Goal: Construct an optical setup and associated software to test the Focal Ratio Degradation (FRD) and change in tilt-angle of a fiber throughout the patrol area of a fiber positioning robot. The testing process will be automated to the point that the user simply places the fiber robot in the test stand, adjusts the test parameters as desired, and presses the "go" button to receive a comprehensive report on the FRD and tilt performance of the robot.

Background: The near and far field intensity distributions of light emitted from a multimode fiber can be fundamentally different from the input intensity distribution. For astronomical fiber-fed spectrographs, it is important to understand and characterize these effects.

One useful effect of cylindrical multimode fibers is azimuthal scrambling, where the in-fiber intensity distribution is effectively averaged over all azimuthal angles. This azimuthal scrambling results in a fiber's near-field output distributions having circular or ring-like structures when a non-uniform intensity distribution is injected into said fiber. As the angle of the off-axis collimated beam is varied, the bright ring in the emitted distribution will change in diameter, with wider angles corresponding to a larger diameter.

On the other hand, Focal Ratio Degradation (FRD) is an unwanted effect that can decrease spectral resolution or spectrograph throughput. Unlike most conventional optics, multimode fibers can fail to conserve etendue, or the product of beam area and solid angle. Stresses induced on the fiber core can result in the emitted light having a lower focal ratio, i.e., a wider angular extent, than that of the input light. A spectrograph designed to accommodate this lower focal ratio will have lower spectral resolution, but disregarding the light on the edges of the diverging beam from the fiber will lower the spectrograph's throughput. Therefore, it is important to minimize the FRD induced in the fiber throughout its length. We can again use an off-axis collimated beam; the more spread out the ring is in the radial direction (thicker ring) the more the focal ratio has been affected.

Method: FRD and tilt angle will be measured using a collimated or ring test, wherein a collimated beam is incident on the end of the fiber at a fixed angle. This will result in a ring of higher intensity in the near-field intensity distribution of the other end of the fiber, which will be imaged using a camera. The angle of the collimated beam from the fiber robot's optical axis will be chosen to ease imaging and analysis. With a collimated beam larger than the patrol area of the positioner, the ring test will be conducted at a number of positions in the robot's patrol area to map out any large scale deviations in FRD or tilt.

It is important to note that we do not need to measure/know the angle between the collimated beam and the fiber to great accuracy. We want this angle to be that of the edge of an f/3.6 beam, but we do not need particularly high accuracy on this value, as we are looking for changes in ring diameter to measure tilt angle changes. Similarly, measurement of the FRD does not depend on the beam-fiber angle.

Precision requirements: Full-cone FRD testing done for DESI showed that, for an input focal ratio of f/3.9, light incident on the fiber core must be within 1 degree, or 60’, of the optical axis. Therefore, the precision on the change in angle must be well below 60’.

The precision on the FRD measurement will also be driven by the DESI requirements, given that Spec-S5 will use the same spectrographs. The requirement for DESI was that 90% of light injected into the fiber at a focal ratio of f/3.9 must be output within the cone defined by a focal ratio of f/3.57. The current design of the Spec-S5 telescope results in a focal ratio of f/3.6 at the fibers. The DESI requirement will have to be translated into a meaningful value for a Spec-S5 ring test, likely by using the data from Poppet et al (2024) concerning the relationship between full-cone and collimated FRD test results.

These two precisions will be affected by the precision to which the inject beam is collimated, and they will drive the choice of collimating optics at the emitting end of the fiber and therefore the camera specifications.

Potential problems/issues:

- Using a bright enough source for the collimated beam that the camera images have good SNR in a reasonable exposure time.
- Verifying the collimation of such a large beam.
- Creating a general program that can control any positioner being developed.
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Timeline:

- 12/1: First day at LBNL
- 12/25: Optics are in place and aligned, and data (images) can be taken with a DESI positioner under manual control.
- 1/15: Analysis of a single image automated.
- 2/1: Images from many different positions analysed to look for FRD and tilt angle changes over the patrol area. (Positioner still under manual or rudimentary control.)
- 3/1: Automated DESI positioner movement allows for single-click analysis report.
- 4/1: Improved (G)UI allows user to define test parameters (full patrol area, exposure time, test position density). Test stand can also accept other positioners given the proper drivers. Documentation available.
- 4/15: Testing conducted with both tilting spine and trillium positioner designs, as well as multiple ferrulization techniques.
- 5/1: Upgrades made to allow for tilt angle measurement in orthogonal directions simultaneously.
- 5/20: Previous tests repeated at different temperatures using a thermal chamber. (*This goal will be cut first if there are any delays.*)
- 6/5: Last day at LBNL. Test stand is simple enough for anyone to use, including a user guide and thorough documentation.