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TITLE: FOS Filter-Grating Wheel Repeatability (FOS CAL. Plan 10D)

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ABSTRACT

Recent measurements of the FOS filter-grating wheel (FGW)repeatability indicate that this mechanism is not operating in a completely satisfactory manner. Implications of the non-repeatability, most importantly with regard to target acquisition, are discussed. The measurements imply that the cause of non-repeatability is some combination of wheel wobble about its central bearings, distortion of the wheel, and imperfect detenting (in order of probable importance). Evidence is presented that the repeatability for at least some of the FGW elements is dependent on operating temperature; measurements made at ambient will underestimate the severity of the problem. There is little indication that the performance has deteriorated with FGW use; the major part of the problem may be inherent in the fundamental limitations of the design. Refurbishment of a motor that had a damaged pinion does not appear to have improved the performance. Some possible work-arounds are proffered, in the event that the mechanism cannot be improved prior to launch.

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I. INTRODUCTION

This report presents a summary of recent measurements of the FOS filter--grating wheel (FGW) positioning repeatability and describes attempts that have been made to diagnose and remedy the problem. In addition to the 9 dispersers, the FGW carries the camera mirror that is used for target acquisition. In order to be able to acquire objects rapidly into the smallest entrance aperture (0.1 arcsec designated A4 by the FOS team and 0.1-PAIR by the STScI), the camera mirror must be capable of repeatably positioning the aperture image to within a fraction of the 14 micron square projection of that aperture onto the Digicon detectors. The FGW must also be capable of positioning the dispersers repeatably so that spectral images will be properly registered on the diode array, without requiring time-consuming Y-mapping, to permit accurate spectrophotometry. This becomes a problem for the larger apertures whose size, combined with distortion inherent in the Digicons, may result in part of the spectrum missing the diode array, if the FGW positioning is not repeatable. The ability to do spectropolarimetry is also impaired because of the relatively small separation especially at short wavelengths of the spectrum of each polarization component and the need for high photometric accuracy in the measurement of each spectrum to determine the polarization.

Measurements which indicate that the FGW repeatability is inadequate were made during the thermal vacuum testing in July 1984 at Martin Marietta in Denver. Subsequent attempts to remedy the problem, including refurbishing one of the drive motors, have met with limited success. If the FGW repeatability cannot be further improved, time consuming work-arounds will be required, particularly for target acquisition into the smaller apertures.

II. FGW REPEATABILITY MEASUREMENTS

A summary of the FGW repeatability test results is presented in Table 1, which shows the observational data, the name of the test configuration, the temperature status, the FOS detector (side A = red, B = blue), direction in which the FGW was rotated, FGW element for which the measurements were made, number of samples (N), and spread (maximum difference in image location) and standard deviation (σ) in microns in the X (along dispersion) and Y (perpendicular to dispersion, if measured) directions. A description of these data, in semi-historical order, follows:

The severity of the repeatability problem was realized during the TV III calibration in July 1984 (meas. #3 of Table 1), when systematic measurements were made which showed spreads in image positioning for some of the dispersers to be quite large. These data, obtained by moving the FGW nine times to each disperser, in semi-random order, are plotted in Figure 1 (along with some later measurements discussed below). The data appear to indicate a sinusoidal dependence of the repeatability (in the X direction) with element position around the wheel. Although the camera mirror was not measured in this test, an interpolation of the data at its position on the FGW indicates a spread of ~20μ is to be expected, somewhat worse than the values measured in March 1983 in ambient calibration I.

Additional measurements of the repeatability in both X and Y of the H40 grating over a longer time period (10 days), during both 'hot' and 'cold' operating conditions were made during TV III (meas. #4, 5). Even larger spreads in X resulted, ranging to ~80μ, with the FGW operated in both directions (the dispersion was comparable to that of meas. #3 if the data set is limited to one direction only) for measurements made at the same operating temperature. An average shift of ~35μ in X and <1μ in Y resulted in going from 'cold' to 'hot' operate; this is probably due predominantly to optical bench and component mounting thermal distortions rather than indicative of a thermal dependence of the FGW positioning.

Shortly after TV III, the H40 measurements were repeated, following the same procedure, at ambient temperature (meas. #6), resulting in an improvement by more than a factor of 2, for this FGW position. Subsequent camera mirror measurements (#10, 12), however, resulted in spreads similar to that predicted by meas. #3 during TV III. Measurements #7, 8 and 9 clearly show that the FGW repeatability is considerably improved when operating in one direction only.

Following these measurements, an inspection of the FGW assembly revealed that the pinion of the 'B' side motor (the wheel may be operated by either of two motors) had suffered noticeable tooth damage. The mating gear and 'A' side motor pinion did not show signs of abnormal wear, however. Failure analysis at GSFC has indicated that the damage was not likely caused by wear, but rather occurred as a result of some accidental mistreatment, possibly during testing before installation. This motor was removed from the FGWA and which binds with its mating gear at cold temperatures when the wheel is positioned on the H13 (blue) side.

(3) Since the repeatability spread in X is similar to that in Y, the cause of the problem cannot be simply inaccurate detent roller settling, since this would, to first order, cause dispersion in Y only. Rather, the major cause is likely to be 'wobble' of the wheel on its bearings, and/or a distortion of the wheel itself (as a result of misdirected forces from the detent roller acting on its outer edge?). If the wheel remains undistorted, a correlation is expected between the image displacements seen on the red and blue sides for any particular orientation of the wheel. A brief attempt to check this hypothesis was made during TV III: shifts of 20μ (X) and -15μ (Y) were seen on the blue side when 30μ (X) and -20μ (Y) were recorded on the red side. Although the magnitudes are not identical, the sense of the offsets does indicate a simple tilt of the (stiff) wheel. This is also confirmed by the similarity of H40 and camera mirror dispersions on opposite sides; see Figure 1, for example. Some distortion may be contributing, however. The FGW is quite thin and is perforated by 10 large holes (for the blocking filters). We recall that alignment of the gratings was severely complicated by the flexure of the wheel as each grating was adjusted and tightened down.

(4) Some (temporary) improvement did result when the flight motor was removed, followed by degradation when the spare motor and then the refurbished motor were installed. Thus, repeatability seems to be correlated with the degree of resistance to wheel rotation imposed by the motors, which might affect the ability of the detent roller to settle properly into the grooves. However, non-repeatability of rotational positioning only does not explain dispersion in the X positioning.

(5) Little, if any, real improvement was made on the overall repeatability as a result of refurbishing the damaged motor. We are unfortunately limited to comparing only H40 grating and camera mirror results that were not obtained in exactly the same manner,

since the standard procedure used for the results shown in Figure 1 was not run at ambient before the motor was removed. Nevertheless we can compare as follows:

		Before Refurb		After Refurb	
Side	Element	Meas #	Spread (microns)	Meas #	Spread (microns)
B	H40	8	20.5	30	25
B	CAM	10	18	29	11
A	CAM	12	19	28	16

We have an additional datum to consider: a bench test of the FGW assembly positioning repeatability was made before the mechanism was modified to include the counter rotating wheel and higher-torque motors. This test measured X, Y, and Z axis displacements of targets located on dummy optics mounted in the wheel. The displacement spread in Z (along the wheel axis) was $\pm 2\mu$. If this is due to wobble of the (stiff) wheel on its bearings, an image motion at the Digicon of order 40μ (spread) is implied. This is remarkably in agreement with the recent measurements. Thus, the FGW has probably been operating with unsatisfactory repeatability since it was first assembled.

IV. SUMMARY AND RECOMMENDATIONS

The data analyzed above indicate that the major part of the non-repeatability of the FGW is probably due to imperfect wheel bearings with some contribution from flexure and inaccurate detenting. Since the data do not indicate a trend of degradation with use and early bench test measurements appear to agree with the positioning dispersion currently seen, we may conclude that the problem is inherent in the FGWA design. We can recommend no particular program (short of redesign) to alleviate the problem, with the following exceptions:

1. An attempt should be made to discover and remedy the source of the gross deterioration of the repeatability of the H57, H13 and H40 gratings when operating at cold temperatures. As mentioned above, the sinusoidal behavior of the positioning spreads may be indicative of eccentricity of either of the main wheel gears. This problem is

particularly problematic from the standpoint of polarimetry with H13, where the separation of polarized images becomes very small, requiring accurate registration of the spectra onto the Digicon diode array. Plans to measure the FGW repeatability should be included in T/V tests at Lockheed.

2. Investigation should be made of the FGW bearings to determine if these are of the highest quality, or if significant improvement might be made by upgrading the existing bearings.

Can the FGW be constructed with the required repeatability in principle? Assume a conservative (even marginal) goal of repeatability to one half of the projected size of the A4 aperture: $\pm 3.5\mu$, which requires that the FGW suffer less than $\pm .35\mu$ displacement at the radius of the optical elements, assuming that it is perfectly stiff. Each of the bearings that constrain the wheel hub must, in turn, keep their inner and outer races concentric to within $\pm 0.1\mu$. This tolerance is certainly difficult to achieve!

Thermal cycling of the FOS produced image shifts, in the dispersion direction, with magnitudes similar to those due to the FGW non-repeatability, while no significant thermally-induced shift was measured in the Y direction. The X shifts can be handled by frequent wavelength calibration. However, for the target acquisition case, the existing calibration lamps are too bright. Even if the FGW short-term repeatability was near perfect, some means of determining where the aperture images fall on the Digicons at any particular time and temperature would be required for rapid target acquisition.

Location of the aperture images can be accomplished with mapping algorithms currently included in the FOS software, but a source of diffuse illumination of the apertures is required. The internal wavelength calibration lamps are not particularly well suited for this application because of their integrated brightness of $\sim 2 \times 10^{14}$ ph $cm^{-2}s^{-1}$ at the FOS aperture plane. This flux is attenuated, for the cross-strapped lamp for either channel, by about a factor of 15, and the FOS camera mode optics throughput is ~70% so, recalling that the optics produce a magnification of 1/2, we have an energy flux of $\sim 13\mu W/cm^2$ incident on the photocathode. Note that, ignoring imaging aberrations, the energy per cm^{-2} is independent of the size of the entrance aperture used. The damage threshold for these photocathodes is nominally $1\mu W/cm^2$. Because of the 'gassy' nature of the current flight (F-3) red Digicon and the resultant higher susceptibility of the photocathode to ion damage, the $1\mu W/cm^2$ should be lowered significantly (E.A. Beaver, private communication).

External sources of aperture illumination are the earth's limb and other diffuse astronomical objects. Use of these would, in general, be difficult and inefficient from an operational point of view.

For greatest operational efficiency, the addition of LEDs in the calibration lamp optics train would be most desirable. The LEDs could be adjusted to yield optimum illumination levels. Power for the LEDs is available but control relays would have to be added. The LEDs could be mounted in a variety of ways in the calibration lamp optics train.

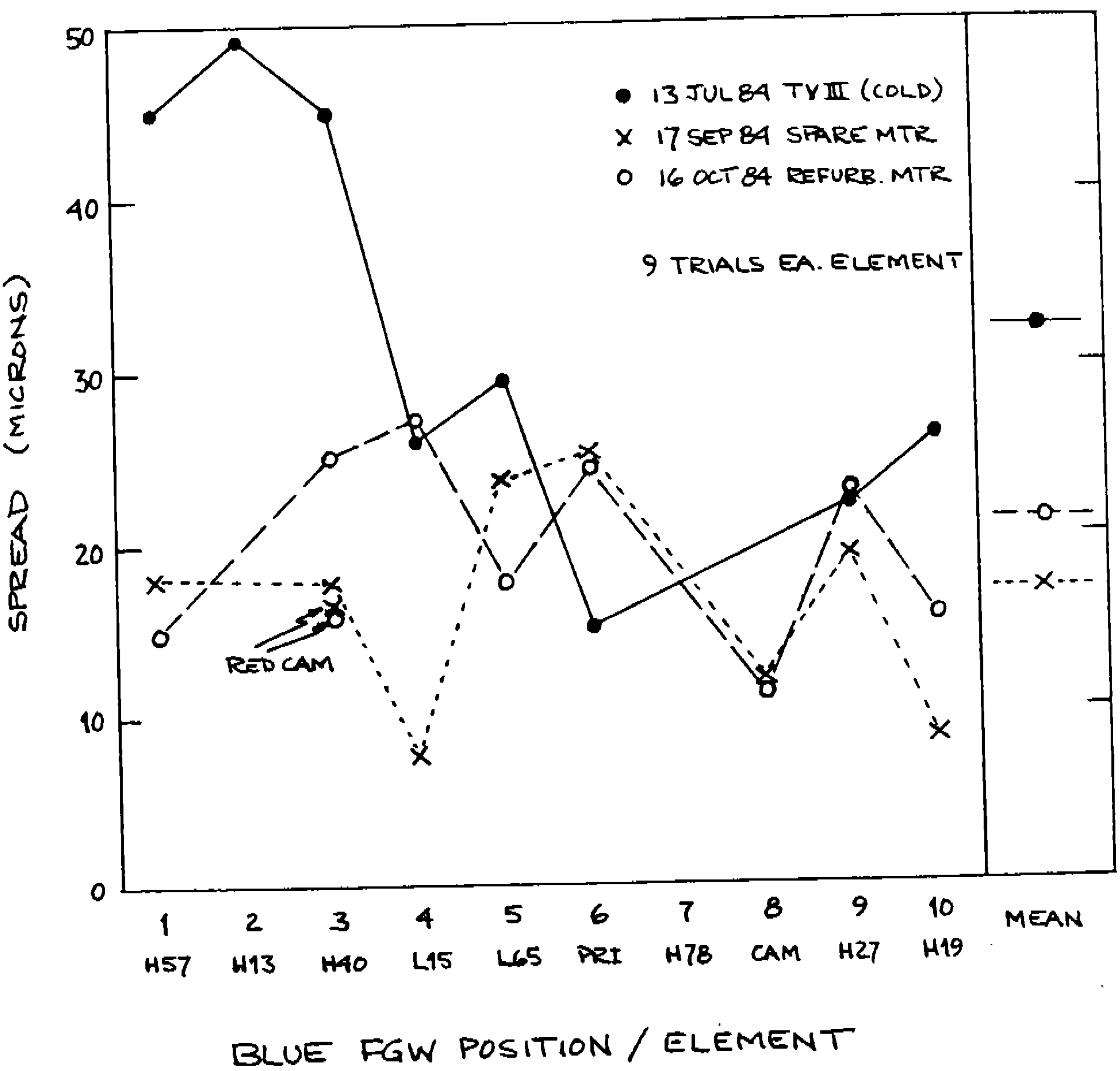
Any of these alternatives to alleviating the FGW problems will require additions to the NSSC-1 software to incorporate the measured aperture position in its routine for conversion from Digicon to spacecraft coordinates.

If none of these improvements are made, a peak-up of the signal (from a point source) through the smallest aperture will be required in order to determine the location of the aperture set in detector coordinates each time the camera mirror is moved into position for target acquisition. This procedure would be very time consuming and operationally unsatisfactory.

Table 1. FGW Repeatability Measurements

Meas #	Date	Test/Config'n	Temp	Side	Dir'n	Element	X			Y	
							N	Sprd	σ	Sprd	σ
1	21 Mar 83	Amb Cal I	Amb	A	Fwd	Cam	10	12μ	4.0μ	12.4μ	6.5μ
2	21 Mar 83	Amb Cal I	Amb	A	Fwd	Cam	10	15	5.1	-	-
3	13 Jul 84	TV III	Cold Op	B	Fwd	H40*	9	45	14.2	-	-
4	13-15 Jul 84	TV III Long-Term	Cold Op	B	Both	H40	15	80	27.9	36	15.2
5	18-22 Jul 84	TV III Long-Term	Hot Op	B	Both	H40	16	81	24.9	53	19.6
6	4 Aug 84	Post TV III	Amb	B	Both	H40	11	35	7.3	14.4	4.5
7	15 Aug 84	Post TV III	Amb	B	Both	H40	12	32.5	8.2	-	-
8	16 Aug 84	Post TV III	Amb	B	Fwd	H40	10	20.5	5.8	-	-
9	16 Aug 84	Post TV III	Amb	B	Bkwd	H40	10	21.0	5.8	-	-
10	16 Aug 84	Post TV III	Amb	B	Fwd	Cam	10	18.0	5.7	-	-
11	16 Aug 84	Post TV III	Amb	B	Bkwd	Cam	5	6.5	2.6	-	-
12	16 Aug 84	Post TV III	Amb	A	Fwd	Cam	11	19.0	5.7	-	-
13	16 Aug 84	Post TV III	Amb	A	Bkwd	Cam	5	10.5	4.1	-	-
14	22 Aug 84	Amb Cal IV	Amb	A	Fwd	Cam	10	13.5	4.7	15.8	4.8
15	29 Aug 84	Motor Removed	Amb	A	Fwd	Cam	10	12.0	3.9	-	-
16	29 Aug 84	Motor Removed	Amb	A	Bkwd	Cam	10	15.5	5.0	-	-
17	29 Aug 84	Motor Removed	Amb	A	Fwd	H40	10	7.5	2.5	-	-
18	29 Aug 84	Mtr Rem, Bal Wt	Amb	A	Fwd	H40	10	7.5	2.9	-	-
19	29 Aug 84	Mtr Rem, Bal Wt	Amb	A	Bkwd	H40	10	9.0	3.3	-	-
20	29 Aug 84	Mtr Rem, Bal Wt	Amb	A	Fwd	Cam	10	11.0	4.0	-	-
21	31 Aug 84	Sp Mtr Inst, Bal Wt	Amb	A	Fwd	Cam	10	13.5	3.7	-	-
22	31 Aug 84	Sp Mtr Inst, Bal Wt	Amb	A	Fwd	H40	10	10.0	3.1	-	-
23	1 Sep 84	Sp Mtr Inst	Amb	A	Fwd	Cam	10	11.0	3.4	-	-
24	1 Sep 84	Sp Mtr Inst	Amb	A	Fwd	H40	10	14.5	4.3	-	-
25	17 Sep 84	Sp Mtr Inst	Amb	A	Fwd	Cam	10	16.5	6.6	12	3.4
26	17 Sep 84	Sp Mtr Inst	Amb	B	Fwd	Cam	10	11.5	3.9	8	2.9
27	17 Sep 84	Sp Mtr Inst	Amb	B	Fwd	H40*	9	17.5	5.4	-	-
28	16 Oct 84	Refurb Mtr Inst	Amb	A	Fwd	Cam	10	16	6.6	16	5.2
29	16 Oct 84	Refurb Mtr Inst	Amb	B	Fwd	Cam	10	11	4.1	30.4	8.6
30	16 Oct 84	Refurb Mtr Inst	Amb	B	Fwd	H40*	9	25	9.1	-	-

*Measurements also made of other elements, see Fig. 1.



13 JUL 84 TY III (COLD)
17 SEP 84 SPARE MTR
16 OCT 84 REFURB. MTR
9 TRIALS EA. ELEMENT
RED CAM
SPREAD (MICRONS)
50
40
30
20
10
0
1 H57
2 H13
3 H40
4 L15
5 L65
6 PRI
7 H78
8 CAM
9 H27
10 H19
MEAN
BLUE FGW POSITION / ELEMENT

FIGURE 1.