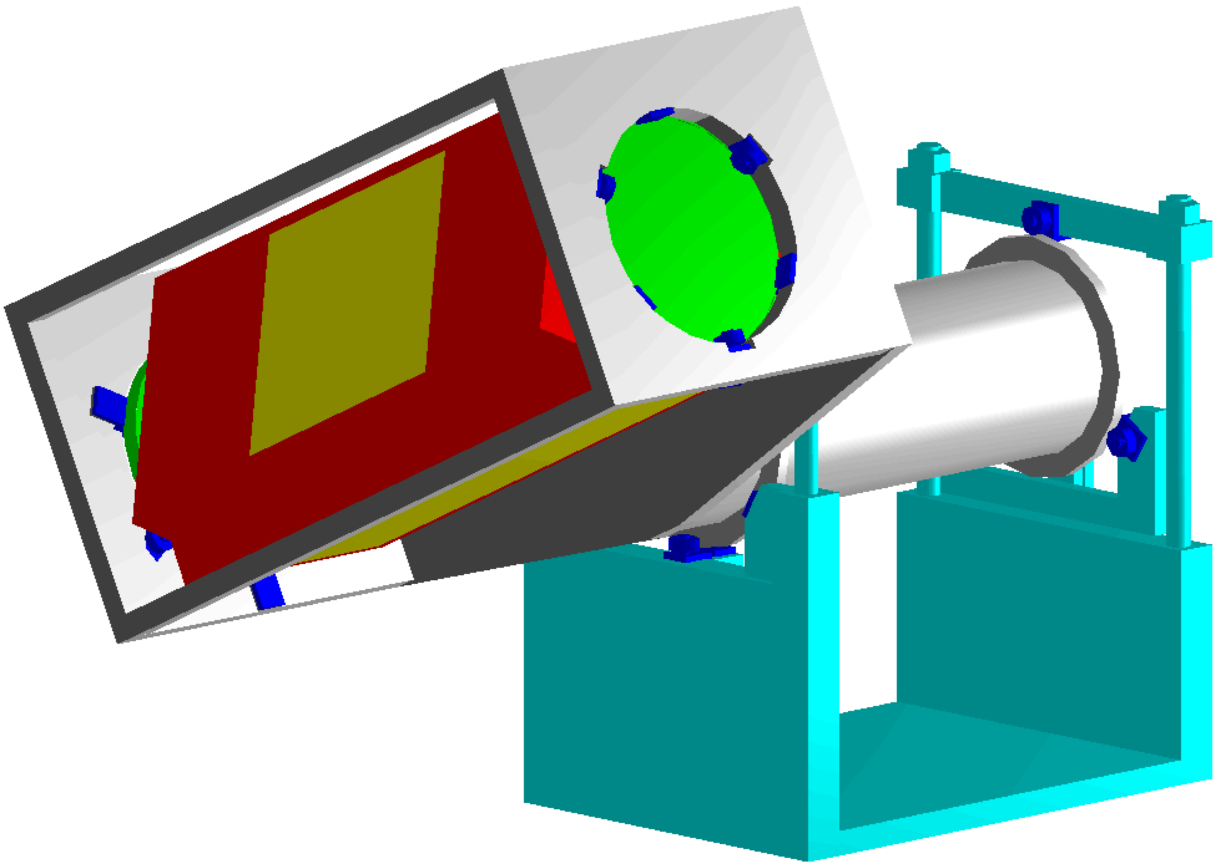

Figure 2: The 2-axis version of the echelle mechanism

I had originally envisaged that we would build only this version, so that we could retrofit the second echelle when and if it became available. Obviously this approach makes the mechanism much more complicated than it needs to be for just a single echelle and flat mirror, and at the Critical Design Review the committee recommended that we should drop the 2-axis version. The review committee also recommended that we try to fit the second echelle into a variant of the one-axis mechanism incorporating all three elements. However we had already looked at this idea and found that there is not enough available space. John and I re-visited the idea just in case there was some way to make it work, but confirmed our earlier finding that it is not practical without major rework of the optical layout and a drastic enlargement of the dewar.

Given these constraints, we decided our best option will be to build the single-axis mechanism with a single echelle and mirror as the default configuration of the instrument. If we do decide to add the second echelle later, then we will have to go for the more complicated 2-axis version in order to fit the mechanism within the space available[1]. This will of course cost more to build, in addition to the cost of the extra echelles. We won't discuss the additional complications of the two-axis mechanism any further in this document: if we ever build it there will be a revised design note.

A factor in our discussions of strategy, and something that has to be resolved before orders can be placed and fabrication starts, is consideration of the dimensions of the echelle. In the 2-axis mechanism the two echelles and mirror sweep out a cylinder as they rotate to swap positions. Of course this cylinder is wider than the individual elements, which are mounted in an equilateral triangle arrangement. There is limited space between the echelle mechanism and the slit wheel, so the echelles must be just wide enough for the incoming beam to fit on the ruled area, so as to keep the swept cylinder as small as possible. This width is about 2 cm less than the standard ruling we want to use for the first echelle. Fortunately Spectronic Instruments (formerly Milton Roy) can make the main echelle from an existing master but on a narrower than standard substrate.

The other thing we have to consider is the *shape* of the echelle substrate. For the one-axis mechanism we would just use a rectangular slab of adequate thickness, but for the two-axis version the back has to be tapered to allow the two echelles and the mirror to fit together as a small enough triangular prism. The taper is bound to make the substrate less rigid. Spectronic Instruments recommend that substrates have a ratio of thickness to longest dimension of between 1:8 and 1:6 (thicker is better). This is so that there is enough aluminum to resist bending induced by the contraction of the epoxy used to attach the replica grating. This bending occurs as the grating cools (like a bi-metallic effect except one material isn't a metal), and could introduce an unacceptable amount of wavefront error.

At NIRSPEC Project Meeting 18 we decided to risk some degradation in the performance of the primary echelle by making it on the tapered substrate that would fit into the 2-axis mechanism. However we spent some more time going to and fro with Spectronic Instruments on this issue, and weren't able to get an unequivocal assurance from them that the tapered substrate would be rigid enough. As a consequence we finally changed our minds (on Wednesday, April 10, 1996) and decided to take the lower risk approach of making the primary echelle a simple rectangular slab. It is unlikely we will manage to find the extra money for the two-axis mechanism within the original budget, so we if we want to build it we will have to go back to the SSC for extra money, perhaps as

[1]We must of course make sure we install sufficient electrical feedthroughs in the dewar wall from the start to drive and monitor the second axis if it is ever installed.

much as $150k. In that context, the extra $25k for another echelle with the same groove density as the original but with the tapered substrate does not seem excessive. Meanwhile the primary echelle will be performing as specified and we can do some work to get a feeling for the extent of the potential problems.

2 The 1-axis design in detail

2.1 Rotating barrel and bearing mechanism

The rotating part of this mechanism must support something close to 20 lbs of aluminum offset to one side (see figure 1). It must rotate smoothly and reproducibly, and remain stable as the instrument cools. Our overall design philosophy for NIRSPEC is to make the whole instrument athermal so that all alignments are preserved as the instrument cools from room temperature to operating temperature. A major concern when we first started looking at this mechanism (and some of the others such as the image rotator) was how to incorporate bearings into a mechanism of this size. The whole structure of the instrument is built of aluminum, but bearings are normally made of steel. The difference in thermal contraction between steel and aluminum is about 10 thou over a 4" bearing. That would mean any aluminum part inserted into the inner race would become loose or even drop out, while the aluminum part holding the outer race would compress it, distorting it or potentially even cracking it[2]. We looked at a few possible solutions including having custom bearings made with aluminum races, and using steel bearings held in springy fingers of aluminum as we do with lenses. The former was abandoned on grounds of both cost and size (the proposed bearings would have a very large cross-section), and the latter by concerns about accuracy of centering.

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[2] It is worth noting that we have never actually tried this. However the 10 thou figure is large enough that our concerns are probably justified.

The proposed solution to the bearing problem is to use multiple small bearings to support a rotating aluminum barrel. The barrel has flanges which run against small steel bearings mounted

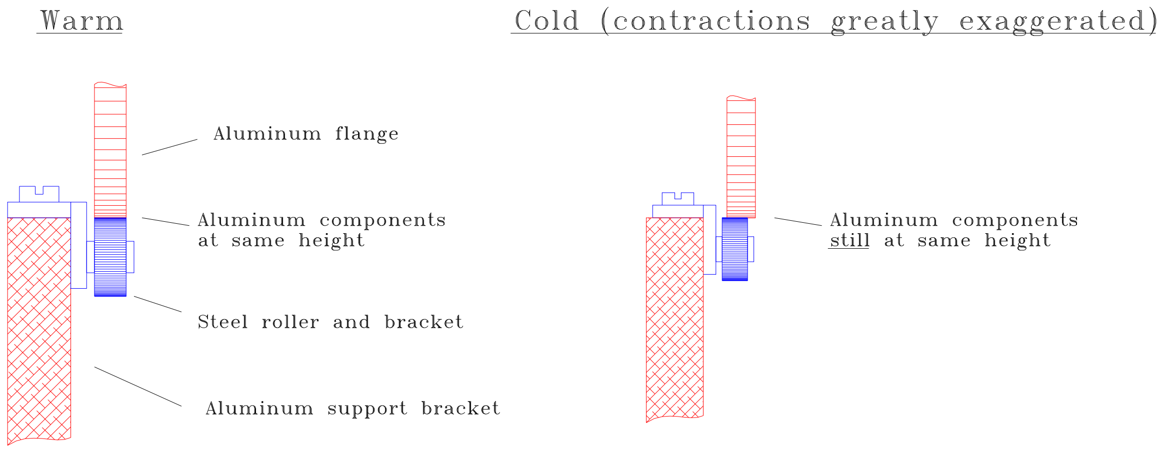

Figure 3: Illustration of the athermal roller mount concept.

around the circumference. Each steel bearing is mounted on a steel L-bracket screwed to the aluminum support structure. This bracket is sized and attached so that as the bearing contracts, an identical length of the steel bracket also contracts, canceling out the contraction. As a result, the fixed and rotating aluminum components always retain the same *relative* positions at any temperature. An illustration of this concept is provided in Figure 3. The effect of this layout is that every part of the mechanism contracts toward the optical plate just as if it were a solid aluminum structure, without any split bridged by steel.

To support the weight of the drum and the components it carries on one end, there are 2 bearings under each flange of the drum and one on top. The top bearing is supported from a cross-bar which is spring-loaded so that it presses the bearing against the flange. We will have the flanges ground to be circular to about 0.0001". So that the four lower bearings are all in one plane, one pair (the far end from the grating/mirror mount) are mounted on a pivoting bar. As soon as the weight of the barrel presses down on them, they will be forced to line up with the other pair. This arrangement is shown in Figure 4.

As described so far, this arrangement has one flaw, in that there is nothing to stop the barrel from slipping along the direction of its axis as it rotates. To take care of that, one of the flanges has

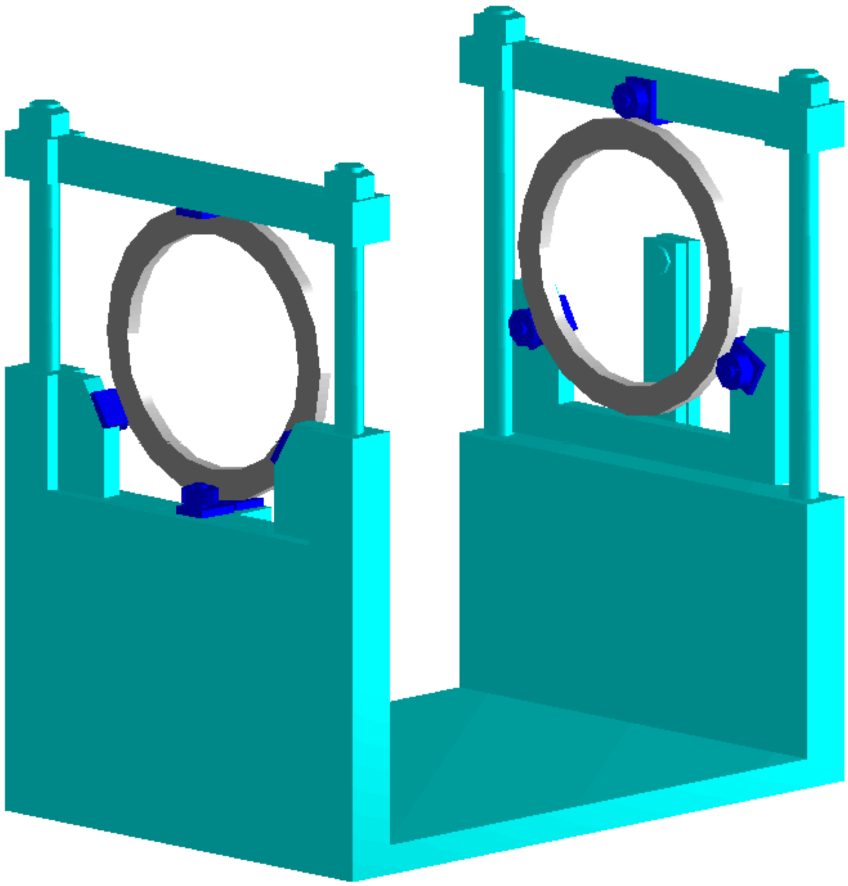

Figure 4: Support of the rotating flanges in the athermal rollers

a pair of bearings pinching it to hold the whole thing steady (shown at lower left in figure 4). One bearing is on a fixed athermal mount, while the other is on a spring mount so that it presses the flange against the fixed one. This feature is in fact the reason we have flanges at all rather than just a simple cylinder.

The barrel mount supports the weight of the optical elements and their support fork as well as the barrel itself. This weight is off to one side as mentioned before, so in order to counteract the tendency to push up the outboard end of the barrel we have made the barrel as long as possible given the space allowed. This turns out to be about ten inches. The support for the whole setup is a simple arrangement of two vertical walls from a baseplate, as shown above.

2.2 The optical mounts

The echelle grating and mirror both have to be attached to the fork, back-to-back. We need to do that in such a way that they can be adjusted during the alignment process and will then be held in a rigid and secure mount. The mounts must not cause any deformation of the optical surfaces.

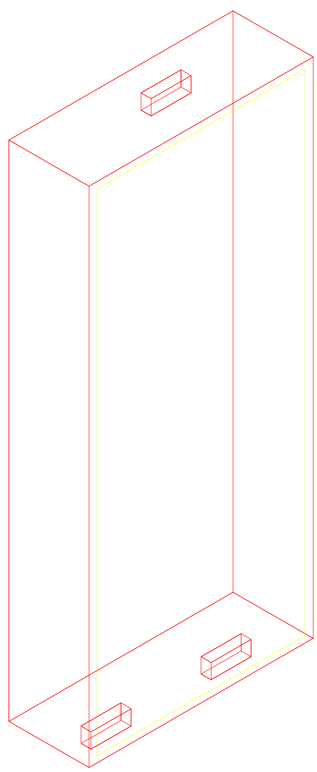

Figure 5: Echelle substrate

What I propose to do to mount both the mirror and the echelle is to have a three-point mounting to flanges on the ends of the substrates. The tolerance on alignment of the optical elements is on the order of a milliradian, which is not too stringent. Since the mechanism itself has to be aligned to the rest of the instrument, it might seem that we only really need the ability to align the mirror relative to the echelle. The echelle could simply be located to machined tolerances and the mechanism located on the optical plate to align the echelle to the beam, then the mirror could be adjusted to the proper orientation once it has been rotated into place. The problem with the idea of only having an adjustment on one element is that it's probably harder to align a whole mechanism on the plate than it is to tweak one single optical element. We also have to make sure that the echelle is aligned not only to the input and output beams, but also to the true axis of rotation of the mechanism. Therefore it will be better if we have the ability to adjust both elements.

To align the echelle and mirror we could use either machined pads or shims, or possibly differential screws. Either way the form of the substrates themselves will be pretty simple, as shown below. Each element will have one mount point at one end, and two at the other. To allow space for the adjustments, the end of the fork with two adjustments on one component will be the end with one on the other. We may also need to be able to remove either element and put it back in the same orientation. The mounting arrangement needs to allow for that, implying that any screws that are used for adjustment of position can't be the same ones that actually join the mirror and echelle to the fork.

2.3 Handling the optics

We need a way to handle each element when it is removed from the mechanism for any reason, so that the delicate (and horribly expensive) optical surfaces are not damaged. To do this I propose we make a cover for each element that fits over it and screws to the mounting flanges at each end. The covers will also have flanges at the ends mating with the mounting flanges. There will be captive screws in the ends of the cover which will screw into tapped holes in the mounting flanges, and clear holes in the cover flanges to allow access to the mounting screws so that the optical elements can be detached and lifted off. The cover can have a handle for easy handling, and drop into an airtight storage box for further protection against dust and contamination.

2.4 Motion and indexing

The single axis of motion will be rotated by a simple worm gear arrangement as we have used extensively before and are using elsewhere in NIRSPEC. I won't go into too many details of the drive system here since overall design of mechanisms and positioning is the subject of another design note (NCDN02). The main thing to be decided is the means of controlling the echelle tilt angle and putting the mirror in precisely the right place. The conservative approach is to use detents to position everything. We are also looking at positioning as we do for the Gemini filter wheels, by step counting from a datum switch position. This investigation continues, with the goal of making the positioning as reproducible as possible. The more reproducible we can make the position of the echelle or mirror in this mechanism (and the cross-disperser grating in its rotator), the less time will have to be spent taking calibration lamp exposures.

The worm gear will be attached to one of the flanges of the rotating drum. There are one or two details to be worked out in terms of the best way to fabricate and assemble the drum and worm gear, but those won't affect the overall layout.

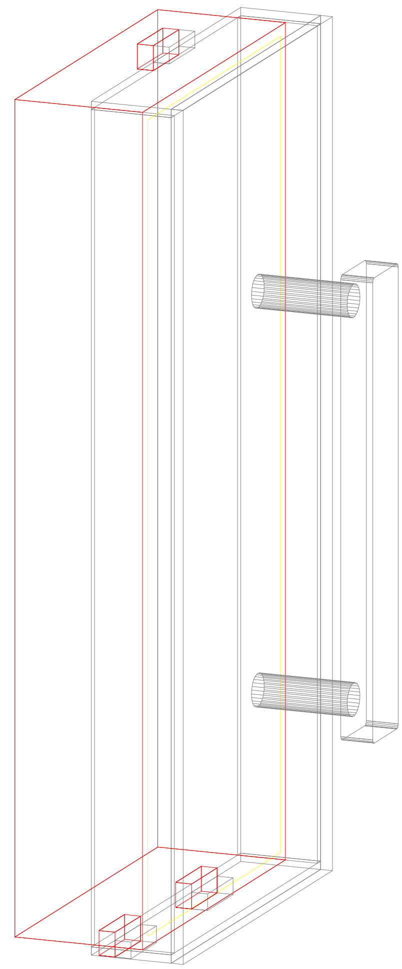

Figure 6: Echelle cover

2.5 Cooling

A definite disadvantage of using ball bearings to support the rotating part of the mechanism is that the area of thermal contact through the bearings will be tiny. We will thus have a lot of thermal mass which is almost completely isolated from the main optical bench for conductive cooling. We need to take care of the cooling by adding a large copper strap from the base plate to the rotating drum. This should not pose any problems, but does have the consequence that the mechanism can not rotate all the way round.

3 Unresolved issues, work still to be completed

There are a few thing which are still not completely settled, but they mostly of the level of details rather than fundamental issues.

- Exact nature of the drive/indexing setup
- Alignment strategy, particularly the mount/alignment method for the echelle and mirror
- Shop drawings must be completed
- Vendor selection for the cryo-cycling of the echelle and mirror substrates
- Vendor selection for the grinding of the flanged tube

4 Drawing list

The following shop drawings should completely describe the mechanism and its assembly.

<Drawing list goes here>