

LATEST NEWS ON INSTRUMENTATION

PRIME FOCUS to COUDE OPTICAL FIBER FEED

During scheduled coudé engineering on the nights of November 21-23, 1985, the throughput of a 50-meter length of Quartz Products AS 100/140 μm optical fiber, run from Prime Focus (PF) to the coudé slit room, was compared to the throughput of the red coudé train with the red transfer objective. This experiment was only the first step towards designing a coudé fibre-feed system as an alternative to the coudé train mirrors. In the slit room, transfer optics input the beam into the spectrograph with a magnification factor of about 5, producing an image of the fiber on the slit of 560-650 μm diameter. A star was focussed on the PF end of the fiber and guiding was performed with the spectrograph exposure meter. On the first night, the 1872 Reticon was used as the detector with the CFH red slicer and the 600 l/mm mosaic grating in place. Exposures were made at 5000, 6000, 7000, 8000 and 9000 \AA . On the second night the 320 x 512 CCD was used as the detector with the CFH red slicer and the 830 l/mm mosaic grating in place. Exposures were made at 5000, 7000, and 9000 \AA . The star observed for both fiber and train measurements was HR 655, an AOV.

The following table lists the relative efficiency of the fiber compared to the red train at several wavelengths with no slit or slicer in position.

Fiber/Train Efficiency Ratio

Wavelength	Reticon	CCD	Mean
5000 \AA	.36	.43	.40
6000	.25		.25
7000	.57	.53	.55
8000	.55		.55
9000	.58	.61	.60

The next table lists the relative efficiency of the fiber compared to the red train at several wavelengths, with the 1872 Reticon as detector and the red slicer in position.

Wavelength	Fiber/Train Reticon
5000 \AA	.70
6000	.41
7000	.72
8000	.78
9000	1.11

Note that the fiber is sensitive to guiding errors, while the train results are not. It is also of interest to note that the fiber/train efficiency ratio is improved by factors of 2 when the red slicer is in position. Typical image

slicer throughputs compared to open slot throughputs were greater than 30% with the fiber as the input source, as compared to 22% with the train as source. This may indicate that the fiber is better matched to the image slicer than is the train. In fact, the Reticon vertical position was aligned at 7000 \AA only, since repositioning was found to lead to changes in the mean flat-field signal of less than 10%. Hence, the Reticon results with the slicer may be $\geq 10\%$ in error, due to the slices not exactly overlapping the Reticon.

If we estimate the fraction of light from the primary mirror that is incident on the spectrograph collimator, assuming laboratory values for the transmission of the various optical elements, we can show that the throughputs of the fiber feed and train, T_f and T_t respectively, are given by the equations:

$$T_f = 0.77 * F_i * t_f * F_a$$

$$T_t = 0.66$$

Here, F_i is the fraction of star light incident on the fiber, t_f is the transmission of the fiber, and F_a is the fraction of fiber output accepted by the transfer optics in the slit room. If we also assume that 15% of the incident starlight is lost due to overfilling the fiber and errors in guiding ($F_i = 0.85$), and that 5% of the light is focally degraded enough to miss the transfer optics ($F_a = 0.95$), then we have:

$$t_f = 1.06 T_f / T_t,$$

which implies fiber transmission values of 0.42, 0.27, 0.58, 0.58, and 0.64 at 5000, 6000, 7000, 8000, and 9000 \AA , respectively. These are somewhat lower values than would have been expected for similar Quartz Products fibers, which typically transmit 70% of the incident light for a 50-meter length. The dip at 6000 \AA is expected due to OH absorption. Some potential sources of improvement in the efficiency of this fiber-feed system are:

(1) More active guiding of the star on the PF end of the fiber and appropriate selection of fiber diameter. Guiding for this test was accomplished by peaking up the fiber output on the spectrograph exposure meter, rather than by viewing the starlight incident on the fiber input. Having several fibers available of different diameter would also allow an appropriate fiber selection based on seeing. We might then expect F_i to be increased to a value of 0.95.

(2) Anti-reflection coatings on the fiber ends would decrease the present 5% loss at each end.

(3) Use of a microscope objective placed up against the end of the fiber (or perhaps optically coupled to it) would ensure that all the output light is accepted. These optics could then be appropriately coated so that the transfer losses would be less than 2% ($F_a = 0.98$).

Combining the above improvements leads to a new fiber-feed transmission of:

$$T_f' = 1.4 t_f' * T_t,$$

which implies that we need a fiber at least 15% more efficient at 9000 Å and 75% more efficient at 5000 Å to match the red train efficiency. This would be a fiber with roughly 75% transmission, which is not unreasonable an expectation.

In summation, the possibility of a fiber feed for the coudé focus is worth pursuing, although the system designed for this experiment is far from being operational. It could potentially compete with the efficiency of the coudé train (especially with image slicer) while simultaneously introducing a number of other advantages. These features include (a) ease of set-up and removal from the telescope; (b) simplification and stabilization of the feed system; (c) elimination of output beam instability; and (d) better flat fielding.

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COUDE TRAIN FLEXURE REPORT

As is well known to CFHT observers, the CFHT coudé train is a system of three sets (UV, blue, and red) of six mirrors and two lenses which transfer starlight from the Prime Focus (PF) of the telescope to the entrance slit of the coudé spectrograph. Due to telescope motion and to the large focal distance involved, each of these mirrors must be very carefully aligned.

In the ideal case, mirror M2 is centered on the optic axis of the telescope and tilted to send the starlight from the primary mirror along the optic axis to an intermediate stellar focus just before the field lens. The optic and delta axes of the telescope intersect at the surface of M3 which is tilted to send light along the delta axis. Mirror M4 is on the delta axis and is tilted to send the beam to the alpha axis intersection point with M5. Mirror M5 is then tilted to send the light along the alpha axis to M6, which is tilted to send the light vertically down from its intersection point with the alpha axis. Mirror M7 then sends the beam along a horizontal line through the spectrograph slit to the center of the spectrograph collimator. The two lenses also need to be centered and oriented so as to introduce no directional deviations. The field lens between M4 and M5 produces an image of the pupil (or primary mirror) just after M7

and thereby enlarges the unvignetted field. The transfer objective between M6 and M7 reimages the intermediate stellar focus onto the spectrograph slit.

If any of these optics should tilt or flex as the telescope moves, then the output beam will also move. This will produce motion of the star on the spectrograph slit, and motion of the pupil image at M7. The first effect is seen as a need for guiding of the star on the slit. The second effect is to illuminate slightly different parts of the collimator, and perhaps to lose some of the light.

Immediate results of coudé train stability would therefore be image and spectrograph stability. Another advantage is that if the beam did not wander, the field lens could be removed after acquiring the desired object, thereby producing an approximate 8% gain in train efficiency.

The effect of coudé train flexure is most simply observed by viewing the exit pupil from the train. This is an image (diameter of 67 mm) of the primary mirror, formed by the field lens, between the last train mirror (M7) and the spectrograph slit. As the telescope moves, this pupil image can also be seen to move. The exit pupil is also the location of an iris mask (diameter of 75 mm) used to match the flat-field illumination of the spectrograph to the illuminator from the train.

A recent study has been undertaken to identify and minimize sources of flexure in the coudé train. When this study was begun, pupil motions within a 10-15 mm diameter circle (with a maximum hysteresis of 3-4 mm) were typical, with the train well aligned, as the telescope was driven in alpha 60 degrees East and West of the zenith (little pupil motion was observed as a response to telescope motions in declination). This amount of pupil motion can produce a 13% change in collimator illumination.

After many tests and measurements, it was decided that the better part of this flexure was due to the instability of the M4 and M5 turrets and their mounting platforms. Initially, the I-beam on which the M4 turret rests was at the wrong angle, and the turret was clamped down on two jackscrews which thus warped the baseplate. These jackscrews were removed and the entire I-beam was rotated so that a new turret could sit flat. Also, a support beam was added to the west side of the beam on which the M5 turret is mounted. Both the M4 and M5 turrets were replaced with reinforced spare turrets prepared in the shop. These new turrets each hold only one mirror and are locked against rotation. Along with the improvements to the M4 and M5 platforms, the mechanical reinforcement of the M4 and M5 turrets has resulted in the reduction of flexure in the coudé train by at least a factor of two. The amount of pupil motion now observed at the 67-mm diameter