FOS FILTER-GRATING WHEEL REPEATABILITY MEASUREMENTS

ANURADHA KORATKAR and STEPHAN MARTIN
Space Telescope Science Institute, 3700 San Martin Drive, Baltimore MD 21218

Abstract. The post-COSTAR FOS Filter-Grating Wheel (FGW) repeatability was tested for both the red and blue detectors. The test consisted of obtaining repeated FOS images in an uninterrupted sequence through 3 different gratings on each detector. The observations consisted of exposures using G190H, G400H and G570H with FOS/RD, and G130H, G190H and G270H with FOS/BL. All other observing parameters were unchanged during the test.

The standard deviations of the positions of spectra with respect to each other are found to be independent of the chosen grating. The rms deviations of the position of the spectra in the FOS X and Y directions are of the order of 0.1 diode and 9 ybases, respectively. Deviations as large as 0.36 diodes and 18 ybases are also seen. These values are similar to those obtained from pre-launch calibration activities. The non-repeatability of the FGW could be a major source of instrumental inaccuracy in the wavelength calibration of spectra obtained without contemporaneous calibration lamp spectra. It should be noted that the absolute wavelength calibration for a typical FOS spectrum is not only affected by internal instrumental effects, such as, FGW position and aperture location, but is also affected by the target acquisition accuracy.

Key words: FOS – Wavelength Calibration

1. Introduction

Pre-flight measurements of the FOS filter-grating wheel (FGW) repeatability showed that the FGW repeatability was of the order of 10 microns (12.8 ybase units in Y and 0.2 diodes in X) in both the X and Y directions of the FOS blue detector, and of the order of 14 microns (17.9 ybase units in Y and 0.3 diodes in X) in both the X and Y directions of the FOS red detector (CAL/FOS-12, CAL/FOS-17, CAL/FOS-49). This non-repeatability of the FGW leads to wavelength calibration errors.

Uninterrupted repeated observations with different gratings were obtained in the first part of the calibration program 6146 to check the FOS FGW repeatability. The red side detector measures used the G190H, G400H and G570H gratings while the blue side detector measures used the G130H, G190H and G270H gratings. Observations for each grating are listed in Tables II-VII. Each observation was in the FOS IMAGE mode, and spectra of the internal Pt-Cr-Ne wavelength calibration lamp using the $0.3''$ aperture were obtained in a continuous random sequence of approximately 10 exposures in each grating. The FGW was the only instrument component that was moved during the entire observing run for each detector which lasted 57 minutes for the red side detector, and 77 minutes for the blue side detector. The exposure times for each single exposure are given in Table I. Other exposure details such as number of diodes used for each grating, and the wavelength range covered are also given in Table I.

TABLE I
Exposure Characteristics for each Grating

Config.	Grating	Exposure Time (s)	Diode Range	Wavelength Range (Å)	Number of Emission Lines Used
FOS/RD	G190H	320	196 – 313	2032 – 1863	24
FOS/RD	G400H	24	196 – 313	4197 – 3845	20
FOS/RD	G570H	24	196 – 313	5965 – 5455	10
FOS/BL	G130H	90	196 – 313	1281 – 1403	15
FOS/BL	G190H	36	196 – 313	1858 – 2034	27
FOS/BL	G270H	6	196 – 313	2629 – 2879	29

2. Data Analysis

Since each IMAGE mode observation used 118 diodes, with NXSTEPS=4, OVERSCAN=5, YSTEPS=24, and YSPACE=24 there were 24 spectra with 488 pixels each, stored as 24 groups in the original data file. The 24 spectra were then converted into two-dimensional images with 488×24 pixels each using the STSDAS task *rapidlook*.

For each grating the first image was chosen as the reference image. The 488×24 pixel images were then cross-correlated two-dimensionally with the reference frame for each grating. The STSDAS task *crosscor* is used to determine the cross-correlation (see Bracewell 1986 for details). Since the centering option is used in the *crosscor* task, the maximum power is expected at the (245, 13) pixel position in the cross-correlated image for this analysis. The shift of an image with respect to the reference image is thus the position of maximum power in the cross-correlated image. The cross-correlated images are of high signal-to-noise, since many (see Table I) emission lines with significance levels $> 3\sigma$ above the background are used in the cross-correlation analysis.

The position of maximum power in the cross-correlated image is given in Tables II-VII (columns 2 and 3). The offsets with respect to the reference central pixel (columns 4 and 5) are given also in the tables. The measuring uncertainty of the cross correlation peak is < 0.02 pixels in X (where 4 pixels = 1 diode) and $\sim$0.05 pixels in Y (where 24 ybases = 1 pixel). The standard deviations (in units of pixels) for each grating are given in the tables.

3. Results

Only the deviations from the reference pixel are important for determining the FGW repeatability, because the absolute value of the reference pixel is arbitrary. These deviations are of the same order for all gratings.

The 1σ rms deviations of the position of the spectra are 0.47 pixels in the FOS

X direction and 0.36 pixels in the FOS Y direction. These rms deviations translate to 0.1 diode in FOS X direction and 9 ybases in the FOS Y direction. The range of deviations is 0.06 - 1.44 pixels in FOS X (0.02 - 0.36 diodes) and 0.01 - 0.74 pixels in FOS Y (0 - 18 ybases). Since the deviations in the analysis are Gaussian distributed, we can expect 3σ deviations as large as 1.5 pixels (0.36 diodes) in FOS X and 1.08 pixels (25 ybases) in FOS Y sometimes. We see that the range of deviations for the red detector are slightly larger than for the blue detector.

We have noted in a previous instrument report (CAL/FOS-133) that the location of the FOS spectra are affected by the ambient magnetic field in the detector. The duration of the entire observing run for each detector in this calibration program is long enough that magnetic field effects could be significant. Thus the scatter in the location of the spectra observed in the present analysis could be not only due to the FGW but also due to changes in the magnetic field environment. We note that the amount of deviation in the position of the spectra obtained in this test are similar to those obtained during pre-launch calibration measurements (CAL/FOS-12, CAL/FOS-17, CAL/FOS-49). Thus, the post-COSTAR test indicates that there has not been dramatic wear in the FGW notches that hold the grating in a given location. Further, since the pre-launch measurements were in a constant magnetic field and showed similar deviations as the post-COSTAR measurements, we conclude that the scatter in the location of the FOS spectra due to non-repeatability of the FGW is no less than the scatter induced by the magnetic field environment.

The scatter along the FOS Y direction (perpendicular to the dispersion axis) affects the flux calibration at a level $< 2\%$ and only for the large apertures ($4.3''$ and $1.0''$) since the spectrum can be misdirected onto the diode array.

The scatter in the FOS X direction (along the dispersion axis) leads to wavelength uncertainties in the range of 0.02 - 0.36 diodes. For a typical FOS observation, uncertainties in the absolute wavelength calibration are due to; (a) the non-repeatability of the FGW, (b) the uncertainty in the location of the FOS apertures in the FOS X direction which ranges from -0.21 to 0.13 diodes (CAL/FOS 131), (c) the changes in the ambient magnetic field of the detector, and (d) the target acquisition accuracy. Of these four sources of uncertainty, the non-repeatability of the FGW is the dominant internal instrumental source of inaccuracy in the wavelength calibration of spectra. A contemporaneous calibration lamp spectrum without any change in the aperture position can reduce the effect of FGW on wavelength calibration.

TABLE II
FOS/RD G190H Grating Observations

Root name	X position (pixel)	Y position (pixel)	X Offset (pixel)	Y Offset (pixel)
y2nc1003t	245.00	13.00	0.00	0.00
y2nc1007t	245.87	13.18	0.87	0.18
y2nc1009t	245.75	12.89	0.75	-0.11
y2nc100ct	245.57	12.87	0.57	-0.13
y2nc100ft	246.14	13.08	1.14	0.08
y2nc100kt	245.94	13.06	0.94	0.06
y2nc100mt	245.69	13.46	0.69	0.46
y2nc100pt	246.44	12.39	1.44	-0.61
y2nc100tt	245.61	13.19	0.61	0.19
standard deviation			0.40	0.29
range			0.00 – 1.44	-0.11 – 0.29

TABLE III
FOS/RD G400H Grating Observations

Root name	X position (pixel)	Y position (pixel)	X Offset (pixel)	Y Offset (pixel)
y2nc1002t	245.00	13.00	0.00	0.00
y2nc1005t	244.66	13.80	-0.34	0.80
y2nc100bt	245.01	13.30	0.01	0.30
y2nc100et	244.88	13.72	-0.12	0.72
y2nc100ht	245.53	13.31	0.53	0.31
y2nc100jt	245.72	13.07	0.72	0.07
y2nc100lt	245.41	13.41	0.41	0.41
y2nc100ot	245.64	13.43	0.64	0.43
y2nc100qt	245.60	12.74	0.60	-0.26
y2nc100st	245.49	12.76	0.49	-0.24
standard deviation			0.37	0.36
range			-0.12 – 0.72	-0.26 – 0.80

TABLE IV
FOS/RD G570H Grating Observations

Root name	X position (pixel)	Y position (pixel)	X Offset (pixel)	Y Offset (pixel)
y2nc1001t	245.00	13.00	0.00	0.00
y2nc1004t	245.06	13.31	0.06	0.31
y2nc1006t	245.28	13.73	0.28	0.73
y2nc1008t	245.10	13.48	0.10	0.48
y2nc100at	245.50	13.16	0.50	0.16
y2nc100dt	245.24	13.64	0.24	0.64
y2nc100gt	246.19	12.99	1.19	-0.01
y2nc100it	246.11	13.31	1.11	0.31
y2nc100nt	245.76	13.74	0.76	0.74
y2nc100rt	245.51	13.50	0.51	0.50
y2nc100ut	245.48	13.74	0.48	0.74
standard deviation			0.40	0.29
range			0.00 – 1.11	-0.01 – 0.74

TABLE V
FOS/BL G130H Grating Observations

Root name	X position (pixel)	Y position (pixel)	X Offset (pixel)	Y Offset (pixel)
y2nc0z03t	245.00	13.00	0.00	0.00
y2nc0z07t	244.35	13.17	-0.65	0.17
y2nc0z09t	244.79	13.15	-0.21	0.15
y2nc0z0ct	244.52	13.44	-0.48	0.44
y2nc0z0ft	244.37	13.00	-0.63	0.00
y2nc0z0kt	244.36	13.68	-0.64	0.68
y2nc0z0mt	244.23	13.17	-0.77	0.17
y2nc0z0pt	245.31	13.67	0.31	-0.33
y2nc0z0tt	244.16	13.51	-0.84	0.51
standard deviation			0.39	0.31
range			-0.84 – 0.39	-0.33 – 0.68

TABLE VI
FOS/BL G190H Grating Observations

Root name	X position (pixel)	Y position (pixel)	X Offset (pixel)	Y Offset (pixel)
y2nc0z02t	245.00	13.00	0.00	0.00
y2nc0z05t	244.86	13.00	-0.14	0.00
y2nc0z0bt	244.92	13.20	-0.08	0.20
y2nc0z0et	244.84	12.32	-0.16	-0.68
y2nc0z0ht	245.04	12.72	0.04	-0.28
y2nc0z0jt	245.48	12.50	0.48	-0.50
y2nc0z0lt	244.51	12.44	-0.49	-0.56
y2nc0z0ot	245.47	12.57	0.47	-0.43
y2nc0z0qt	244.79	12.73	-0.21	-0.27
y2nc0z0st	245.04	12.54	0.04	-0.46
standard deviation			0.30	0.28
range			-0.49 – 0.48	-0.68 – 0.28

TABLE VII
FOS/BL G270H Grating Observations

Root name	X position (pixel)	Y position (pixel)	X Offset (pixel)	Y Offset (pixel)
y2nc0z01t	245.00	13.00	0.00	0.00
y2nc0z04t	245.51	13.48	0.51	0.48
y2nc0z06t	244.56	13.13	-0.44	0.13
y2nc0z08t	245.50	12.63	0.50	-0.37
y2nc0z0at	245.49	12.71	0.49	-0.29
y2nc0z0dt	245.01	13.37	0.01	0.37
y2nc0z0gt	245.13	12.84	0.13	-0.16
y2nc0z0it	245.99	13.16	0.99	0.16
y2nc0z0nt	245.73	12.46	0.73	-0.54
y2nc0z0rt	245.95	13.08	0.95	0.08
y2nc0z0ut	244.54	12.57	-0.46	-0.43
standard deviation			0.50	0.33
range			-0.46 – 0.99	-0.54 – 0.37

References

Bracewell, R. N.: 1986, *The Fourier Transform and Its Application, 2nd ed.*, New York.
Dahlem, M. & Koratkar, A.: 1994, 'Post-COSTAR FOS Aperture Wheel Repeatablilty Measurements', *CAL/FOS* **131**,
Hartig, G.: 1984, 'FOS Filter-Grating Wheel Repeatability', *CAL/FOS* **12**,
Hartig, G.: 1985, 'Improvements in the Filter-Grating Wheel Repeatability', *CAL/FOS* **17**,
Hartig, G.: 1988, 'FOS Filter-Grating Wheel Repeatability', *CAL/FOS* **49**,
Koratkar, A., Keyes, C. & Holfeltz, S.: 1995, 'Location of FOS Spectra: Cycle 4', *CAL/FOS* **133**,