Prime Focus Spectrograph (PFS): the Prime Focus Instrument

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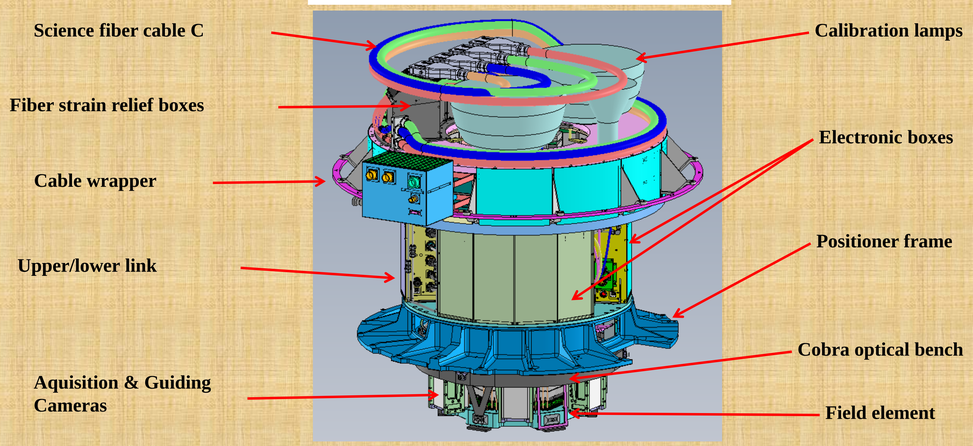
Abstract

The Prime Focus Spectrograph (PFS) is a new optical/near-infrared multi-fiber spectrograph design for the prime focus of the 8.2m Subaru telescope. PFS will cover 1.3 degrees diameter field with 2394 fibers to complement the imaging capability of Hyper SuprimeCam (HSC). The prime focus unit of PFS called Prime Focus Instrument (PFI) provides the interface with the top structure of Subaru telescope and also accommodates the optical bench in which Cobra fiber positioners and fiducial fibers are located. In addition, the acquisition and guiding cameras (AGCs), the cable wrapper, the fiducial fibers illuminator, and viewer, the field element, and the telemetry system are located inside the PFI. The mechanical structure of the PFI was designed with special care such that its deflections sufficiently match those of the HSC's Wide Field Corrector (WFC) so the fibers will stay on targets over the course of the observations within the required accuracy. The delivery of PFI components started in 2017. After the verification of these components, the mechanical structure of the PFI is fully assembled in early 2019 and all Cobra positioners are integrated in summer 2020. A temperature controlled chamber with precise x-y scanner was setup for the verification of the Cobra fiber positioners. The testing of the convergence performance of Cobra positioners is now in progress.

PFI Overview

- The PFI is the prime focus unit of PFS to be installed in the prime focus structure called POpt2. The PFI structure has two parts: the upper part comprised of calibration lamps, the cable wrapper, science fibers and fiber strain relief boxes. The lower parts mounts to the POpt2 Rotator and comprised of the upper/lower link structure, the positioner frame, the fiber positioning system, A&G cameras, electronic boxes and the field element.
- The mass load for the entire PFI is 487kg and for the rotating part is 348kg.
- The total power dissipation of PFI to the ambient air will be less than 10W to maintain stable dome seeing.

PFI Overview

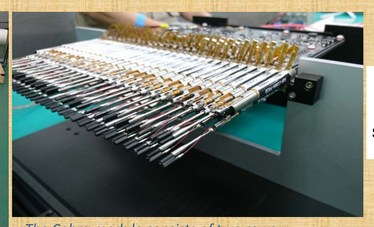


Test of Cobra Modules

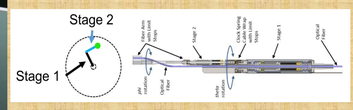
All Cobra modules were tested after the delivery from Caltech. The test items including

- The arm lengths, center and hardstop angles of the two rotational motors of each positioner
- Average motor speed adjusted to be around 0.07 degree/step
- The motor speed at different angle, i.e. motor map
- One dimensional target convergence for Phi and Theta motor respectively

The Cobra module test setup in our lab.



The Cobra module consists of two rows of Cobra positioners.

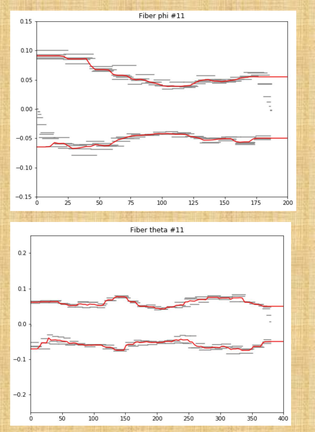


Each positioner has two rotational stage; Theta and Phi. (top)

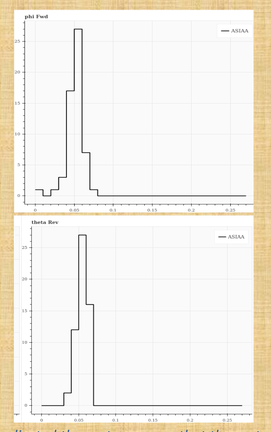
In order to quantify the performance for target convergence, we defined the signal to noise ratio (SNR) for each Cobra positioner after each iteration. The equation used to calculate the SNR is:

$$SNR = \left[1 - \left(\frac{d}{k_{offset}}\right)^2\right]\sqrt{\frac{t_{max} + t_{obs} - n \times t_{step}}{t_{obs}}}$$

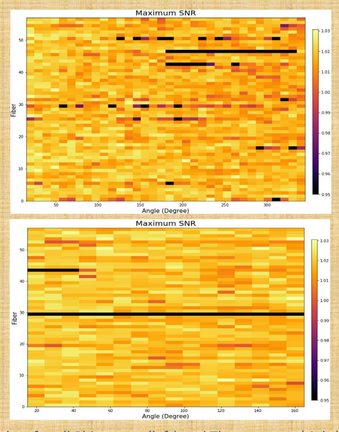
where d is the distance to the target position, k_{offset} is the coupling radius which is 0.075 mm, t_{obs} is 900 sec; the typical integration time for PFS observations, t_{max} is 105 sec; the maximum allocated time to move the fiber and t_{step} is 12 sec; the time used for each steps, n is the iteration number. When fiber is within 10μm to the target, the SNR should be higher than 0.92.



The motor map for the Phi motor (left) and Theta motor (right) for Cobra #11 of module number 10. The vertical axis is the motor speed and the horizontal axis is the motor angle



We adjusted the motor map so that the motor speed is around 0.06 degrees/step which can deliver good accuracy and speed. The histogram of average forward speed for Phi (left) and Theta (right) motors after the adjustment.

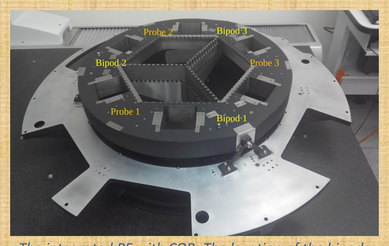


The SNR plots for all Phi motors (left) and Theta motors (right) of module #10. The vertical axis is the Cobra positioner number in the module and the horizontal axis is the target angles. The color of each cell indicates the SNR of the particular target and Cobra positioner.

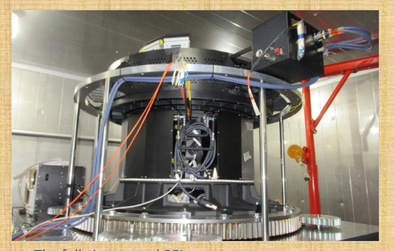
PFI Structure Integration

The integration sequence of the PFI structure includes

- Integrate Positioner frame with Cobra optical bench
- Fiducial fiber installation
- Add Upper/lower ink and cable wrapper
- Install all cables and coolant lines
- Install the electronics boxes



The integrated PF with COB. The location of the bipods and the deformation measurement are marked.



The fully integrated PFI structure.

The location and deformation of the PFI focal plane

The location of the focal plane is controlled by the shims between the positioner frame and the COB. The distance is within 10 μm to the designed distance and the difference among the three bipods are within 5 μm.

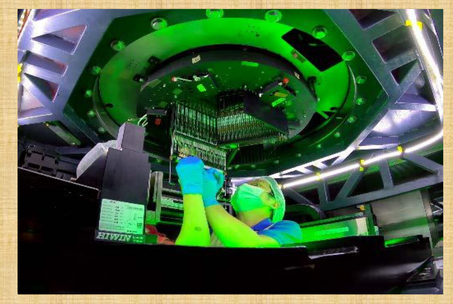
The deflection is measured with dummy weight installed on the optical bench. The deflection at different elevation angle is shown in the following table.

The measured deflection of the PFI focal plane under different elevation angle

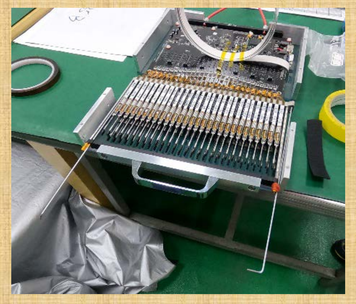
90 degree	60 degree	30 degree
33, 39, 38 (μm)	49, 26, 21 (μm)	58, 8, -1 (μm)

Cobra Modules Integration in PFI

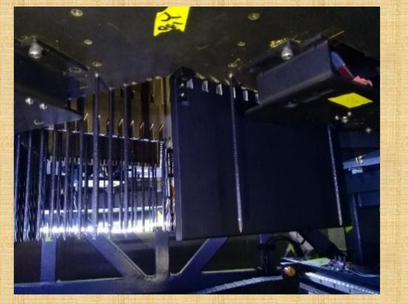
Since the Cobra modules are closely packed. Extreme cares were taken during the installation of the modules to protect the Cobra positioners as well as the fiducial fibers. Several tools have been made for facilitate the process. After the installation is completed, we measured the home positions and repeated the Cobra module measurement items. In order to reduce the risk of removing the installed modules, the Cobra modules were installed by 4 steps. We installed one module first, then added to 9 modules, 21 modules and finally a fully populated focal plane.



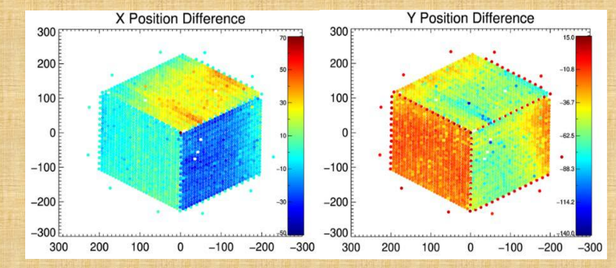
A picture taken during the Cobra module installation.

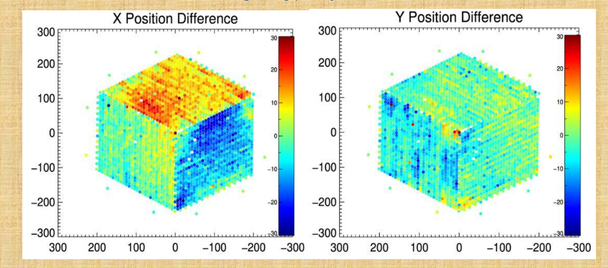


The handling tool of Cobra module.

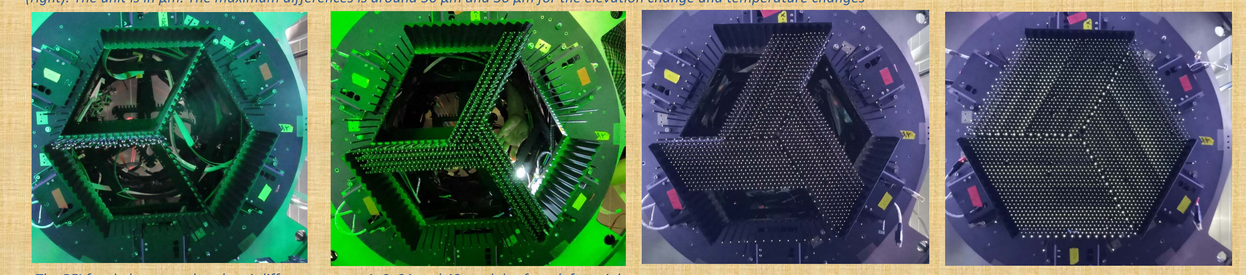


The guiding plate for the Cobra module installation.

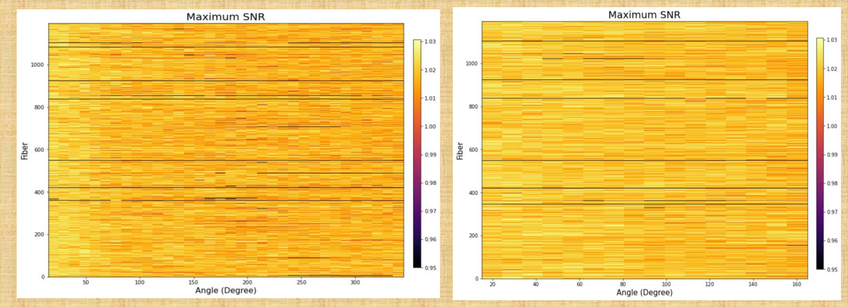




The position difference of the Cobra home positions in X and Y direction between 90 degrees to 30 degrees of elevation angle at 20 ℃ (Left) and between 5 to -5 ℃ at 90 elevation angle (right). The unit is in μm. The maximum differences is around 50 μm and 30 μm for the elevation change and temperature changes



The PFI focal plane populated at 4 different stages; 1, 9 ,21 and 42 modules from left to right.



The SNR plots for all Phi motors (left) and Theta motors (right) with 21 modules were tested. The failure rate is about 0.13% for all Phi motors and 0.27% for all Theta motors. The black lines are from the broken fibers or motors that could not generate any signal.

Summary

The integration and test of the PFI is still ongoing. After all Cobra modules were installed, there were 5 broken fibers in the system including 4 broken fibers damaged during the module fabrication. With all Cobra modules installed, we have started the connectorization of the Tower connectors each connects to one PFS spectrograph. The final target convergence tests with all modules will start in early 2021. We will also test the target convergence with the real target positions prepared for the survey. After it is completed, we will install AGCs and the field element and the associated calibration and tests as the last step for the focal plane integration. Then, we will install the calibration lamp and the covers for the PFI. The PFI is planned to be shipped to Hawaii in May 2021.