

SDN 1017 NICI Flexure Requirements

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1.0 Introduction

The requirements for instrument flexure are driven by the science objectives. There are two key issues. The image must remain sufficiently stationary over an individual integration such that the image is not smeared, reducing Strehl ratio. Secondly there must be a method to register individual frames so that they can be combined to represent the total integration time desired. An observer will want to achieve both of these goals to a level that does not appreciably reduce the sensitivity of the observation. For this analysis it is assumed that one tenth of the diffraction core is taken as the goal for both of these issues.

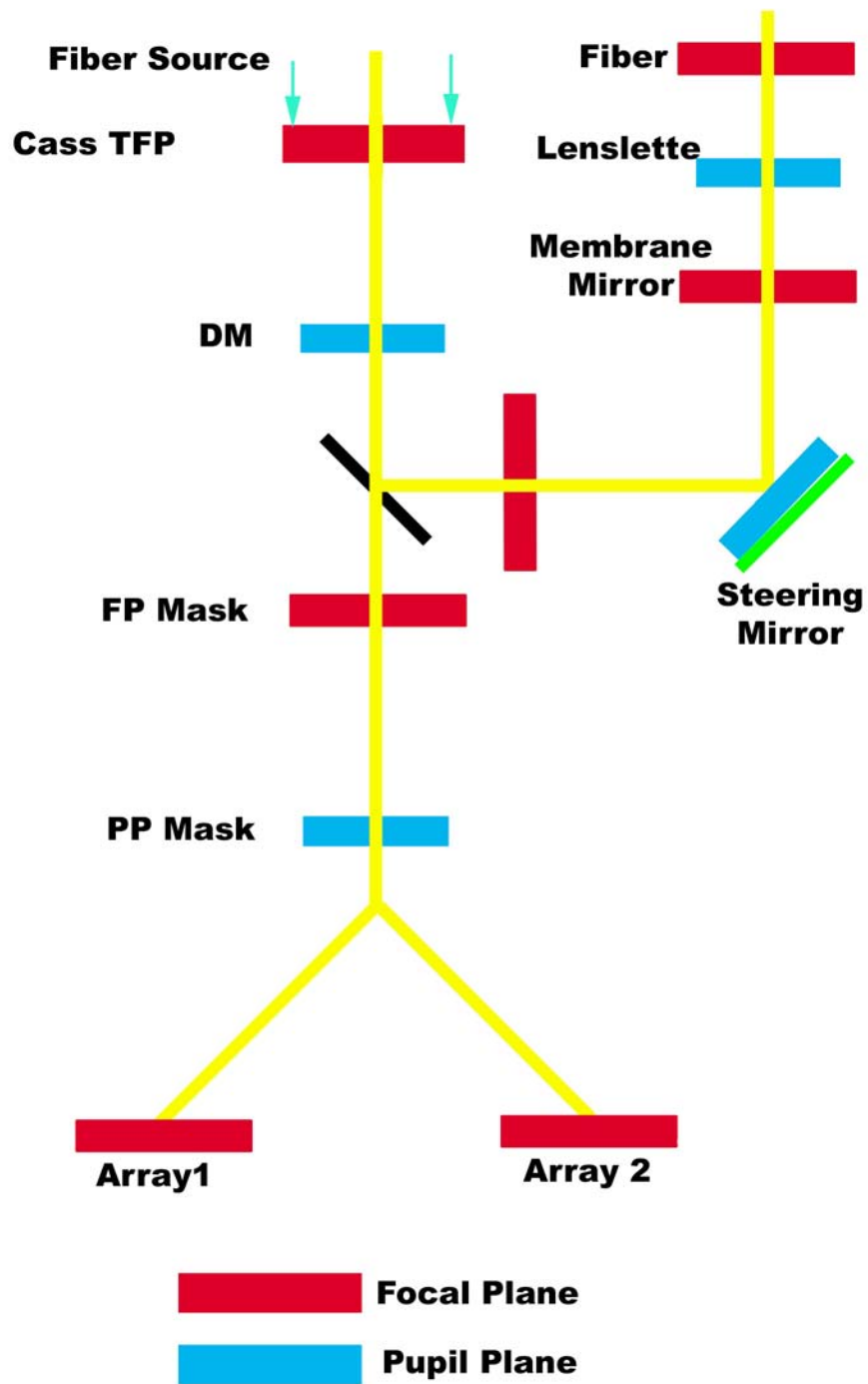
A Stability of one tenth of the diffraction core is a difficult goal to achieve. Most instrument designs address this problem by mounting a lower order wavefront sensor on the cold part of the instrument. This way flexures of the overall structure are sensed and corrected. NICI, however, has some special challenges.

The diagram shown on the following page is a schematic of the instrument that shows all of the focal planes and pupil planes. There are seven focal planes and 4 pupil planes in NICI. NICI is part warm instrument and part cold instrument with a focal plane mask that obscures the central part of the psf where all the low order information lies. The wavefront sensor must be before the focal plane mask and the focal plane mask is right outside the window of the cryostat. Therefore the wavefront sensor cannot be on the cold structure. This means that there are flexure weaknesses in the vacuum jacket and fiberglass trusses that will exceed the one tenth of the diffraction core goal. Therefore to meet the science goals a combination of low flexure and calibration techniques will have to be used.

Before discussing the flexure approach there are four important aspects of the NICI design that must be explained.

1)NICI has an AO system with active tilt correction but only some flexures are corrected. Any flexures in the AO Relay are sensed by the WFS and corrected. Flexures in the Camera are not sensed by the WFS and therefore not corrected. Flexures within the WFS are sensed and corrected but are not flexures seen at the science image and therefore should not have been corrected.

2) NICI has an accurate steering mirror in the WFS that can introduce an offset in the star position in the IR array and focal plane mask in less than 1/10 pixel steps while integrating. When the steering mirror is moved the WFS senses a image tilt and corrects it. This offsets the image in the science channel. This is a power tool for doing precision dithers, guiding on offset objects, atmospheric refraction correction and flexure correction. The Steering Mirror is a Kaman sensor, voice coil mirror assembly made by Ball Aerospace. Accuracy, backlash and resolution are below 1/10 pixel.



Focal Plane and Pupil Plane Schematic

3) Since NICI is designed to be used occulting bright stars there is always a bright ring around the mask. Slow image translation information can be derived from the donut image of the occulted star. The desired offset correction is a nonlinear function of the donut centroid position but if multiplied by a low gain term it can be applied and achieve a good correction in 10 frames or so. This method has been used at the IRTF with CoCo to drive the fast tip/tilt system with excellent results. Using this method each frame would be analyzed in the DHS and a correction sent to the steering mirror

4) NICI has a mechanism that inserts fibers into the first focus(cass focus) of the instrument. This is an important calibration tool used before and during science integrations. There are four positions in this Fiber Calibration Slide. One is open, one has a single fiber mounted in the center of the field fed by a red laser diode. The third has a metal plate with 25 calcium fluoride fibers, with an IR source, on a 5x5 grid covering the focal plane. This is used before an integration to get accurate information about the mapping function between the two science arrays. The fourth position has a mostly clear field with two calcium fluoride fibers mounted in two opposite corners of the science field. These are used during a science observation and are fed by a variable source. The image of the fiber is about 10 pixels. These fibers produce spots in the focal plane that originate in the common mode part of the optical path and since they are broad band they will produce spots on both IR arrays. The two arrays can be registered by centroiding the spots and calculating translation and rotation. The 5x5 grid can be used to characterize distortion.

2.0 Flexure Issues

NICI is a complex instrument from a flexure perspective. There are many issues involved with achieving all of the Instrumental Requirements. The issues are summarized below

1. Image smear during an single integration
2. Ability to coadd sequential integrations
3. Maintaining alignment of the AO system
4. Maintaining alignment of the coronagraphic system
5. Maintaining image quality
6. Ability to difference images from two arrays

These issues must be grounded in a typical integration. Individual broadband exposures would typically be 60 seconds or less. The grism option would drive integrations to as long as 5 minutes. Total integration times per object would as long as 2-4 hours.

Taking these issues one at a time.

1. Image smear during an single integration

For a maximum allowable image movement of one-tenth the diffraction core over a 5 minute integration. Scaled to one hour that would be 2.4 pixels of image movement in an

hour of tracking the telescope. This is a hard requirement since there is no way to unsmear the image in post processing.

Many target objects will require shorter intergrations to avoid saturation of the important inner region. This calculation was done based on the time to be background limited on the sky and so is a bit worst case.

2. Ability to coadd sequential integrations

The use of the twin, corner fibers while integrating allows tracking of the flexure from one end of the instrument to the other including the DM tilt adjustments. It also allows you to map one arrays coordinates to the other array's. As long as the spot in the focal plane is sufficiently bright and covers enough pixels the observer can use these spots to get $\sim 1/10$ pixel positions. Given that the spot brightness is variable and the size is 10 pixels this should not be a problem.

The fibers track flexure through the science channel but not the WFS channel. Therefore flexure in the WFS is still present and will cause image movement. Therefore there is also a hard requirement on the WFS that it not cause image movement greater than 2.4 pixels/hour.

3. Maintaining alignment of the coronagraphic system

The key issues for maintaining coronagraphic performance is to maintain good image quality, covered in section 5 below and maintaining alignment on the focal plane and pupil plane masks. Coronagraphic performance does not suffer perceptibly until the star is decentered by 5 % of the mask half power width. The pupil plane mask will be undersized about 90% of the reimaged telescope pupil and does not show perceptible performance degradation when misaligned 2%. These are quite easy requirements. To put them into perspective the pupil is ~ 13 mm so a 2% misalignment would be 0.26mm or about 0.010 inches. The focal plane mask is 0.3 arcseconds or about 0.2 mm or about 0.007 inches. These numbers are very large. They are about a factor of 2 more than the alignment requirements and about the image movement requirements will constrain movement at these masks to a 10 times lower level. In other words meeting the flexure requirements will meet the coronagraphic performance requirements at a level about 10 times below the required level.

4. Maintaining alignment of the AO system

For the AO system to maintain performance the deformable mirror and the lenslette array must stay aligned to 3% and the fibers on the lenslette must stay aligned with the image to about 2 arcseconds. These requirements are also easily met if the image movement requirement is met. The AO Relay is on the same bench as the WFS and the WFS has a tight flexure requirement so if the image movement goal is met in the WFS the AO system alignment will be easily achieved.

5. Maintaining image quality

The image quality budget gives a 0.1 mm translational allowed error and a 50 micron step at one edge wedge requirement (about 400 arcseconds). The image movement goals require translations and tilts to be about 1.4 arcsecond and 0.01 mm. Again if the image movement goals are met the optics will never move enough to degrade image quality.

6. Ability to difference images from two arrays

Properly differencing the two arrays can be accomplished by using the twin fiber produced spots to determine any flexure-induced shift between the two arrays. Flexure limits based on this argument are very low. Ten pixels over the course of the objects total time would be a reasonable goal so as not to reduce the final differenced image field.

2.1 Summary of Hard Flexure Requirements

Using the arguments in the previous section we can define a set of hard requirements for NICI flexure issues

Image Movement in Science Arrays

Requirement	< 0.043 arcseconds(2.4 pixels)/1 hour
Goal	0.018 arcseconds(1 pixel)/1 hour

Image movement caused by WFS

Requirement	< 0.043 arcseconds(2.4 pixels)/1 hour
Goal	0.018 arcseconds(1 pixel)/1 hour

Image Movement between the two Science Arrays

Requirement	< 0.180 arcseconds(10 pixels)/1 hour
Goal	0.018 arcseconds(1 pixel)/1 hour

Movement of star on focal plane mask	5% mask diameter
Miss-alignment of telescope secondary to DM	2% pupil diameter
Miss-alignment of DM to Lenslette	2% pupil diameter
Miss-alignment of Telescope secondary to Pupil Mask	2% pupil diameter

These last four specs will be automatically met if the first three are met.

3.0 Comparing goals to PDR FEA Results

An FEA model of NICI has been built to analyze the flexure. This flexure model is discussed in the Quartus PDR power point presentation. The results of the analysis were input into the Zemax model as described in SDN 1007. The results are reproduced on the graphs below. In the graphs each lower quadrant is the size of one pixel. The flexure is the difference of the zenith positions from the 70 degree over case scaled to pixels in 15 degrees linearly. Imagining that the dots all started at the origin when at zenith the dots on the graph show where the star image would be for two orthogonal tilts for both the read and blue detectors in the science image plane. There is more flexure in the Y direction than the X direction due to the orientation of the fiberglass V-trusses that support the cold mass. The WFS flexure is lower than the cryostat flexure as expected.

Comparing to the hard requirements in section using the worst case FEA flexures

Issue	Requirement	Goal	FEA
Image Movement in Science Arrays	2.4 pixels/hr	1 pixel/hr	1.0 pixel/hr
Image movement caused by WFS	2.4 pixels/hr	1 pixel/hr	0.41 pixels/hr
Image Movement between the two Science Arrays	10 pixels/hr	1 pixel/hr	0.55 pixels/hr

These results are all for using the instrument open loop. Since there is a steering mirror with high accuracy and small steps corrections can be made to reduce these flexures. A correction routine will be written in the Epics software that will use this mirror to correct for boresight shifts between the science beam and the WFS due to atmospheric refraction. A nearly identical routine can be employed with a flexure correction lookup table to correct for flexure that should be able to reduce these numbers factors of a few.

Flexure is only half of the image movement story. Slop in real world mechanisms often exceeds the flexure cause image movement. NICI by design has only one mechanism whose slop could affect the image positions which is the dichroic wheel. This wheel is designed with stability in mind. It has two central bearings preloaded on a shaft and three outrigger bearings pressing on the bottom of the wheel. This is a very stable design that has been used in the SPEX grating turntable. Image movement caused by slop in this mechanism is difficult to predict but based experience it should be lower than 0.5 pixels per hour. Including this movement with the FEA flexure results still yields a tolerable budget but a bit close for comfort. We also believe that this performance represents about the maximum that could be expected based on experience with other instruments of this size. It should be remembered that this analysis was based on worst case estimates for integration times and flexure. In median cases the integration times will be 5 times shorter which results in a 5 times increase in the requirement.

