Revised FOS Wavelength Calibration

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Abstract

In February 1988 the FOS was re-assembled at Lockheed and a new red detector (F12) was installed in the FOS. Subsequent to installation, new wavelength calibration data was acquired for each detector in March 1988. In August 1988 the detectors were removed for installation of new heat pipes. After the FOS was reassembled (including attachment of the outer panels and the MLI blanket), a full set of wavelength calibration data was obtained once again. Since these calibrations were obtained under ambient conditions, there is no data for the blue H13 grating. Following the reduction procedure described in *FOS Wavelength Calibration* (Sirk and Bohlin 1986, CAL/FOS-026), we determined new dispersion solutions for all dispersers for the blue and red detectors. The blue detector shows only slight differences from the results in CAL/FOS-026. The new red detector has a higher dispersion by $\sim$1.5% from F8, and the distortion terms are qualitatively different. For both the blue and red detectors the internal errors of the dispersion solutions are $\sim$0.05 diodes or less for the gratings, and $\sim$ 0.1 diodes for the prisms.

I. Introduction

The delay in launch of the *Hubble Space Telescope (HST)* has enabled the FOS team to make several adjustments to the instrument which will improve its in-flight performance. These adjustments required the removal of the detectors from the FOS and realignment of the grazing mirror and of the red collimator. Since the red detector F8 had suffered a drastic loss in quantum efficiency at Hα (λ6563) and beyond, when the FOS was reassembled at Lockheed in February 1988, an improved red detector (F12) was installed in the FOS. After reassembly of the FOS was complete, a full set of wavelength calibration data were obtained at Lockheed on 8, 9, and 21 March 1988.

In August 1988 the detectors were removed once again for the installation of new heat pipes. After re-installation, the side panels and the MLI blanket were attached to the FOS. A full set of wavelength calibration data were obtained once again on 24, 25, 26 August 1988. These data represent the final flight-ready configuration of the FOS, and the derived wavelength calibration coefficients from these data will be used for the initial inputs to the database of the Routine Science Data Pipeline (RSDP). Here we discuss the reduction of these calibration data and the derivation of the diode-to-wavelength conversion coefficients.

II. The Calibration Data

Both the March and August calibrations were performed under ambient conditions. The data were acquired in the default standard acquisition mode (XSTEPS = 4, OVRSCN = 5) with the 0.1 arcsec square aperture (A4) using the internal direct Pt-Cr-Ne lamp.

Several of the red spectra from the March calibration were over-exposed (H57, L65, H78, and the Prism), and the brightest lines exceeded the 16 bit capacity of the FOS counters. Properly exposed spectra for these dispersers using the direct calibration lamp were taken from the internal/external offset procedure run on the same day. The direct lamp exposure for H78 was still overexposed in this procedure, however, so a direct lamp spectrum from the YMONTH procedure run on March 18 was used instead. This spectrum was actually underexposed by a factor of ~2, and this is reflected in the higher than usual rms error of the dispersion solution.

All data obtained in August were properly exposed.

III. New Dispersion Solutions

The data were reduced following the procedures described by Sirk and Bohlin in CAL/FOS-026. The selected lines tabulated by Sirk and Bohlin were identified in the calibration spectra and centroided using the cross-correlation algorithm described in CAL/FOS-026. Since the calibration spectra were obtained under *ambient* conditions rather than vacuum, the *air* wavelengths of the identified lines were used. All lines below 1900 Å are absent in the observed spectra, so the line lists for the short wavelength gratings were adjusted accordingly. It was not possible to obtain new calibration spectra for the H13 grating.

The diffraction grating spectra were fit with a cubic polynomial of the form

$$\lambda = A + Bx + Cx^2 + Dx^3 \quad .$$

where x is the diode number and λ is the corresponding wavelength. Uniform weighting for each line was used in the fit. The resulting dispersion solutions for the diffraction gratings are presented in Table 1 (March results) and Table 2 (August results).

The prism spectra were fit with the dispersion formula given in CAL/FOS-026:

$$\lambda = A_o - \frac{A_1}{(x-X_o)} + \frac{A_2}{(x-X_o)^2} + \frac{A_3}{(x-X_o)^3} + \frac{A_4}{(x-X_o)^4} \quad .$$

While the fitting procedure for the prisms in CAL/FOS-026 used a uniform weighting for each emission line, we find that weighting the lines by the reciprocal of the local dispersion produces significantly better fits. This is because the measurement errors for the centroid of each line are roughly uniform in diode space. The prism spectra have large changes in the local dispersion from one end of the spectrum to the other: hence, these errors transform to wavelength space in a non-uniform way. Weighting by the reciprocal of the local dispersion preserves the uniformity of the errors in diode space.

As noted by Sirk and Bohlin in CAL/FOS-026, the dispersion of the blue prism changes rapidly at the red end, and unless there is a data point to constrain the red end, the fit behaves badly beyond the last visible feature (λ5208). Following Sirk and Bohlin, we estimate a diode number for an "artificial" feature (λ7034) used to anchor the red end of the dispersion solution for the blue prism based on the prism dispersion solution for the red tube and the positions of the reddest visible features in the blue prism spectrum. We assign λ7034 to diode 21.997.

The best fit dispersion solutions for the red and blue prism spectra are given in Table 3.

In general, linear fits ($\lambda = a + bx$) for the grating dispersion solutions are not adequate, yet they provide a quick estimate of wavelength accurate to a few tenths of a diode. Only for the blue side L15 grating does a linear fit give consistently acceptable results. On the red side, while CAL/FOS-026 found that a linear dispersion solution for the L15 grating was acceptable, we find that a cubic fit gives significantly better results for the March data, but that a linear fit for the August data is acceptable. These differences from CAL/FOS-026 may be due to the lack of observed lines below 1900 Å in the ambient calibration data. The wavelength ranges covered by each grating and the best linear fits are given in Table 4. The higher dispersion of the new red detector decreases the wavelength overlap of the red gratings even more than first noted in CAL/FOS-026, but there is still sufficient overlap to obtain good relative photometric calibrations.

IV. Conclusions

The removal and re-installation of the blue detector leads to only slight differences in the FOS wavelength calibration, predominantly in the zero point of the dispersion solution. These zero-point offsets are of the order of one diode, and they represent the accuracy to which the detectors can be removed and re-installed in the same orientation. Since a completely new red detector was installed, however, the calibrations for the red side dispersers are significantly different from CAL/FOS-026. These differences can be attributed to the different focus and distortion properties of the new red tube. Removal and re-installation of the new red detector, like the blue detector, predominantly changes the zero point of the dispersion solution without significantly affecting the higher order terms.

The only disperser with significantly different high order terms in the dispersion solution in August compared to March 1988 is H78. The March data for the solution in Table 1 was obtained as part of the YMONTH procedure rather than the standard YCWAVC wavelength calibration. The YMONTH data are obtained as five spectra through the lower A4 aperture each spaced by one y-step. The middle spectrum was used for the March dispersion solution We attribute the differences in the dispersion solution to the differing manner in which the data were acquired and to the lower signal-to-noise ratio of the March data.

The August 1988 calibration data represent the final assembly of the FOS prior to launch We thus will use the calibration coefficients derived from these data as the initial input to the RSDP calibration database. Since no new data were obtained for the H13 grating on the blue side, the coefficients from CAL/FOS-026 for this combination will be initially entered into the database.

References

Sirk, M., and Bohlin, R. 1986. CAL/FOS-026, *FOS Wavelength Calibration*.

Table 1 — FOS Grating Dispersion Solutions for March 1988

Detector	Grating	A	B	C	D	rms (pix)
B	H19	1574.085	1.46083	+0.612830e-04	−0.101052e-06	0.019
B	H27	2222.561	2.09494	+0.447020e-04	−0.982219e-07	0.035
B	H40	3248.563	3.07234	+0.490674e-04	−0.116910e-06	0.027
B	H57	4580.621	4.47300	+0.548856e-04	−0.148933e-06	0.048
B	L15	−1050.385	6.92905	0.0	0.0	0.046
B	L65	−3835.369	24.185	+0.382176e-02	−0.434960e-05	0.090
R	H19	2310.268	−1.43571	+0.240375e-04	−0.612472e-07	0.026
R	H27	3279.930	−2.04647	+0.206702e-04	−0.430259e-07	0.029
R	H40	4785.647	−2.99540	+0.185822e-04	−0.515515e-07	0.031
R	H57	6815.351	−4.35837	+0.375924e-04	−0.962657e-07	0.029
R	H78	9228.451	−5.68693	−0.706748e-04	+0.176530e-07	0.061
R	L15	2425.724	−6.60319	−0.659592e-02	+0.536788e-04	0.065
R	L65	8718.723	−24.7336	+0.997677e-03	−0.198896e-05	0.037

Table 2 — FOS Grating Dispersion Solutions for August 1988

Detector	Grating	A	B	C	D	rms (pix)
B	H19	1572.697	1.45921	0.655585e-4	−0.104806e-6	0.020
B	H27	2226.317	2.09511	0.448176e-4	−0.993657e-7	0.038
B	H40	3243.789	3.07293	0.447469e-4	−0.110737e-6	0.028
B	H57	4574.574	4.46737	0.986855e-4	−0.242637e-6	0.041
B	L15	−1058.283	6.9244	0.0	0.0	0.046
B	L65	−3870.573	24.1794	0.384453e-2	−0.436322e-5	0.091
R	H19	2307.671	−1.43711	0.255049e-4	−0.630319e-7	0.022
R	H27	3277.001	−2.04822	0.209608e-4	−0.429817e-7	0.028
R	H40	4779.930	−2.99813	0.215440e-4	−0.559330e-7	0.034
R	H57	6808.591	−4.36403	0.479083e-4	−0.107755e-6	0.026
R	H78	9223.999	−5.72216	0.402792e-4	−0.103140e-6	0.035
R	L15	2417.253	−6.8401	0.0	0.0	0.047
R	L65	8681.749	−24.7888	0.115493e-2	−0.220117e-5	0.026

Table 3 — FOS Prism Dispersion Solutions							
Detector	X_0	A_0	A_1	A_2	A_3	A_4	rms (pix)
				March 1988			
B	−15.2214	1105.42	+1.42010e+5	+5.37196e+5	−4.36484e+7	4.24597e+9	0.104
R	513.123	1168.34	−1.31602e+5	−1.09814e+6	−2.02080e+7	−4.27062e+6	0.131
				August 1988			
B	−15.1030	1113.186	+1.41109e+5	+6.22733e+5	−3.20073e+7	4.33397e+9	0.119
R	517.1889	1099.320	−1.50628e+5	−2.04904e+6	−7.28142e+7	−2.33852e+8	0.096

Table 4 - Wavelength Coverage of FOS Dispersers and Best Linear Fits						
Detector	Disperser	Low λ (Å)	High λ (Å)	a	b	rms (pix)
B	H19	1573	2328	1574.23	1.4639	0.273
B	H27	2226	3305	2226.82	2.0955	0.344
B	H40	3244	4825	3244.41	3.0719	0.202
B	H57	4575	6872[a]	4574.49	4.4761	0.051
B	L15	1150[b]	2513	−1058.28	6.9244	0.046
B	L65	3540	9024[a]	−3933.89	25.1518	0.298
B	PRI	1850[a,c]	5500	...	...	...
R	H19	1565[d]	2308	2307.63	−1.4346	0.030
R	H27	2220	3277	3277.39	−2.0483	0.138
R	H40	3232	4780	4780.53	−3.0003	0.150
R	H57	4556	6809	6809.43	−4.3653	0.178
R	H78	6269	9226[e]	9225.88	−5.7295	0.152
R	L15	1600[d]	2417	2417.25	−6.8401	0.047
R	L65	3540	8682	8676.17	−24.6358	0.047
R	PRI	1850[b]	8950[e]	...	...	...

[a]Quantum efficiency of the blue tube is very low beyond 5500 Å.
[b]Short wavelength end set by MgF_2 cutoff.
[c]Short wavelength end set by sapphire cutoff and large dispersion of the prism.
[d]The quartz window of the red detector attenuates sharply below 1650 Å.
[e]Quantum efficiency of the red tube is very low beyond 8950 Å.