(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 illuminaton 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 exit pupil located after M7 is within a circle of diameter 6 mm, with a maximum hysteresis of 2 mm for telescope motions between 4 hrs East and West of the zenith. The M5 turret and platform are still known to contribute 3.0 mm of pupil motion and 2.7 mm of hysteresis. This contribution is reduced to 2.2 mm of pupil motion and 0.9 mm of hysteresis by removing the M5 mirror pad and mirror clamping system. Roughly half of this remaining pupil motion (about 1.6 mm) is from the M5 turret itself. The contribution to the flexure of the M6 turret and platform is small, corresponding to about 0.5 mm of pupil motion, while the field lens provides a negligible contribution. The M4 turret contributes about 1 mm of pupil motion and along with its platform may contribute a comparable amount to that of the M5 system. The remaining flexure probably comes from the telescope itself.

Both the M4 and M5 turrets need to be finalized. Presently, they each hold one mirror and the two turrets do not have automatic covers. Train changes therefore require manual removal and installation of mirrors rather than simply a turret rotation. The lack of an automatic cover requires that the Telescope Operator uncover and recover the mirrors at the beginning and end of each night. These are functions which were originally designed into the turrets, but which had to be removed in order to prevent turret rotation and permit reinforcement of the turret base and baseplate. These two features should be built back into the M4 and M5 turrets along with sturdier mirror pads and mirror clamping systems.

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COUDE EFFICIENCY IMPROVEMENT WITH A POLARIZATION DEVICE

A proposal for a Polarizer at Coudé was written in September, 1985. Since then, optics have been purchased, mechanics designed and built, and an initial test performed. Basically, unpolarized light input into the spectrograph is separated by this device into components with polarizations parallel and perpendicular to the grating grooves. One of these components then has its polarization rotated to match that of the more efficient grating polarization mode. In this manner, all light incident on the grating is linearly polarized either parallel to or perpendicular to the grating grooves. Since the efficiency of a grating depends upon the direction of polarization of the incident light, the device could result in significant gains in spectrograph efficiency.

The device uses a polarizing beamsplitter cube to separate the two orthogonal components. A right-angle prism is used to make the two beams parallel and to vary the optical path length of one of the beams to match the other. A half-wave Fresnel Rhomb Retarder is used to rotate the polarization vector of one of the beams parallel to the other. The beams, unfortunately, cannot be recombined and are displaced with respect to each other by about 4 mm in the detector plane. This is too high for the 0.75-mm height of the Reticon, but is well within the 9-mm height of the 320 x 512 RCA1 CCD. With 2-d detectors a spectral line from the two beams can be placed on the same vertical column allowing for integration of the line upon readout.

A series of exposures was taken with the RCA1 CCD at the coudé focus on December 13, 1985. The CFH red slicer and 830 l/mm mosaic grating were used. The polarization device was placed directly behind the image slicer and the Th-Ne lamp was used for focussing. For both polarizations, the two paths of the device could be focussed simultaneously on the CCD to produce line profiles of less than one pixel (30 µm). The flat field lamp was used for relative efficiency measurements. Use of area detectors such as the new RCA2 CCD (15 µm pixels) which permit on-chip summing before readout is essential if real gains in S/N are to be achieved.

The following table gives the efficiency of the device (oriented for each of the two cases of polarization), relative to the throughput with no polarizer in place, for several wavelengths:

Wavelengths	E (Par.)	E (Perp.)
4000 Å	0.70	----
5000	1.28	0.34
6000	1.23	0.48
7000	1.02	0.68
8000	0.78	0.88

With the device oriented for polarization parallel to the grating grooves, the spectrograph efficiency was improved at 5000 Å by 28%! Note that this device was designed for the wavelength range of 4000-7000 Å, beyond which the beamsplitter cube becomes a much less efficient polarizer. The transmission of the beamsplitter is ≥ 97% in the range of 5000-7000 Å and ≥ 85% in the range of 4000-5000 Å. The Fresnel Rhomb Retarder is an effective rotator from 3300-10,000 Å, while the anti-reflection coating on the right-angle prism is better that 2% in the range 4200-7500 Å. This implies that a different beamsplitter and prism will be required for other wavelengths.

This test has shown (at least for the 830 ℓ/mm grating) that the polarization device in its parallel mode can produce substantial improvements in spectrograph efficiency, once on-chip signal summing with area detectors becomes available. For gratings with more rulings, the improvement in efficiency should be even larger.

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