NIRSPEC

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NIRSPEC Cryo-mechanics Design Note 19.00
Mechanism ATP

1 Introduction

This document describes the performance specifications for the six cryogenic and three noncryogenic mechanisms in NIRSPEC, the procedures followed to verify that they meet these requirements, and the results of these procedures. Because the mechanisms are independent modules with unique functions and specifications, this document is organized by mechanism, with a table at the end which summarizes the specifications and test results.

1.1 Definition of Terms

There are five motion performance characteristics that each mechanism must satisfy: resolution, reliability, stability, accuracy, and repeatability. *Resolution* refers to the smallest increment each mechanism can be moved. *Reliability* characterizes the mechanism failure rate, with failure defined as the mechanism not performing the user's command (e.g., loss of motor synchronization, slippage in a coupler). *Stability* is how well the mechanism maintains its position over time with no move demands. *Accuracy* is a measure of whether the mechanism moves to the exact position that was demanded, and *repeatability* is how well the mechanism returns to its position after moving away. These last two characteristics are similar but differ in an important way. In some cases, a large inaccuracy is tolerable as long as it is repeatable.

1.2 Deriving the Specifications

The specifications listed in this document are set so that the mechanisms simply cannot be delivered if they are not met. Certainly, we would like each mechanism to far exceed these requirements, because the limits of each mechanism's performance will in many cases determine how astronomical observations must be conducted and if a given observation can even be made. Ambitious observers who plan to push NIRSPEC to its limits should not assume that just because the mechanisms have passed their ATP, they will perform as desired. Before using NIRSPEC, the mechanism performance characteristics should be noted, and observing sequences planned accordingly.

2 Image Rotator

2.1 Resolution

Requirement

The image rotator must be able to correct for field rotation without noticeably degrading the image; i.e. increasing the size of a point source. This angular resolution corresponds to 0.1 pixels at the far corner of the slit viewing camera’s 256x256 pixel format, or 0.03°.

Test procedure

Resolution requirements are satisfied in the mechanism design and can be verified by moving the image rotator from one limit to the other (180°), counting the number of motor half-steps required to achieve this change of position.

Results

The selected stepper motor drives at 400 half-steps per revolution, and the gear ratio of the mechanism is 270. This gives 108000 total half-steps per image rotator revolution, or a resolution of 0.003°. Sending the motor 54000 steps moved the rotator 180° as expected.

2.2 Reliability

Requirement

There has been no stated requirement for reliability.

Test procedure

Verifying low failure rates would require thousands of cryogenic motor moves. This is unreasonable to perform and causes unnessesary wear on the mechanisms. A minimum of 100 moves -- with no failures -- would give a reasonable probability that the reliability is of the proper order. Since many mechanism moves are required to test software, optics and electronics, reliability data can be gathered during other tests. A mechanism log sheet should be kept, making a record of all moves and results.

It is important that all moves for this test are done under fair conditions. The mechanism must be at a stable cryogenic temperature and operated at normal speed and ramp settings, and the moves must reflect normal usage in both their size and frequency.

Because the image rotator must move in a nearly continuous tracking mode, this mode must be independently tested by setting the rotator on the worst practical tracking curve (i.e., near the zenith). Motor temperature should be monitored during this test to make note of overheating.

Results

2.3 Stability

Requirement

The requirement for stability is that the rotator not move more than a discernable increment over a reasonable observing time. Defining the discernable increment is the resolution requirement of 0.03°. A long observing sequence will take an hour. Thus, the image rotator should be stable to 0.03° per hour.

Test procedure

Place a resolved pinhole target at the telescope focal plane, at the edge of the SCAM field of view, back-illuminated with a gooseneck light. Select the NIRSPEC-1 filter and a slit. Take ten images with the SCAM. Wait at least two hours, and then take ten more images. Make centroid measurements of the pinhole image, and compute the median and standard deviation of both sets of images. The measurement error is the standard deviation divided by the square root of 10. The difference between the two median positions should be smaller than 0.03° × hours between sets, plus the measurement error.

Results

2.4 Accuracy

Requirement

Field rotation must be corrected to the precision given in the resolution requirement, 0.03°, approaching from either direction. Selection of position angle does not need to be more accurate than this.

Test procedure

Place a resolved pinhole target at the telescope focal plane, at the edge of the SCAM field of view, back-illuminated with a gooseneck light. Select the NIRSPEC-1 filter and a slit. Start with the image rotator at one end of its range of travel. Move it at 10° increments through its complete range, taking ten SCAM images between moves. Reverse the procedure, moving the rotator at -10° increments back to the start. Calculate the median position of the pinhole image at each rotator position. The measurement error is the standard deviation within a set of ten images divided by the square root of 10. The difference between pinhole positions should not differ from 10° by more than 0.03° plus the measurement error. Make note of any shift in the pinhole image when approaching a rotator position from the opposite direction, which indicates mechanism backlash. Note that the accuracy cannot be measured to a higher precision than the repeatability of the mechanism will allow.

Repeat test without the software backlash corrector to measure the actual backlash that must be taken out when changing directions in tracking mode.

Results

2.5 Repeatability

Requirement

The image rotator must be repeatable to no worse than the required accuracy of 0.03° (10 half-steps).

Test procedure

Place a resolved pinhole target at the telescope focal plane, at the edge of the SCAM field of view, back-illuminated with a gooseneck light. Select the NIRSPEC-1 filter and a slit. Move the image rotator to a fiducial position, e.g., 0°. Take ten SCAM images. Move the image rotator 10° and back, 20° and back, etc., taking ten SCAM images at each position. Repeat, moving off position in the other direction. Calculate the median position of the pinhole image at each rotator position. The measurement error is the standard deviation within a set of ten images divided by the square root of 10. The difference between pinhole positions at the fiducial rotator position should not differ by more than 0.03° plus the measurement error.

Results

2.6 Position Sensors

The image rotator has three position sensors: one initialization switch and a limit switch on either end of the range of travel.

Requirement

All switches must operate reliably in a cryogenic environment. The position of the initialization switch must be measured and repeatable to the required mechanism accuracy and repeatability of 0.03° (10 half-steps). The limit switches are not as critical since they are beyond the operating range of travel (+/- 90°), but their positions should be roughly measured to ensure that is the case.

Test procedure

Until NIRSPEC is installed on the telescope, the absolute position of the initialization switch cannot be ascertained because only then will there be an absolute reference to measure from. For now, it can be assumed to be at the exact up-and-down position. Now test the initialization repeatability. Initialize the slit wheel. Reinitialize and take ten SCAM images. Move -18000 half-steps, reinitialize and take ten SCAM images. Repeat with -36000, -54000, and -72000 half-steps. Calculate the median slit position after all initializations and the standard deviation. The measurement error is the standard deviation divided by the square root of 10.

The relative distance between the initialization switch and the limit switches can be measured by initializaing the mechanism and then stepping the mechanism until the switch closes, recording the number of steps travelled. The backlash steps in the software code should be set to 0 for this test.

Results

The intrinsic reliability of these switches has been thoroughly tested in a cryogenic environment. When properly applied, there have been no failures in thousands of activations.

2.7 Non-mechanical Requirements

In addition to the mechanical performance requirements outlined above, the image rotator has software, optical, and electrical requirements that must be satisfied. These non-mehcanical requirements are outlined in their respective ATP documents.

3 Dual Filter Wheels

3.1 Resolution

Requirement

The dual filter wheel must be able to travel to each of 12 equally spaced positions which are populated around 360°. This angular resolution corresponds to 30°.

Test procedure

Resolution requirements are satisfied in the mechanism design and can be verified by moving each filter wheel from one centered position to an adjacent position, counting the number of motor half-steps required to achieve this change of position.

Results

The selected stepper motor drives at 400 half-steps per revolution, and the gear ratio of the mechanism is 270. This gives 108000 total half-steps per filter wheel revolution, or a resolution of 0.003°. Sending each motor 9000 half-steps moved the filter wheels 30° to the next filter position as expected.

3.2 Reliability

Requirement

There has been no stated requirement for reliability.

Test procedure

Verifying low failure rates would require thousands of cryogenic motor moves. This is unreasonable to perform and causes unnessesary wear on the mechanisms. A minimum of 100 moves -- with no failures -- would give a reasonable probability that the reliability is of the proper order. Since many mechanism moves are required to test software, optics and electronics, reliability data can be gathered during other tests. A mechanism log sheet should be kept, making a record of all moves and results.

It is important that all moves for this test are done under fair conditions. The mechanism must be at a stable cryogenic temperature and operated at normal speed and ramp settings, and the moves must reflect normal usage in both their size and frequency.

Results

3.3 Stability

Requirement

The filter wheels must not drift so far as to vignette the beam (4mm=2.88°=865 half-steps) or to move the lyot stops on a scale larger than the aberrations in the pupil image (267 microns=0.19°=58 half-steps). Since the filter wheels cannot be recentered easily between observations, the wheels must be continually stable to this level.

Test procedure

Send filter wheel #2 to its lyot stop position by selecting position 11 in filter wheel #1. With the alignment telescope aligned to the NIRSPEC optical axis, focus on the lyot stop obscuration and measure its position. Every hour, measure its position in the alignment telescope. The total drift over a 12 hour period should not exceed 267 microns. Move filter wheel #1 +9000 steps and step filter wheel #2 off position enough to see the lyot stop obscuration in filter wheel #1. Repeat procedure.

Results

3.4 Accuracy

Requirement

The filter wheels must be positioned to an accuracy no worse than the stability requirement of 2.88° in the filtered positions and 0.19° in the lyot stop positions, approaching from either direction.

Test procedure

With the alignment telescope aligned to the NIRSPEC optical axis, focus on filter wheel #2. Move the wheel to the lyot stop position and step the motor until it is centered. Give the filter wheel +9000 half-steps and measure how far off center the new position is. Repeat for all twelve positions, including the lyot stop. Reverse the procedure, moving -9000 half-steps at a time and measuring whether the positions are centered in the alignment telescope. Step the lyot stop off center enough to measure the position of filter wheel #1. Repeat test with filter wheel #1. Note that the accuracy cannot be measured to a higher precision than the repeatability of the mechanisms will allow.

Now measure the backlash in the filter wheels. In the occam software, set the backlash corrector to 0. Move filter wheel #2 to its lyot stop in the positive direction. Keep stepping in positive steps until it is centered. Move +500 half-steps, then return with -500 half-steps. Keep stepping in negative steps until the lyot stop is centered once again. Count the number of negative half-steps after the -500 command to return to a centered lyot stop. This is the backlash in fiter wheel #2. Move the lyot stop off center enough to see the lyot stop in filter wheel #1. Repeat procedure with filter wheel #1.

Results

3.5 Repeatability

Requirement

Repeatability requirements are the same as for accuracy.

Test procedure

With the alignment telescope aligned to the NIRSPEC optical axis, focus on filter wheel #2. Move the wheel to the lyot stop position and step the motor until it is centered. This is the fiducial position. Give the filter wheel +9000 half-steps and return with -9000 half-steps. Measure the position of the lyot stop in the alignment telescope.. Repeat with 18000, 27000, 36000, and 45000 half-steps. Now repeat whole procedure, moving off position in negative half-steps and returning in positive. Step the lyot stop off center enough to measure the position of filter wheel #1. Repeat test with filter wheel #1.

Results

3.6 Position Sensors

The filter wheels have four position sensors apiece: two initialization switches and two position verification switches.

Requirement

All switches must operate reliably in a cryogenic environment. The position of the initialization switches must be measured to the required mechanism accuracy/repeatability of 0.19° (58 motor half-steps). The position switches must be closed when the filter wheels are in each centered position but not in between positions.

Test procedure

With the alignment telescope aligned to the NIRSPEC optical axis, focus on filter wheel #2. Initialize filter wheel #2. Move wheel -9000 half-steps to reach the lyot stop. Step the wheel until the lyot stop is centered to the required accuracy. Count the number of steps taken to center the lyot stop after moving -9000 half-steps. This is the value to subtract from the switch location given in the file *motor.inc*. Change the code so it will initialize on the other initialization switch. Initialize filter wheel #2. Move wheel +45000 half-steps to reach the lyot stop and repeat above procedure.

Step the lyot stop off center enough to measure the position of filter wheel #1. Repeat test with filter wheel #1, moving +9000 half-steps and -45000 half-steps from the primary and secondary switches, respectively.

Now test the initialization repeatability. Initialize the slit wheel. Reinitialize and take ten SCAM images. Move -18000 half-steps, reinitialize and take ten SCAM images. Repeat with -36000, -54000, and -72000 half-steps. Calculate the median slit position after all initializations and the standard deviation. The measurement error is the standard deviation divided by the square root of

10.

After all intialization switches have been calibrated, initialize both wheels and choose every possible filter position. If the position switches are working correctly, a “move success” report should be displayed every time. If the position switches fail, a “position switch error” report will be displayed. Change the code so it will use the backup position switches. Repeat test.

Results

The intrinsic reliability of these switches has been thoroughly tested in a cryogenic environment. When properly applied, there have been no failures in thousands of activations.

3.7 Non-mechanical Requirements

In addition to the mechanical performance requirements outlined above, the image rotator has software requirements, such as proper handling of the dual filter wheels and proper reporting of errors. These non-mehcanical requirements are outlined in their respective ATP documents.

4 Slit Wheel

4.1 Resolution

Requirement

The slit wheel must be able to travel to each of 12 equally spaced positions which are populated around 360°. This angular resolution corresponds to 30°.

Test procedure

Resolution requirements are satisfied in the mechanism design and can be verified by moving each slit wheel from one centered position to an adjacent position, counting the number of motor half-steps required to achieve this change of position.

Results

The selected stepper motor drives at 400 half-steps per revolution, and the gear ratio of the mechanism is 270. This gives 108000 total half-steps per slit wheel revolution, or a resolution of 0.003°. Sending the motor 9000 half-steps moved the slit wheel 30° to the next slit position as expected.

4.2 Reliability

Requirement

There has been no stated requirement for reliability.

Test procedure

Verifying low failure rates would require thousands of cryogenic motor moves. This is unreasonable to perform and causes unnessesary wear on the mechanisms. A minimum of 100 moves -- with no failures -- would give a reasonable probability that the reliability is of the proper order. Since many mechanism moves are required to test software, optics and electronics, reliability data can be gathered during other tests. A mechanism log sheet should be kept, making a record of all moves and results.

It is important that all moves for this test are done under fair conditions. The mechanism must be at a stable cryogenic temperature and operated at normal speed and ramp settings, and the moves must reflect normal usage in both their size and frequency.

Results

4.3 Stability

Requirement

The slit wheel must not drift so far as to move a slit more than 0.1 spectrometer pixels over the course of an observation. (After each observation, targets can be recentered in the slit.) A spectrometer pixel is 0.07mm in the dispersion direction at the slit plane, so the wheel must be stable to 0.007mm=0.005°=1.5 half-steps over an hour.

Test procedure

Remove all targets from the telescope focal plane. Select the NIRSPEC-1 filter and the 0.14" slit. Take ten SCAM images every hour. Measure the position of the slit in each image by fitting a gaussian across the slit in many different places, calculating the median position at each place within each ten image set, and then calculating a least-squares fit to the points. The standard deviation within each set divided by the square root of 10 gives the error in the measurement. The total drift should not exceed 0.005°=0.08 SCAM pixels times the number of hours elapsed.

Results

Ten SCAM images were acquired every hour for 17 hours. The light levels varied over the course of the experiment, and because the images could not be properly reduced, this affected the measurement of the slit position. However, even with this effect, the slit wheel met the stability requirements. The slit position did not change by more than 0.05 SCAM pixels during any one-hour increment, or by more than 0.08 SCAM pixels over the whole 17 hour experiment.

4.4 Accuracy

Requirement

The slit wheel does not need to accurately center the slits in the beam, because target acquisition can occur after slit selection. The goal would be that each slit falls at the same position on the SCAM array to ± 1 pixel, approaching from either direction, in case the user decides to change slits after acquiring the target.

Test procedure

Remove all targets from the telescope focal plane. Select the NIRSPEC-1 filter. Center the 0.14" slit onto the SCAM array by stepping the wheel appropriately after initialization. Take ten SCAM images. Move the slit wheel +9000 half-steps to the next slit and take ten more SCAM images. Repeat for all twelve positions. Reverse the procedure, moving -9000 half-steps at a time. Measure the position of the slit in each image as described in the stability procedure. Note that the accuracy cannot be measured to a higher precision than the repeatability of the mechanism will allow.

Now measure the backlash in the slit wheel. In the occam software, set the backlash corrector to 0. Move the slit wheel to the 0.14" slit in the positive direction. Keep stepping in positive steps until it is centered on the SCAM array. Take ten SCAM images. Move +500 half-steps, then return with

-500 half-steps. Keep stepping in negative steps until the slit is centered once again. Take tem more SCAM images. Count the number of negative steps after the -500 command to return to a centered slit, and measure the difference in slit position from the intial image set to the final image set. Convert this pixel difference into motor half steps using the relation 1 half-step=0.05 pixels. The total backlash is the number of half-steps moved between image sets plus the final difference measured in the image sets..

Results

Approaching slits from a constant direction, the 12" slits coincide to within 0.5 pixels, the 24" slits coincide to within 0.8 pixels, the 12" and 24" slits coincide with each other to within 1 pixel, and the 42" slits coincide to within 0.3 pixels.

When changing directions, there is a shift of 0.5 ± 0.1 pixels in the position of the slits.

There are 53 ± 1 half-steps of backlash.

4.5 Repeatability

Requirement

Since the SCAM will be used for guiding, pointing models must be developed for every slit. This requires that the slit positions be repeatable to the desired guiding accuracy, or about 0.1 SCAM pixels (0.006°, or 2 half-steps).

Test procedure

Remove all targets from the telescope focal plane. Select the NIRSPEC-1 filter. Center the 0.14" slit onto the SCAM array by stepping the wheel appropriately after initialization. This is the fiducial position. Take ten SCAM images. Move the slit wheel +9000 half-steps and return with -9000 half-steps. Take ten SCAM images. Repeat with 18000, 27000, 36000 and 45000 half-steps. Repeat whole procedure, this time moving off position in the negative half-steps and returning in positive. Measure the position of the slit in each image as described in the stability procedure.

Results

A hysteresis of about 0.02 pixels per 9000 steps was measured. This causes an unrepeatability of about 0.1 pixels, depending on how far the wheel travelled to reach the desired position. The direction of the hysteresis is the same regardless of the direction travelled, which suggests that it may be a thermal effect. The 0.5 pixel shift with directional changes seen in the accuracy test is seen here. The problem almost certainly lies with the flexible coupler connecting the motor and worm shafts. To avoid failing the repeatability requirement, either this directional shift must be corrected (perhaps a solid coupler) or the wheel code must be changed to move in only one direction.

4.6 Position Sensors

The slit wheel has four position sensors: two initialization switches and two position verification switches.

Requirement

All switches must operate reliably in a cryogenic environment. The position of the initialization switches must be measured to the required mechanism accuracy (none) and repeatable to the required mechanism repeatability (0.1 SCAM pixels=0.006°=2 half-steps). The position switches must be closed when the filter wheels are in each centered position but not in between positions.

Test procedure

Remove all targets from the telescope focal plane. Select the NIRSPEC-1 filter. Initialize the slit wheel. Step the wheel until the 0.14" slit is centered on the SCAM array. Count the number of steps taken to center the slit. This is the value to subtract from the switch location given in the file *motor.inc*. Change the code so it will initialize on the other initialization switch. Initialize the slit wheel. Select the 0.14" slit and repeat the above procedure.

Now test the initialization repeatability. Initialize the slit wheel. Reinitialize and take ten SCAM images. Move to slit position #11 (-9000 half-steps), reinitialize and take ten SCAM images. Do this ten times and then once each from position #10, #8, #6, #4 and #2. Calculate the slit position after all initializations as described in the stability procedure.

Next, initialize the wheel and select every slit in order. If the position switch is working correctly, a “move success” report should be displayed every time. If the position switch fails, a “position switch error” report will be displayed. Change the code so it will use the backup position switch. Repeat test.

Results

All four switches operate correctly. The intrinsic reliability of these switches has been thoroughly tested in a cryogenic environment. When properly applied, there have been no failures in thousands of activations.

If half-step #0 corresponds to a centered 0.14" slit, the primary initialization switch is located at #10 ±3 half-steps, and the secondary initialization switch is located at half-step #81030 ± 3.

Initializations are repeatable to ±0.1 pixels (1 sigma=0.05 pixels) with a constant 9000 half-step distance from the initialization switch. Varying the initialization distance imparts hysteresis error on the initalization, adding another ±0.05 pixels for a total unrepeatability of ±0.15 pixels.

5 Echelle Grating Mechanism

5.1 Resolution

Requirement

There is no stated requirement for resolution.

Test procedure

Resolution is fixed by the mechanism design and can be verified by moving the grating from one easily verified position (horizontal) to another (vertical), counting the number of motor half-steps required to achieve this change of position.

Results

The selected stepper motor drives at 400 half-steps per revolution, and the gear ratio of the mechanism is 270. This gives 108000 total half-steps per mechanism revolution, or a resolution of 0.003° (1.8 spectrometer pixels). Sending the motor 27000 half-steps moved the grating from horizontal to vertical as expected.

5.2 Reliability

Requirement

There has been no stated requirement for reliability.

Test procedure

Verifying low failure rates would require thousands of cryogenic motor moves. This is unreasonable to perform and causes unnessesary wear on the mechanisms. A minimum of 100 moves -- with no failures -- would give a reasonable probability that the reliability is of the proper order. Since many mechanism moves are required to test software, optics and electronics, reliability data can be gathered during other tests. A mechanism log sheet should be kept, making a record of all moves and results.

It is important that all moves for this test are done under fair conditions. The mechanism must be at a stable cryogenic temperature and operated at normal speed and ramp settings, and the moves must reflect normal usage in both their size and frequency.

Results

5.3 Stability

Requirement

The grating must not drift more than 0.1 spectrometer pixels (0.00017°=0.05 half-steps) over the course of an observation (after each observation, new calibrations can be taken).

Test procedure

Select the 0.29" slit and the NIRSPEC-1 filter. Place an arclamp near the telescope focal plane so it evenly illuminates the slit. Set the echelle and cross-disperser gratings so that at least one emission line is selected on the spectrometer array. Take ten spectrometer images every hour. Measure the position of these lines in each image and calculate the median position within each ten image set. The standard deviation within each set divided by the square root of 10 gives the error in the measurement. The total drift should not exceed 0.00017°=0.1 spectrometer pixels times the number of hours elapsed.

Results

5.4 Accuracy

Requirement

There is no stated accuracy requirement.

Test procedure

Select the 0.29" slit and the NIRSPEC-1 filter. Place an arclamp near the telescope focal plane so it evenly illuminates the slit. Set the echelle and cross-disperser gratings so that one emission line is identified on the spectrometer array. Take ten spectrometer images and calculate the median position of this line. Calibrate the angle of the echelle grating using this line position. Move the echelle and cross-disperser the appropriate number of steps to put a longer wavelength order on the spectrometer array. Change filters. Identify another line. Take ten spectrometer images, calculate the median position of this line, and compute the actual change in grating angle. Note that the accuracy cannot be measured to a higher precision than the repeatability of the mechanism will allow.

Now measure the backlash in the echelle grating mechanism. In the occam software, set the backlash corrector to 0. With a spectral line selected, move the mechanism a few thousand steps in the positive direction and then return the same number of steps in the negative direction. Measure the position of this line on the array. It should be roughly where it was initially. Now move the mechanism a few thousand steps in the negative direction and return the same number of steps positive. Keep stepping positive until the line returns to its former position. This is the mechanism backlash.

Results

5.5 Repeatability

Requirement

The goal for repeatability is that the grating return to the demanded angle to within 0.1 spectrometer pixels (0.00017°=0.05 half-steps) so that calibrations do not have to be acquired for every observation.

Test procedure

Select the 0.29" slit and the NIRSPEC-1 filter. Place an arclamp near the telescope focal plane so it evenly illuminates the slit. Set the echelle and cross-disperser gratings so that one emission line is identified on the spectrometer array. Take ten spectrometer images and calculate the median position of this line. Move the echelle 100 half-steps and then return. Take ten more images. Repeat with 500, 1000, 2000, 4000, and 10000 half-steps. Repeat the whole procedure, moving off position in negative steps and returning in positive steps. Measure the line position in each image and calculate the median position within each ten image set. The standard deviation within each set gives the error in the measurement.

Results

5.6 Position Sensors

The echelle grating mechanism has four position sensors: one initialization switch, one flat mirror position verification switch, and two limit switches.

Requirement

All switches must operate reliably in a cryogenic environment. The position of the initialization switch must be measured to the required mechanism accuracy (none) and repeatable to the required mechanism repeatability (goal of 0.1 spectrometer pixels=0.00017°=0.05 half-steps). The position switch must be closed when the mechanism is in the low-resolution flat position (180°). The limit switches are not as critical since they are beyond the operating range of travel (58 - 180°), but their positions should be roughly measured to ensure that is the case.

Test procedure

Select the 0.29" slit and the NIRSPEC-1 filter. Place an arclamp near the telescope focal plane so it evenly illuminates the slit. Initialize the echelle mechanism. Send it and the cross-disperser to the appropriate angles to send a specific arclamp line to a certain pixel. Measure the position of the arclamp line, and calculate the true angle of the echelle based upon this line position. The difference between the commanded angle and the calculated angle, converted to motor steps, is how much to correct the switch position in the file *motor.inc*.

Now test the initialization repeatability. Initialize the echelle mechanism. If there are any spectral lines present, reinitialize and take ten spectrometer images. If not, move as little as possible to get to a line feature and take ten spectrometer images. This is the fiducial position. Move -1000 half-steps, reinitialize, move to the fiducial if necessary, and take ten more images. Repeat with -2000, -4000, and -10000 half-steps. Repeat the whole procedure, moving off position in positive steps instead of negative. Calculate the median slit position after all initializations and the standard deviation. The measurement error is the standard deviation divided by the square root of 10.

Next, initialize the wheel and check to see that the position switch is open. Send the mechanism to the low resolution flat position (180°). If the position switch is working, a “successful move” report will be displayed. If not, a “position switch error” report will be displayed. Move to 170° and make sure the switch opens again.

Now measure the position of the limit switches. In the occam code, set the backlash steps to 0. The relative distance between the initialization switch and the limit switches can be measured by initializaing the mechanism and then stepping the mechanism until the switch closes, recording the number of steps travelled.

Results

The intrinsic reliability of these switches has been thoroughly tested in a cryogenic environment. When properly applied, there have been no failures in thousands of activations.

6 Cross-Disperser Grating Mechanism

6.1 Resolution

Requirement

There is no stated requirement for resolution.

Test procedure

Resolution is fixed by the mechanism design and can be verified by moving the grating from one easily verified position (edge-on) to another (face-on), counting the number of motor half-steps required to achieve this change of position.

Results

The selected stepper motor drives at 400 half-steps per revolution, and the gear ratio of the mechanism is 180. This gives 72000 total half-steps per mechanism revolution, or a resolution of 0.005° (2.5 spectrometer pixels). Sending the motor 18000 half-steps moved the grating from edge-on to face-on as expected.

6.2 Reliability

Requirement

There has been no stated requirement for reliability.

Test procedure

Verifying low failure rates would require thousands of cryogenic motor moves. This is unreasonable to perform and causes unnessesary wear on the mechanisms. A minimum of 100 moves -- with no failures -- would give a reasonable probability that the reliability is of the proper order. Since many mechanism moves are required to test software, optics and electronics, reliability data can be gathered during other tests. A mechanism log sheet should be kept, making a record of all moves and results.

It is important that all moves for this test are done under fair conditions. The mechanism must be at a stable cryogenic temperature and operated at normal speed and ramp settings, and the moves must reflect normal usage in both their size and frequency.

Results

6.3 Stability

Requirement

The grating must not drift more than 0.1 spectrometer pixels (0.0002°=0.04 half-steps) over the course of an observation (after each observation, new calibrations can be taken).

Test procedure

Select the 0.29" slit and the NIRSPEC-1 filter. Place an arclamp near the telescope focal plane so it evenly illuminates the slit. Set the echelle and cross-disperser gratings so that at least one emission line is selected on the spectrometer array. Take ten spectrometer images every hour. Measure the position of these lines in each image and calculate the median position within each ten image set. The standard deviation within each set divided by the square root of 10 gives the error in the measurement. The total drift should not exceed 0.0002°=0.1 spectrometer pixels times the number of hours elapsed.

Results

6.4 Accuracy

Requirement

There is no stated accuracy requirement.

Test procedure

Select the 0.29" slit and the NIRSPEC-1 filter. Place an arclamp near the telescope focal plane so it evenly illuminates the slit. Set the echelle and cross-disperser gratings so that one emission line is identified on the spectrometer array. Take ten spectrometer images and calculate the median position of this line. Calibrate the angle of the cross-disperser grating using this line position. Move the echelle and cross-disperser the appropriate number of steps to put a longer wavelength order on the spectrometer array. Change filters. Identify another line. Take ten spectrometer images, calculate the median position of this line, and compute the actual change in grating angle. Note that the accuracy cannot be measured to a higher precision than the repeatability of the mechanism will allow.

Now measure the backlash in the cross-disperser grating mechanism. In the occam software, set the backlash corrector to 0. With a spectral line selected, move the mechanism a few thousand steps in the positive direction and then return the same number of steps in the negative direction. Measure the position of this line on the array. It should be roughly where it was initially. Now move the mechanism a few thousand steps in the negative direction and return the same number of steps positive. Keep stepping positive until the line returns to its former position. This is the mechanism backlash.

Results

6.5 Repeatability

Requirement

The goal for repeatability is that the grating return to the demanded angle to within 0.1 spectrometer pixels (0.0002°=0.04 half-steps) so that calibrations do not have to be acquired for every observation.

Test procedure

Select the 0.29" slit and the NIRSPEC-1 filter. Place an arclamp near the telescope focal plane so it evenly illuminates the slit. Set the echelle and cross-disperser gratings so that one emission line is identified on the spectrometer array. Take ten spectrometer images and calculate the median position of this line. Move the cross-disperser 100 half-steps and then return. Take ten more images. Repeat with 500, 1000, 2000, 4000, and 10000 half-steps. Repeat the whole procedure, moving off position in negative steps and returning in positive steps. Measure the line position in each image and calculate the median position within each ten image set. The standard deviation within each set gives the error in the measurement.

Results

6.6 Position Sensors

The cross-disperser grating mechanism has three position sensors: one initialization switch and two limit switches.

Requirement

All switches must operate reliably in a cryogenic environment. The position of the initialization switch must be measured to the required mechanism accuracy (none) and repeatable to the required mechanism repeatability (goal of 0.1 spectrometer pixels=0.0002°=0.04 half-steps). The limit switches are not as critical since they are beyond the operating range of travel (58° - 180°), but their positions should be roughly measured to ensure that is the case.

Test procedure

Select the 0.29" slit and the NIRSPEC-1 filter. Place an arclamp near the telescope focal plane so it evenly illuminates the slit. Initialize the cross-disperser mechanism. Send it and the echelle to the appropriate angles to send a specific arclamp line to a certain pixel. Measure the position of the arclamp line, and calculate the true angle of the cross-disperser based upon this line position. The difference between the commanded angle and the calculated angle, converted to motor steps, is how much to correct the switch position in the *motor.inc* file.

Now test the initialization repeatability. Initialize the corss-disperser mechanism. If there are any spectral lines present, reinitialize and take ten spectrometer images. If not, move as little as possible to get to a line feature and take ten spectrometer images. This is the fiducial position. Move -1000 half-steps, reinitialize, move to the fiducial if necessary, and take ten more images. Repeat with -2000, -4000, and -10000 half-steps. Repeat whole procedure, moving off position in positive steps instead of negative. Calculate the median slit position after all initializations and the standard deviation. The measurement error is the standard deviation divided by the square root of 10.

Now measure the position of the limit switches. In the occam code, set the backlash steps to 0. The relative distance between the initialization switch and the limit switches can be measured by initializaing the mechanism and then stepping the mechanism until the switch closes, recording the number of steps travelled.

Results

The intrinsic reliability of these switches has been thoroughly tested in a cryogenic environment. When properly applied, there have been no failures in thousands of activations.

7 Calibration Unit Flip Mirror Mechanism

8 Calibration Unit Pinhole Mechanism

9 Calibration Unit Cover Mechanism