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NIRSPEC Cryo-mechanics Design Note 2.00
Cryogenic Mechanisms

Description

The NIRSPEC instrument will have at least five cryogenic moving mechanisms: an image rotator (IROT), a filter wheel (FILT), a slit wheel (SLIT), an echelle grating scanner (EGSC) and a cross-disperser scanner (CDSC). Two additional mechanisms may be required, a lens turret (LENS) and an echelle grating selector (EGSL). In addition to the internal mechanisms, some external motions may be needed for the calibration unit; however, these motions are simple and can probably be accomplished with off-the-shelf systems.

Mechanisms

Image Rotator

The image rotator is the first optical component inside the dewar window. Its two functions are to compensate for the rotation of the image due to the alt-az telescope mount and to allow the user to set the position angle of the slit. A detailed description of this mechanism can be found in NIRSPEC design note NCDN 0100.

Filter Wheel

The filter wheel will have about 12 positions including a "blank" or closed position. This will accommodate many spectral regions from 1 - 5 µm. This stepper motor/worm drive system is basically the design used successfully in the Gemini and NavyCam cryogenic wheels with the following improvements. Filters are individually mounted in the wheel (worm gear), independent of each other; the wheel support structure is much wider to help eliminate wheel "wobble" that can jam the worm and also to provide a better thermal path to the wheel; motor and worm are aligned as a unit, independent of the worm/wheel alignment; motor has a better thermal path to reduce heating problems.

Lens Turret

A lens turret that holds a separate refractive doublet for each waveband has been discussed, in light of the difficulty in designing a single doublet that performs adequately from 1 - 5 µm. No design work has been attempted on this mechanism in part because no design work has been attempted on the optics for the turret. The goal is to eliminate the need for a lens turret, and only if it is clear that a turret is required optically will this mechanism be considered.

Slit Wheel

The slit wheel contains many different fixed slit sizes that have been cut into reflective substrates. This way, a slit width can be chosen that best matches the seeing on a given night, and a slit length chosen to capture the target(s) of interest. The spectrometer is fed by light passing through the slit, and the slit-viewing camera is fed by the reflected light.

At this time we have proposed 5 different slit widths (from 0.2 to 1.0 arcsec), two slit lengths (up to 30 arcsec) and one set of orthogonally oriented slits for low-resolution mode. In addition, we wish to have one position with no slit for a straight imaging mode. This requires 16 positions, making this mechanism larger than the filter wheel but essentially the same design.

Echelle Grating and Cross-Disperser Scanners

The grating scanner mechanisms make it possible to control where particular wavelengths fall onto the detector. This feature is critical for wavebands that do not have an echelle optimized such that the detector captures the complete spectral region in one shot. In these cases, it is necessary to "scan" the spectral region to observe the wavelengths of interest or to obtain the complete waveband in multiple exposures.

Scanners should provide for about 20 user positions within a 10° total throw, and they will utilize the same design concepts as the wheel mechanisms.

Echelle Grating Selector

Although the original budget contained only one echelle grating, we hope to provide at least the means to add at least one additional grating. A given echelle can only be optimized for one spectral regime, so although that waveband can be perfectly matched to fit the format of the detector, shorter wavebands will underuse the format and longer wavebands will not be fully captured in a single exposure. Thus, we want the capability to select different echelles, depending on the waveband of interest. In addition, the low-resolution mode of NIRSPEC requires that the echelle grating be replaced with a mirror.

The current design calls for a three-position grating selector: two gratings (probably optimized for J and K bands) and a mirror. Because the rotation axis required for scanning falls across the surface of the echelles, it is impossible to use this same axis for selecting different gratings and still put all gratings in the correct plane. Thus, a two-axis mechanism is required. Figure 1 contains a preliminary two-axis echelle grating mechanism concept which incorporates both the scan and the select features.

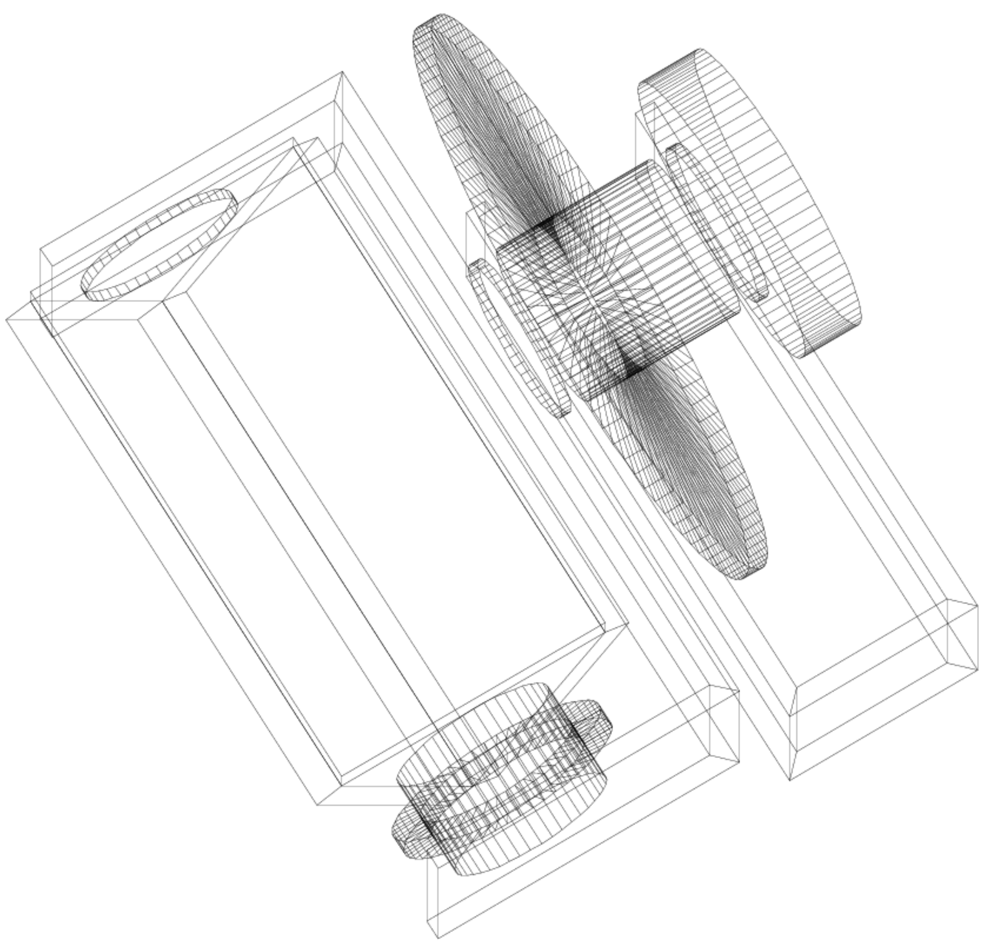


Figure 1. Two-axis echelle grating concept, incorporating grating select and grating tilt features.

Performance Specifications

There are two general motion characteristics that we want each mechanism to satisfy: resolution and repeatability. Resolution is the minimum discrete motion increment in order to reach each user position and is a requirement. Repeatability is defined as the tolerable error associated with moving a mechanism and demanding that it return to the same position. Due to the extreme repeatability required for non-calibrated high spectral resolution, this specification must be considered a goal. Table 1 lists these specifications for each cryogenic mechanism.

In addition to moving precisely, the mechanisms must have a way for their positions to be verified and/or calibrated. The calibration must be accurate to either the motion repeatability level or one discrete motor moving increment, whichever is larger.

TABLE 1. Mechanism Performance Specifications

Mechanism	Resolution Requirement	Repeatability Goal
IROT	0.1 pix @ field corner (0.016°)	same
FILT	12 positions (30°)	1 mm beam clearance (0.6°)
SLIT	16 positions (22.5°)	0.1 pixel on array (0.005°)
EGSC, CDSC	20 positions thru 10° (0.5°)	0.1 pixel on array (0.00023°)
EGSL	3 positions (120°)	0.1 pixel on array (0.00023°)

Strategy

We plan to capitalize on our experience with the Gemini motion control system to drive the NIRSPEC mechanisms. Every mechanism will be worm-driven with API stepper motors and positional feedback will be supplied by Microswitch miniature switches. The motors will be modified in-house for cryogenic operation by replacing their bearings with degreased, MoS_2 burnished stainless steel bearings. Worms, bushings and wheel axles will be made out of Vespel SP3, which is impregnated with MoS_2 for lubrication. Worm gears, mounts and housings will be made of aluminum.

Resolution requirements can be satisfied with simple gearing techniques, but the repeatability goals are challenging and will require methods that are as yet untested. Two options have been identified to meet this challenge. One relies upon the inherent repeatability of the stepper motor, gearing the mechanism properly to turn that into the desired mechanism repeatability level. This option demands that all backlash be removed from the system; thus, anti-backlash prototyping is required. This method has been attempted in other instruments such as CGS4, but their effectiveness is unknown.

The other method is to use detents to force the mechanism into place. Detents are commonly used in cryogenic instruments, but our lack of experience will again necessitate a prototyping effort. Of course, this method is only useful for discrete positioning mechanisms and is unsuitable for the image rotator. Unlike the first option, the detent method actually requires a fair amount of backlash in the system to allow the detent to move the mechanism independently from the motor.

We plan to utilize the test chamber to investigate both of these methods and determine their suitability for each of our applications.

Motor Performance Characteristics

The room temperature performance of a modified stepper motor was determined through laboratory laser tests, discussions with API engineer Russell Fulle, studies of stepper motor technology and Gemini test experience. This section summarizes the most relevant of this information.

When motor drives power up (or are sent a "reset" pulse) they begin with a default "zero-phase" current configuration, which is one out of eight possible phase configurations when half-stepping. This causes the motor to jump to the nearest of 50 equally spaced positions that are valid for this configuration. Thus, the motor will jump 0-4 half-steps, depending on what position it is resting on, and this is repeatable to < 1/30 half-steps.

As long as motor power is enabled (imparting a particular current phase to the stator windings) and the motor does not become desychronized with the drive, stepping positions are repeatable to < 1/30 half-steps, independent of directional changes, ramps, or size of move.

When power to the motor is cut, the rotor is allowed to slide towards a "natural detent" position. There are 200 of these positions around the motor (every other half-step). Thus, the motor will move between 0 and 1 half-steps and this slip is repeatable to less than 1/30 half-step measured for a given position *only if the position is reached from the same direction using the same number of steps*. Using different sized moves to reach a given position will cause a spread of about 1/10 half-step when power is disabled, and approaching from different directions can cause a change in position of up to 3/4 half-steps.

When power is re-applied to the motor, the driver applies the same phase configuration it left off with, forcing the motor back to the position it held before the power was cut. Therefore, the motor should not creep or lose steps when motor power is cycled, and repeatability will be maintained. Because the motor must shift into position when power is applied, it is not advisable to send a step pulse simultaneously with the power-up pulse as is currently done with Gemini.

Magnetic hysteresis can cause a 1/30 half-step shift when changing directions.

The current supplied to the motors can be changed with the driver DIP switches. This could be important for the image rotator motor which must move frequently and may overheat. Heat output goes as $2I^2R$ but torque goes directly with I. Thus, decreasing the current (and torque) by a factor of 2 decreases the heat output by a factor of 4. This motor could also be driven in "low power" mode (1/3 of rated current) instead of the full power used in the Gemini system.

Mechanism Gearing

If we are to rely upon the inherent motor repeatability to give our mechanisms the required performance characteristics, certain gear ratios are demanded. Table 2 lists the necessary gear ratios for each mechanism and what resolution and repeatability (1/30 resolution) results from them. Without going to excessively large gear ratios it is possible to meet the performance specifications outlined above for each mechanism.

Positional Feedback

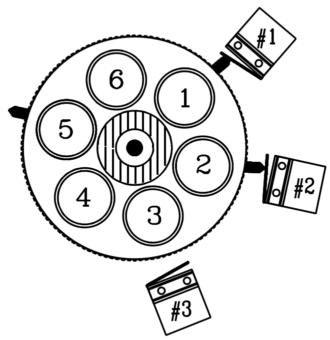
Position referencing and mechanism initializations will be accomplished by employing miniature switches at discrete positions in the mechanisms. We will use Microswitch brand switches, which are inexpensive and were identified in a Gemini research effort to be the most cryogenically reliable of a half dozen different brands. In fact, after 1.5 years of service, not one of Gemini's 10 cryogenic Microswitches have failed.

TABLE 2. Proposed Mechanism Gear Ratios

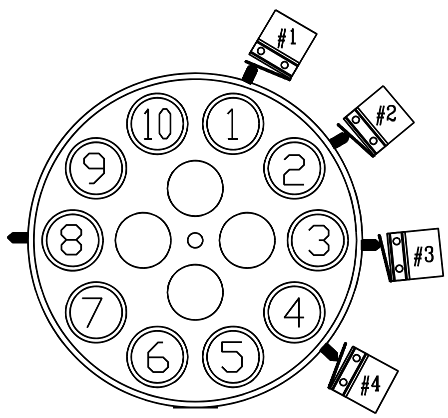
Mechanism	Gear Ratio	Resolution (Spec)	Repeatability (Spec)
IROT	120	0.0075° (0.016°)	0.00025° (0.016°)
FILT	240	0.00375 (30)	0.000125 (0.6)
SLIT	300	0.003 (22.5)	0.0001 (0.005)
EGSC, CDSC	360	0.0025 (0.5)	0.00008 (0.00023)
EGSL	120	0.0075 (120)	0.00025 (0.00023)

Mechanism initializations must be accurate to the same half-step in most cases. This is difficult because the switches must be fully depressed in order to behave reliably, giving them quite a large "on" range (~400 half-steps). In the Gemini system, the mechanisms are centered within this activation range. For NIRSPEC, we plan to take this concept one half-step further. We hope that the switch centering is reliable to within about 4 steps (which has not yet been verified). A reset pulse would then be sent to the motor drive, causing it to send the "zero-phase" configuration to the motor. The motor then jumps to the valid position nearest to the switch center, making the initialization accurate to the same half-step.

Each mechanism will contain up to four on/off switches, giving up to 16 unique switch status patterns that can be used to verify each user position in the discrete-position mechanisms. One of these switches can be designated for initializations. A preliminary filter wheel status scheme is shown in Figure 2.



Filter Position	Bit Pattern
1	110
2	100
3	001
4	010
5	101
6	011



Filter Position	Bit Pattern
1	1111
2	1110
3	1100
4	1000
5	0001
6	0010
7	0100
8	1001
9	0011
10	0111

Figure 2. Sample position referencing schemes using miniature switches. Each user position is uniquely determined by its bit pattern.

The image rotator is not a discrete-position mechanism; its user positions are almost continuous and cannot all be independently verified. Also, this mechanism cannot be allowed to travel continuously in one direction: even though its motion is circular, the arm of the rotator does not clear one wall of the dewar. Hard stops must be built to prevent the arm from travelling too far. While not necessary, switches could be put at these stops which are hard-wired into the motor power circuit, with their activation cutting the motor power. Another switch must be put around the middle of the range of travel for accurate initializations. Finally, some means of verifying that the mechanism is moving properly would be ideal. We propose to construct a simple strip with multiple contacts (about every degree) that runs the length of the rotator travel. All contacts would be wired into the same circuit, so that the software is fed a regular, predictable signal while in operation that it can automatically check to verify that the IROT is moving successfully.

With a detent system, initializations do not need to be so accurate (and cannot due to the backlash) but must be accurate enough to ensure that the motor will bring the mechanism safely inside the detent's range of control. It has been demonstrated that our current Gemini mechanisms (which do have a fair amount of backlash) can be initialized to less than 1/4 of their backlash range. This is more than sufficient for bringing the mechanism to rest inside the detent's control. The concept, then, is to have a switch attached to the detent, so that its activation signals that the mechanism is at a user position and the detent has deployed. A second switch would activate independently of the detent, perhaps on the opposite side of the wheel. This would be the initialization switch and would be triggered only once per wheel revolution.

Path to CDR

The concepts described in this document must be demonstrated before the Critical Design Review. Specifically, this means that we must prototype both anti-backlash and detent mechanisms and measure their reliability/repeatability in the test chamber. High-precision bearings must be modified for cryogenic use and tested for runout and other deleterious effects. The switch centering/drive reset initialization scheme must be tested for accuracy and repeatability. Motors must be driven to destruction with regular duty-cycle tests to estimate their expected lifetimes.

The test chamber will be completed shortly. In the meantime, we should order new motors and bearings, modify them, build a prototype mechanism that can incorporate both anti-backlash and detent systems, and set up a motion control system to execute the tests we need to make.