Instrument Science Report WFC3 2005-03

WFC3 IR Channel Corrector Alignment

G. F. Hartig
31 January 2005

ABSTRACT
A direct assessment of the alignment sensitivities of the IR channel corrector, using the flight hardware, was performed in Oct 2004 during the first thermal-vacuum test of the integrated WFC3 instrument. The significant level of cross-coupling between focus and coma-correcting cylinder offsets has been measured and encoded into IDL tools that enable rapid convergence to an optimal image quality configuration of the IR corrector.

Introduction

The WFC3 IR channel incorporates a corrector mechanism to permit adjustments of focus and pupil alignment, to compensate for small internal misalignments as well as those associated with gravity release and installation into the HST OTA. This mechanism, on which the IRM2 mirror is mounted, is very similar to that used on previous HST science instruments, as well as on the WFC3 UVIS channel, but the opto-mechanical design of the IR channel is relatively compact. (Note that the layout diagram in the WFC3 Instrument Handbook is not to scale; see, e.g., Turner-Valle, 2000.) The large included angle (~24°) in the raypath at the IRM2 results in much greater cross-coupling between the focus adjustment and pupil shear at the refractive corrector plate (RCP). As the focus is adjusted, the pupil image "shears" at the RPC, predominantly in the detector X direction, inducing coma. Also, the substantial focal plane tilt (~24°) results in defocus with field position shift, such as that induced by pupil alignment with the corrector.

Furthermore, the mechanism used for pupil alignment is of the nested eccentric cylinder ("Wally Wobbler") design, for which the mapping of pupil image position with cylinder position is not straightforward. This design is intrinsically very stiff and can be used for large mirrors, hence its choice for the ACS WFC and WFC3 UVIS applications, but it incurs some operational complications. Ideally, the pupil image motion produced by rotation of the inner cylinder would be orthogonal to that produced by the outer cylinder, so that a given amount of pupil shear-induced coma can be mapped, without cross-coupling ambiguity, to corrective cylinder rotations. However, this can be true only for

IRM2 mirror pointings falling on a single angular radius from the mechanism center of rotation. The mechanism was optically aligned in the instrument such that its nominal position lies near to this radius (Sullivan, 2002b). The chief ray direction (pupil location) had earlier been mapped to cylinder rotation in a region around this nominal alignment, at the subsystem (mechanism) test level.

The interaction of focus adjustment and pupil shear and resulting use of the corrector cylinders away from the region of our experience base became readily apparent when the IR-2 detector was found to be ~ 0.6 mm beyond its nominal focus position. Many adjustment iterations were required to converge on a well-corrected image, contrary to earlier alignment exercises with the surrogate (bare MUX) IR detector, which was well-positioned in focus. To investigate these cross-coupling effects and provide empirical sensitivity coefficients to permit deterministic alignment adjustments in the future, a small test program was devised and added to the TV#1 procedure.

Measurements & Analysis

A set of IR channel images were obtained on 5 Oct 2004, near the end of the TV1 program, to empirically assess the corrector sensitivities. The CASTLE stimulus provided out of focus point source illumination near field center (point IR-01) at 1.06μ, through filter F105W, so that phase retrieval analysis could be used to measure the coma content and image positions. After successively setting the focus to its nominal, center of travel position, and to ±500 steps from nominal, the cylinders were iteratively adjusted to approximately remove coma. Images were then obtained at settings of ±20 steps from this position on both inner and outer cylinders, using a special CCL script, TIIRALCORTEST, to expedite data acquisition. The step-by-step procedure is attached as Appendix 1. Table 1 lists the measurement database entry numbers, focus setting relative to nominal, focus position sensor (LVDT) reading, and inner and outer cylinder resolver readings, along with relative cylinder step offsets.

Phase retrieval analysis was performed using IDL tool **wfc3fit** on each of the images, which are about 8 mm out of focus at the detector. Only focus, coma and astigmatism were fit, with other aberrations and gaussian pupil apodization fixed at values determined from more complete, through focus, data sets at the IR-01 field point. The image center position (px) and coma (μ, RMS) results are reported in the last four columns of Table 1. The large amount (>0.1 μ) of coma induced as a result of the focus offsets of ±500 steps (~0.48 mm at detector) as well as the large shift in image X-position, are seen in the results for entries 17372 and 17382.

Linear fitting of the coma induced as a function of image offset, yields:

$$\text{Xcoma } (\mu, \text{RMS}) = 0.00160 \cdot \Delta X \text{ (px)},$$
$$\text{Ycoma } (\mu, \text{RMS}) = 0.00183 \cdot \Delta Y \text{ (px)}.$$

The image offset induced by each step of cylinder rotation offsets (about the position of minimal coma) for each of the three studied focus positions is shown in Table 2.

Table 1. IR Corrector Sensitivity Measurements

entry	rel foc	Lvdt	inner	outer	innstep	outstep	x	y	xcoma	ycoma
17362	0	2243	56091	43311	0	0	650.2	643.5	0.0027	-0.0066
17363	0	2243	57229	43311	20	0	637.6	639.5	-0.0185	-0.0099
17364	0	2243	54898	43311	-20	0	662.4	648.5	0.0222	0.0062
17366	0	2243	57229	43311	20	0	637.5	639.5	-0.0186	-0.0093
17367	0	2243	54898	43311	-20	0	662.4	648.5	0.0222	0.0062
17368	0	2243	56083	43311	0	0	650.5	643.5	0.0027	-0.0019
17369	0	2243	56084	44520	0	20	653.4	654.5	0.0065	0.0157
17370	0	2243	56087	42099	0	-20	648.5	632.4	0.0008	-0.0243
17371	0	2243	56084	43312	0	0	650.2	643.4	0.0040	-0.0075
17372	-500	2074	56085	43312	0	0	661.4	642.5	0.0459	-0.1250
17373	-500	2074	58117	43312	35	0	638.4	637.4	0.0089	-0.0175
17374	-500	2074	58110	43797	35	8	639.2	641.5	0.0117	-0.0065
17375	-500	2074	58458	43796	41	8	634.8	641.2	0.0046	-0.0087
17376	-500	2074	59579	43796	61	8	621.2	640.2	-0.0177	-0.0109
17377	-500	2074	57294	43796	21	8	647.8	643.4	0.0256	-0.0097
17378	-500	2074	58427	43796	41	8	634.8	640.9	0.0022	-0.0091
17379	-500	2074	58428	45008	41	28	638.2	651.6	0.0059	0.0113
17380	-500	2074	58426	42586	41	-12	632.4	629.6	0.0030	-0.0302
17381	-500	2074	58426	43796	41	8	634.4	640.6	0.0039	-0.0077
17382	500	2411	58427	43796	41	8	613.1	640.9	-0.1017	-0.0079
17383	500	2411	53729	43796	-39	8	663.1	658.8	-0.0049	0.0206
17384	500	2411	53724	42587	-39	-12	660.9	647.5	-0.0049	0.0007
17385	500	2411	53147	42587	-49	-12	666.1	650.8	-0.0004	0.0078
17386	500	2411	53145	41979	-49	-22	665.6	645.5	0.0002	-0.0035
17387	500	2411	54234	41979	-29	-22	655.5	638.8	-0.0165	-0.0140
17388	500	2411	51937	41979	-69	-22	675.9	653.2	0.0160	0.0097
17389	500	2411	53149	41979	-49	-22	666.1	645.6	0.0011	-0.0045
17390	500	2411	53150	43191	-49	-2	667.5	656.5	0.0006	0.0192
17391	500	2411	53165	40763	-49	-42	665.9	634.6	0.0045	-0.0244
17392	500	2411	53164	41979	-49	-22	666.1	645.4	0.0021	-0.0053

Table 2. IR image offset per cylinder step at 3 focus settings

Focus:	nom	-500	+500	Cylinder
LVDT:	2243	2074	2411	
Δx (px)	-0.621	-0.665	-0.51	INNER
Δy (px)	-0.225	-0.08	-0.36	INNER
Δx (px)	0.123	0.145	0.04	OUTER
Δy (px)	0.552	0.55	0.548	OUTER

Using the above results, for a given focus (LVDT) setting in the measured range, the sensitivity matrix coefficients relating coma to cylinder offset can be interpolated. Parabolic fits are used for the inner cylinder sensitivities; linear fits suffice for the outer cylinder. The inverse sensitivities can then be computed by inverting the matrix to determine the cylinder offsets required to correct a measured amount of coma. This process has been encoded in the IDL procedure **wfc3_ir_corr**, which is called by **wfc3fit** when performing IR phase retrieval analysis. The cylinder offsets (steps) and resulting image position offset required to compensate 1 nm (RMS) of coma in each axis, at the nominal focus setting, is shown in Table 3. The cross-coupling between the cylinders is evident.

Table 3. IR corrector compensation per 1 nm (RMS) of coma at nominal focus

	INNER	OUTER	Δx (px)	Δy (px)
Xcoma	1.09	0.44	-0.63	0
Ycoma	-0.21	-1.08	0	-0.55

Conclusion

The significant cross-coupling between focus and coma-correcting cylinder offsets in the WFC3 IR channel has been studied for the range of focus offset that is expected in future alignment operations. The appropriate sensitivity coefficients have been determined and encoded into IDL tools to enable rapid convergence to an optimal image quality configuration of the IR corrector.

Acknowledgements

Special thanks to Dave Hickey for rapidly producing the CCL script used for efficient data collection and to the entire WFC3 TV team for accommodating this unscheduled investigation.

References

Turner-Valle, J. *“Primary Imaging Optic Axes Clocking Relative to CAD Model”*, Ball SER OPT-046, 21 Aug 2000.

Sullivan, J.F. “*IRM2 and Corrector Mechanism Integration and Alignment in the Optical Bench*”, Ball SER OAT-019, 25 May 2002.

Appendix 1.

TV1 IR Alignment Investigation Procedure

Part 1. Determine IR-2 alignment offsets.

1. Set WFC3 IR corrector to FOCUS=2244±2 (nominal ctr of travel), INNER=56400±40, OUTER=43066±40. This is best current estimate for coma minimization at nominal corrector focus.
2. Move CASTLE LD1060 fiber to IRN01, nominal focus, 6.5 mA.
3. Configure WFC3: CSM at IR, filter=F105W, GAIN=2.5
4. Obtain RAPID, NREADS=2, 512SQ image.
5. Move CASTLE to –35 mm focus, LD1060 current 20mA
6. Obtain RAPID, NREADS=2, 512SQ image.
7. Run **wfc3fit** to determine possible corrector adjustments. Optimal setting leaves (0.005,-0.003) in (X,Y) coma at IRN01, corresponding to ~ (+3,+3) step indicated correction.
8. Apply corrector adjustments, if required. Repeat steps 6-8, as required.
9. Run SMSs IRAL1S4B,5A,6A, which obtain EE focus data centered on current best focus position (~+2.5 mm at CASTLE fiber).

Part 2. Determine Corrector Sensitivities and Cross-coupling Effects at Nominal Focus

With correctors set at nominal focus (2244) and coma minimized, per Part 1:
Run CCL TIIRALCORTEST to obtain IRN01 images (RAPID/2/512SQ) at ±20 steps on both INNER and OUTER cylinders, with LD1060 at 20mA and –35mm focus.

Part 3. Determine Corrector Sensitivities and Cross-coupling Effects at -500 Steps Focus

Apply -500 steps focus (move –600, then +100 steps)
Obtain –35 mm image
Adjust cylinders to minimize coma, per Part 1 steps 2-8, above
Run CCL TIIRALCORTEST

Part 4. Determine Corrector Sensitivities and Cross-coupling Effects at +500 Steps Focus

Apply +1000 (to +500 from nominal) steps focus (watch focus motor temperature!)
Obtain –35 mm image
Adjust cylinders to minimize coma, per Part 1 steps 2-8, above
Run CCL TIIRALCORTEST

Part 5. Return IR Corrector to settings at start of this procedure, to ensure IR images in following tests are in focus:

Set IR corrector focus to LVDT=2409 (should already be very close)
Set IR corrector INNER cylinder to resolver=53154
Set IR corrector OUTER cylinder to resolver=42407

Note: The IDL programs and data required are publicly accessible in subdirectories of /wfc3/data20/intdata/pro/hartig, which can be placed in your IDL path.