FOS Filter-Grating Wheel Repeatability: Dependence on Motor Selection

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Abstract

The repeatability of the FOS Filter-Grating Wheel (FGW) was measured in a series of special tests at LMSC on 11-12 May 1989, aimed at evaluating the effects of motor selection on the FGW performance. Measurements were made of the repeatability in both X and Y at the camera mirror positions on both red and blue sides, with the standard motor selections, and in X for 7 dispersers on each side, with each motor. The FGW repeatability was found to be significantly degraded, by about a factor of 2, when the A motor is used, as compared to measurements made with the B motor selected, on both sides of the spectrograph. With the B motor, the FGW repeatability remains somewhat unsatisfactory, but no evidence for performance degradation with time or usage is present. The B motor should always be selected, regardless of which detector is in use, contrary to current procedure. The cause of the reduced repeatability with the A motor, and other effects seen prominently in the data, remain unexplained.

I. Introduction

During analysis of data obtained in August, 1988, after the final rework was performed on the FOS, shifts in the wavelength scales of line source spectra were noticed that were explainable only if the FGW repeatability was considerably worse than expected. Additional analysis showed that data obtained (in August) on the blue side of the FOS were consistent with the previous FGW repeatability tests, but the red side repeatability was degraded by about a factor of two. Nearly all previous tests of the repeatability were made on the blue side; it was assumed that similar performance would be achieved on the red side, since there is no reason to expect otherwise. The single identified difference in the FGW operation on each side of the FOS is the selection of the drive motor: when the blue detector is used, the 'B' motor is selected, and the 'A' motor is used with the red detector. However, both motors remain engaged to the drive gearing, and the motor power is removed after the nominal position is reached, after which the mechanical detent system performs the final wheel positioning. In all cases, the wheel is driven in the forward direction only, and two additional (forward) motor steps are applied after the original positioning: this procedure was found to improve the repeatability by about a factor of two in 1985. To investigate the hypothesis that the motor selection did indeed affect the FGW performance, and to ascertain that the repeatability (on the blue side) had not degraded, a series of special tests were undertaken at LMSC on 11-12 May, 1989.

Two basic test procedures were used: YFGR$, which measures the repeatability of the camera mirror positioning in both dispersion (X) and cross-dispersion (Y) directions, was run on both sides of the FOS, and YFGWR$$, which measures the repeatability in the dispersion direction only, for 7 dispersers, was run on each side, once with each motor. The former measurements are particularly important to gauge when special target acquisition (TA) techniques must be invoked to circumvent the non-repeatability problem, *e.g.*, use of the aperture illuminating LEDs to determine the aperture image position, or 'peak-up' TA. The YFGWR$$ measurements indicate the ultimate accuracy of the standard FOS wavelength calibration; for higher accuracy, contemporaneous comparison spectra must be obtained with the onboard calibration lamps.

II. Camera Mirror Repeatability

The test of FGW repeatability at the camera mirror, run on the red side on 11 May and on the blue side on 12 May, 1989, is identical to ~~the~~ those performed during thermal vacuum testing in 1986, and in ambient in March 1988. The 'A' motor was used on the red side, and the 'B' motor on the blue side. A description of the measurement and analysis technique are included in CAL/FOS–033 (Hartig, 1986), along with the results of the TV tests; the 1988 results are detailed in CAL/FOS–049 (Hartig, 1988). Briefly, the camera mirror image of the A4-lower aperture, illuminated by the TA LEDs, was mapped with fine Y-stepping after 9 separate FGW positionings, originating from each of the disperser positions, such that one complete rotation of the wheel was effected between consecutive measurements. The FGW was always rotated in the forward direction, and two motor steps were applied after the normal positioning. The resulting images were cross-correlated to determine relative offsets in both the X (dispersion) and Y directions.

Results of the test are shown in Figure 1, in which the relative X and Y image locations are plotted, with numerical symbols indicating the order of the measurements. There is strong evidence for a bimodal distribution in the red side data, similar to that intimated by the TV test results, as well as a possible X-Y correlation. It is also intriguing to note that, especially on the red side, the even numbered positionings are generally grouped away from the odd numbered ones, indicating that the repeatability would be improved if the FGW is rotated through multiples of two full turns between positionings. Although the separation between the image locations in X between odd and even positionings is not as clearly separated on the blue side as it is on the red, there is an obvious propensity for the odd numbered points to lie on the right, while the even ones prefer the left half of the plot.

Table 1 compares the current results with those previously obtained. The spreads and standard deviations are similar indicating that no significant change to the repeatability performance has occurred. The spread over 9 positionings is approximately the same size as the smallest FOS entrance aperture (A4, 0.1-PAIR). Accurate positioning of targets into the smaller FOS apertures will clearly require use of the TA LEDs to determine the aperture image location.

III. Repeatability at Dispersers

The FGW repeatability in the dispersion direction was measured, using a SATS version of the STOL procedure YCGWR$$. The FGW is positioned 6 separate times to each of 7 dispersers (gratings G130H, G780H, and the camera mirror were excluded in the blue side test, and G130H, PRISM, and the camera were excluded in the red side measurements). The order of observations was chosen such that all combinations of initial and final FGW position (among the 7 selected dispersers) were included. The direction of rotation was always forward, and two motor steps were applied after normal positioning. Spectra of the internal, direct Pt-Cr/Ne hollow cathode calibration lamp were obtained through the A4-lower aperture after each positioning. This test is very similar to the FGW repeatability tests run in ambient on the blue side in 1985 (the order of the positionings is somewhat different), and to the ambient test run in March 1988, except that an external Pt-Cr/Ne lamp was used for the latter.

Results of the March, 1985 tests are the subject of CAL/FOS–017 (Hartig, 1985); additional tests run on December 9, 1985, were mentioned in CAL/FOS–033, and the March 1988 tests were reported in CAL/FOS–049.

The data were reduced by selecting a region of the spectrum of each disperser that contains a number of strong, sharp spectral features, and cross-correlating the spectra in these regions for each of the 6 positionings to determine the offset in X. The range in the offsets and their standard deviation was then computed, and the mean of these quantities, taken over the 7 disperser locations, was calculated.

Table 2 presents the results of the 1985 and 1988 tests, along with the latest measurements. On the blue side, when the 'B' motor was selected, both the mean spread and standard deviation are very similar to the values measured in the previous forward direction tests, in the same configuration. However, when the 'A' motor was used, the repeatability was significantly reduced. Similarly, the red side data show a marked reduction in repeatability when the 'A', rather than 'B', motor is selected. Even with the 'B' motor, the red side performance is somewhat inferior to that realized on the blue side.

The data are presented in less refined form in Tables 3–6, which show the spread and standard deviation at each of the selected dispersers and the relative image locations (in X) at each positioning, in the lower portion of each table. The positions enclosed in parentheses are those corresponding to measurements made after the FGW was rotated through an odd number of revolutions since the first positioning at each disperser, while the other measurements were made after an even number of revolutions. Typically, about 18 or 19 revolutions were made between the first and last measurements at any disperser. The odd-even effect seen in the camera mirror measurements appears to operate at most positions around the wheel. The mean absolute difference in the odd and even locations is greater than, or similar to, the spread in the odd or even distributions, for all four tests.

V. Analysis

The analysis of CAL/FOS-012 (Hartig, et al. 1984) concluded that the observed FGW non-repeatability is probably a manifestation of imperfections in the bearings on which the wheel rotates, and that sufficient bearing play was observed during bench testing of the FGW assembly, prior to its installation in the FOS, to account for the observed dispersion in image location at the detectors. Inaccurate detenting alone cannot explain the non-repeatability seen in the X location of the images, since detenting error should result in significant image decenter only in the Y direction, yet similar dispersion is seen in the X and Y directions. The efficacy of the application of the additional motor steps in improving the repeatability could then be attributed to a settling of the bearings into a more relaxed (and repeatable) configuration as result of the extra jostling about the destination position.

The bearing relaxation scenario does not directly account for several additional observed properties of the FGW, however. These are: 1. The wheel is significantly less repeatable when operated in the reverse direction only, than in the forward direction (with the application of two forward steps following gross positioning), with the 'B' motor. No similar 'A' motor test have been made; 2. The repeatability was noticeably improved when the 'B' motor was removed and the wheel was driven with only the 'A' motor (Strein, 1984); 3. With both motors installed, use of the 'A' motor results in significantly less repeatability than the 'B' motor, when the wheel is operated in the forward direction only (this paper); 4. There is distinct evidence for a bimodal distribution in the image X location at the camera mirror position, on both sides of the FOS, such that alternate (odd or even) revolutions of the FGW repeat with greater accuracy than the total sample (CAL/FOS-33, -49, this paper: see Figure 1). There is no evidence for such a bimodal distribution in the Y location, however, even in the cases where the Y spread is relatively large (B side, 'B' motor). This same effect is also seen (in the X direction) at most other positions around the FGW: positionings separated by an even (or odd) number of wheel revolutions tend to be clustered more tightly than the total sample, and the mean location difference between the odd and even samples is comparable to, or greater than, the spread in either (odd or even) distribution.

A possible explanation for the odd-even effect lies in the fact that the ratio of the main gear on the FGW to the counter-rotating wheel pinion is exactly 10.5. If the pinion is eccentric, such that binding with the main gear occurs (or other cyclic binding of the counter-rotating wheel is present), the effectiveness of the FGW detenting and/or bearing relaxation may be affected differently on alternate revolutions of the FGW. If this hypothesis is correct, elements on opposite sides of the FGW should be most strongly affected, while those at 90 degrees to the strongly affected positions should be more repeatable. The data are ambiguous, however: while the L65 and H19 gratings, which are diametrically opposed, have the largest disparity in odd-even image position, when the 'A' motor is used (Tables 3,6), these have moderate odd-even offsets when the 'B' motor is selected. In those tests run with the 'A' motor, the prism, H57, H27, and H40 have the smallest odd-even offsets; only the latter lies at about 90 degrees to H19 and L65, the other three are adjacent to one or the other.

An explanation for the motor selection dependence is equally elusory. The ratio of motor pinion to FGW revolution is exactly 90:1, so the same motor pinion teeth are is contact with the idler teeth at each FGW position (there are 10), and the motor is nominally in the same state (at or between magnetic detents) at each FGW position, regardless of number of revolutions of the wheel or element selected. Because the idler pinion to FGW main gear ratio is 43:180, different idler teeth are in contact with the motor pinion and the main gear for all positionings. The motors are mounted such that they cannot be adjusted to lie at relaxed (magnetically detented) orientations when the mechanical detenting is relaxed. If the 'B' motor is in 'phase' with the FGW detents, while the 'A' motor is not, the motor dependence of the repeatability may have its roots in this difference. However, in 1984, while the 'B' motor was removed for analysis of damage to its pinion (in a region that did not contact the idler, such that FGW performance was unaffected), tests run with the 'A' motor alone showed significantly improved repeatability, compared to results obtained with both motors installed (before and after the 'B' motor removal).

The main FGW bearings, which almost certainly play an important role in the observed non-repeatability, should be studied to see if their properties can supply reasonable explanations for the odd-even, direction of rotation, and/or motor selection effects.

VI. Conclusions

The repeatability properties of the FGW, as measured at the disperser positions on the blue side of the FOS, have not changed significantly since the previous ambient and thermal/vacuum tests were made. The repeatability at the camera mirror, as measured on either side of the FOS, also remains unchanged. However, there is unambiguous evidence that use of the 'A' FGW drive motor results in significantly degraded repeatability, on either side of the FOS, when the wheel is operated in the forward direction.

The repeatability in the dispersion direction also appears to be degraded, by approximately a factor of two, due to a propensity for the wheel to settle in different orientations for even and odd revolutions. This effect operates at most dispersers and at the camera mirror, and is apparent in data obtained with both motors, on both sides of the FOS. No clear explanation for the odd/even disparity is proposed. It would be very difficult to implement a solution whereby the wheel is always rotated by increments of two revolutions from the previous setting at each FGW element, and this would entail significant operational inefficiency.

An additional test which may illuminate the cause of the motor selection dependence of FGW repeatability is proposed: Use the standard YCGWR1A and YCGWR2B tests (i.e., operate the FGW with the 'A' motor from both sides of the FOS), adapted to run in the *reverse* direction, with the extra motor steps also applied in the *reverse* direction. This should be symmetric to operation in the forward direction with the 'B' motor, and could result in improved repeatability for operation with the 'A' motor.

Even with the 'B' motor always selected, the wheel operated in the forward direction only, and the extra motor steps applied, the FGW non-repeatability will require use of TA LED-assisted TA when the smaller FOS apertures are selected, and will be the dominant source of inaccuracy in the wavelength calibration of science spectra obtained without contemporaneous cal lamp spectra.

Table 1
FOS FGW Repeatability at Camera Mirror

Date	Environ.	Side	X Spread	X Std Dev	Y Spread	Y Std Dev
18 May 86	TV Hot	Blue	8.5 μm	3.2 μm	14.4 μm	5.0 μm
23 May 86	TV Hot	Red	11.6	3.4	17.2	5.3
1 Jun 86	TV Cold	Red	11.8	4.4	16.4	5.9
9 Jun 86	TV Cold	Blue	6.7	2.5	10.6	3.8
12 Mar 88	Ambient	Red	17.4	6.5	6.9	3.1
14 Mar 88	Ambient	Blue	8.3	2.1	19.2	6.3
11 May 89	Ambient	Red	17.7	7.4	5.4	2.0
12 May 89	Ambient	Blue	8.1	2.6	12.9	4.3

Table 2
FOS FGW Repeatability at Dispersers

Date	Side	Motor	Direction	X Spread	X Std Dev
6 Mar 85	Blue	B	Forward	10.2 μm	3.2 μm
9 Dec 85	Blue	B	Forward	8.1	3.3
9 Dec 85	Blue	B	Reverse	21.9	9.1
14 Mar 88	Blue	B	Forward	8.2	3.0
11 May 89	Red	A	Forward	31.4	10.5
11 May 89	Red	B	Forward	13.3	5.1
12 May 89	Blue	B	Forward	10.6	4.1
12 May 89	Blue	A	Forward	18.9	7.2

TABLE 3. RED SIDE, 'A' MOTOR, 11 MAY 1989, YEX0007-0048

Disperser:	H27	H19	H57	H40	L15	L65	PRI	H78	Mean
Num positionings:	6	6	6	6	6	6	0	6	
Spread (microns):	12.3	38.1	18.5	25.7	31.7	52.5	0.0	41.0	31.4
Std Dev (microns):	4.9	13.6	7.5	10.4	11.8	20.5	0.0	13.6	11.8
ODD positionings:	4	1	3	3	2	2	0	3	
Spread (microns):	5.4	0.0	14.2	14.7	8.6	10.4	0.0	13.8	9.3
EVEN positionings:	2	5	3	3	4	4	0	3	
Spread (microns):	2.1	7.0	18.5	3.1	11.1	34.3	0.0	19.1	13.0
ODD-EVEN (microns):	-8.8	-32.7	1.2	-16.8	-21.1	-31.6	0.0	-19.4	18.8

Relative image X location (microns):

DISP	POS 1	POS 2	POS 3	POS 4	POS 5	POS 6	SPREAD	STD DEV
H27	-0.01	(-6.94)	(-12.35)	-2.16	(-11.01)	(-9.09)	12.35	4.93
H19	0.04	0.85	0.04	(-31.13)	7.02	-0.02	38.15	13.63
H57	0.00	(2.37)	(9.50)	6.50	18.49	(16.61)	18.49	7.48
H40	0.01	(-23.80)	(-16.97)	-1.25	1.90	(-9.10)	25.70	10.38
L15	-0.23	0.77	(-15.81)	(-24.37)	-3.77	7.29	31.66	11.79
L65	0.00	(-18.21)	12.32	27.83	34.32	(-7.81)	52.53	20.52
H78	0.00	0.29	(-21.89)	(-8.05)	(-8.88)	19.08	40.97	13.59

TABLE 4. RED SIDE, 'B' MOTOR, 11 MAY 1989, YEX0058-0099

Disperser:	H27	H19	H57	H40	L15	L65	PRI	H78	Mean
Num positionings:	6	6	6	6	6	6	0	6	
Spread (microns):	22.8	10.0	5.1	14.0	11.5	11.2	0.0	18.8	13.3
Std Dev (microns):	8.3	4.0	1.8	5.1	4.8	4.6	0.0	8.4	5.3
ODD positionings:	4	1	3	3	2	2	0	3	
Spread (microns):	8.4	0.0	3.9	8.9	0.9	0.6	0.0	2.7	4.4
EVEN positionings:	2	5	3	3	4	4	0	3	
Spread (microns):	4.1	7.4	2.8	3.2	9.1	4.6	0.0	6.9	5.3
ODD-EVEN (microns):	14.8	6.5	-1.5	7.5	7.1	8.3	0.0	14.7	8.6

Relative image X location (microns):

DISP	POS 1	POS 2	POS 3	POS 4	POS 5	POS 6	SPREAD	STD DEV
H27	-0.01	(10.36)	(11.04)	-4.08	(10.77)	(18.75)	22.83	8.34
H19	-0.26	4.10	-0.25	(9.70)	5.35	7.12	9.96	3.99
H57	0.00	(-0.25)	(-4.12)	0.95	-1.81	(-1.00)	5.06	1.77
H40	0.00	(3.65)	(6.62)	-1.40	1.81	(12.56)	13.96	5.10
L15	-0.03	1.55	(11.43)	(10.56)	4.90	9.04	11.45	4.83
L65	0.00	(8.92)	2.94	-1.71	2.59	(9.53)	11.23	4.60
H78	0.00	0.85	(16.94)	(16.10)	(18.84)	6.86	18.84	8.45

TABLE 5. BLUE SIDE, 'B' MOTOR, 12 MAY 1989, YEY0007-0048

Disperser:	H27	H19	H57	H40	L15	L65	PRI	H78	Mean
Num positionings:	6	6	6	6	6	6	6	0	
Spread (microns):	8.7	7.2	7.7	14.0	12.1	13.5	7.3	0.0	10.1
Std Dev (microns):	3.2	2.5	3.1	5.7	4.2	5.2	3.0	0.0	3.8
ODD positionings:	4	1	3	3	2	2	3	0	
Spread (microns):	3.6	0.0	0.7	6.1	2.6	5.4	6.7	0.0	3.5
EVEN positionings:	2	5	3	3	4	4	3	0	
Spread (microns):	8.7	4.4	3.7	10.5	8.5	4.2	5.6	0.0	5.5
ODD-EVEN (microns):	-2.1	-4.5	-5.1	7.3	5.4	9.1	-1.6	0.0	5.0

Relative image X location (microns):

DISP	POS 1	POS 2	POS 3	POS 4	POS 5	POS 6	SPREAD	STD DEV
H27	0.01	(-5.56)	(-8.49)	-8.71	(-7.04)	(-4.90)	8.72	3.22
H19	-0.01	0.58	4.09	(-3.13)	2.29	-0.28	7.22	2.45
H57	0.00	(-3.33)	(-4.04)	3.68	0.49	(-3.74)	7.72	3.07
H40	0.00	(7.93)	(11.85)	1.35	10.47	(14.00)	14.00	5.73
L15	3.32	11.24	(12.83)	(15.42)	8.49	11.82	12.10	4.18
L65	0.02	(7.89)	3.98	2.28	-0.25	(13.28)	13.54	5.23
PRI	0.22	-3.27	(-7.04)	(-0.35)	(-5.80)	-5.39	7.26	3.00

TABLE 6. BLUE SIDE, 'A' MOTOR, 12 MAY 1989, YEY0058-0099

Disperser:	H27	H19	H57	H40	L15	L65	PRI	H78	Mean
Num positionings:	6	6	6	6	6	6	6	0	
Spread (microns):	18.7	17.3	12.8	7.8	21.2	31.8	22.7	0.0	18.9
Std Dev (microns):	7.6	6.4	5.7	3.2	8.1	11.9	7.8	0.0	7.3
ODD positionings:	4	1	3	3	2	2	3	0	
Spread (microns):	13.4	0.0	1.0	3.0	4.6	19.5	2.0	0.0	5.9
EVEN positionings:	2	5	3	3	4	4	3	0	
Spread (microns):	6.1	7.5	6.4	1.6	19.5	17.4	22.7	0.0	11.0
ODD-EVEN (microns):	11.0	14.4	9.6	-5.5	-9.8	-14.2	-3.0	0.0	9.6

Relative image X location (microns):

DISP	POS 1	POS 2	POS 3	POS 4	POS 5	POS 6	SPREAD	STD DEV
H27	0.02	(14.32)	(17.83)	6.07	(5.29)	(18.73)	18.71	7.65
H19	-0.07	-2.50	-3.78	(13.51)	-1.62	3.75	17.29	6.41
H57	0.00	(11.57)	(10.61)	-1.18	5.21	(10.61)	12.75	5.69
H40	0.00	(-5.32)	(-7.60)	0.25	-1.39	(-4.60)	7.84	3.20
L15	0.33	8.18	(-12.99)	(-8.40)	-0.68	-11.30	21.17	8.14
L65	0.02	(-31.81)	-0.31	-17.35	-13.97	(-12.31)	31.83	11.86
PRI	0.10	-22.60	(-16.02)	(-17.89)	(-15.93)	-18.29	22.70	7.83

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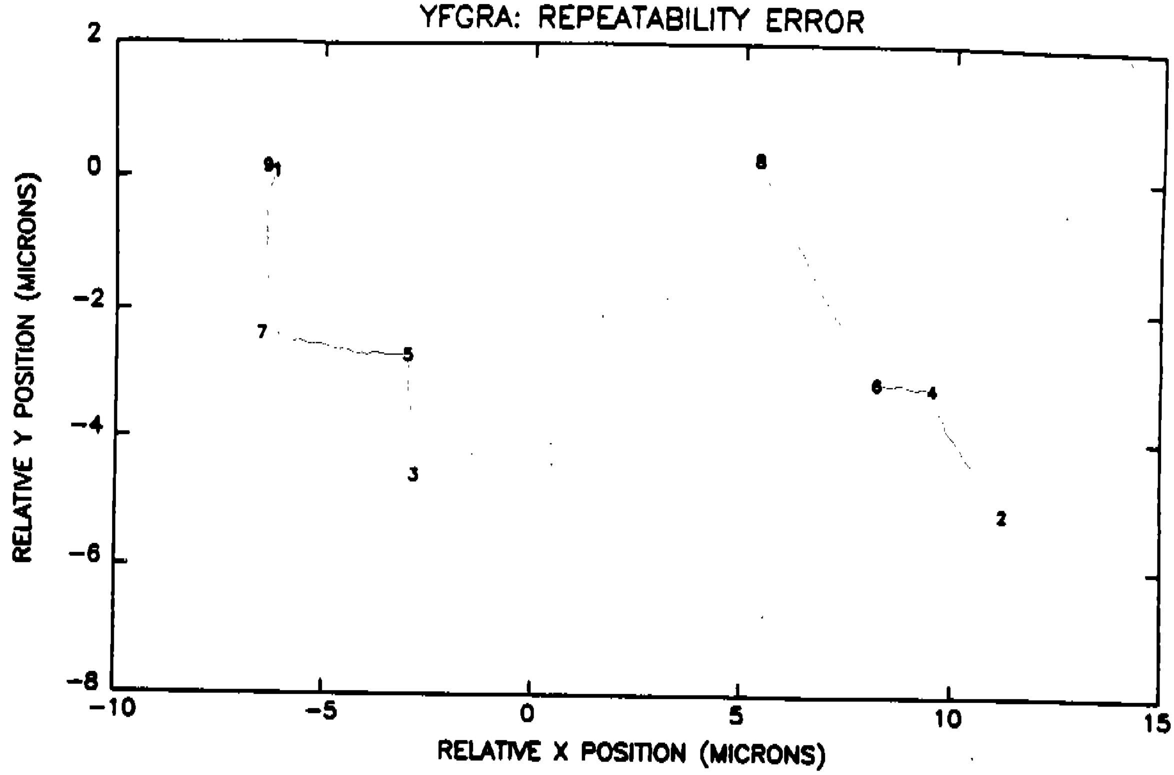

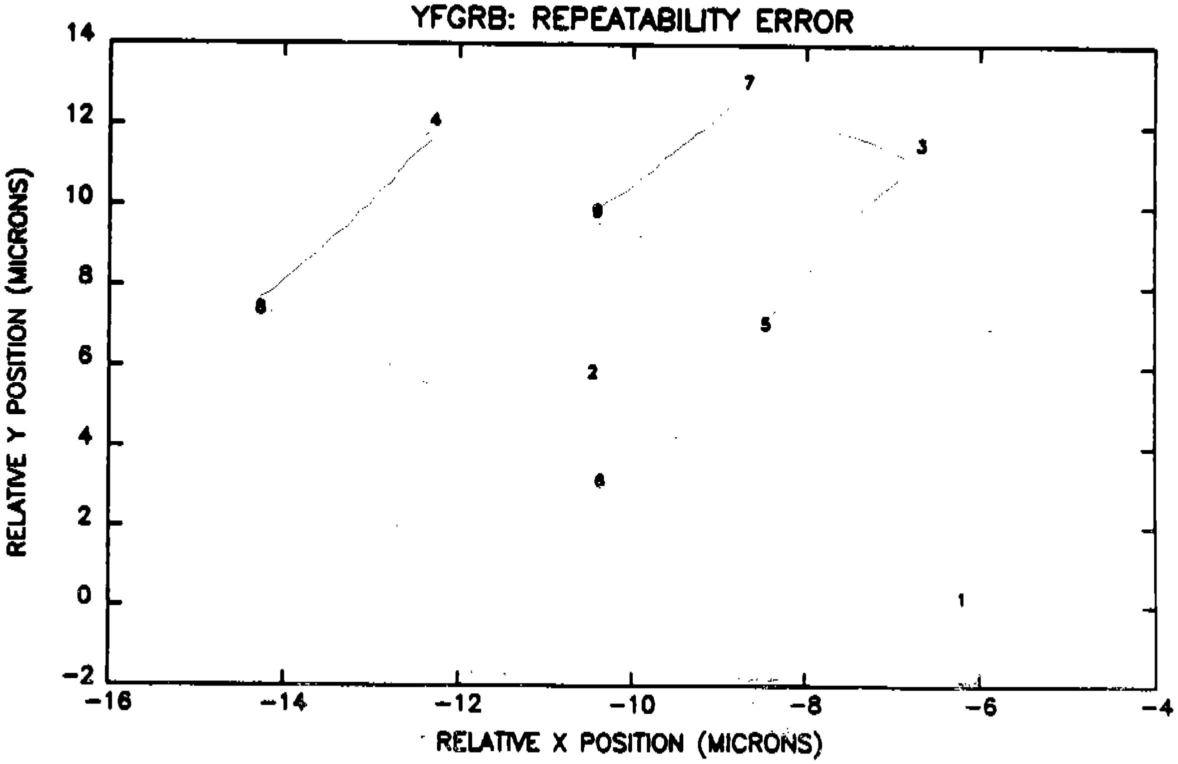

Figure 1. Relative image positions (μm) from the red side (top) and blue side (bottom) measurements of the FGW repeatability at the camera mirror. Strong evidence for a bimodal distribution is apparent in the red side data, confirming a similar result from the measurements made during the thermal vacuum test [illegible] 1986, and later data obtained in March 1988. Even and odd revolutions of the wheel produce images whose X positions are much more repeatable than for the total sample. The blue side data show a similar, though less pronounced, pattern. The dispersions in both X and Y compare well with previous tests.