



Automated X-ray Inspection Confirmation and Adjustments: The How & Why

This paper will discuss the theory behind the major elements of Confirmation and Adjustment as well as what happens when they are not maintained.

Photometric Adjustment Theory

Photocal, PixTest & Column Correction

The **Photocal** MXB adjustment process serves two purposes:

- The process flat-fields (evens out) the image from the X-ray Image Camera to account for different pixel sensitivities in the CCD.
- The process also attempts to remove system-to-system variations to help standardize FGCalc & Soldercal.

To do this, **Photocal** takes two image snaps:

- The first snap is a full-bright snap at the MXB open space (nothing between the x-ray tube and the scintillator), with X-rays on. This represents the brightest image the X-ray Image Camera should ever see in that image chain configuration.
- The second snap is taken at the same XYZ stage position, with X-rays off. This represents the darkest image the X-ray Image chain should ever see.

These bright & dark image snaps are used to calculate and scale the sensitivity

of each CCD pixel.

A gain (M) and an offset (B) is calculated for each pixel responsiveness so that a dark snap gets mapped into a gray level of 0, and a bright snap is mapped into a gray level of 3000. This serves to flatten the pixel variations across the image, and remove gray level variations between systems with different brightness (Normalization). The gray levels are then inverted and scaled to a floating point 0.0 to 255.0 (now 255.0 = dark)

During the adjustment, information about the 4X4 and 2X2 binning calibration results are printed on the screen

Number of pixels analyzed

Number of pixels out of range (too non-linear)

The average scale (Gain)

The average offset (pre-stretch)

The average dark gray level (Black)

The program then saves the buffered data to MBtable1.dat for the 2X2 binning mode and to MBtable2.dat for the 4X4 binning mode. The tables contain the offset and gain coefficients for each pixel in each mode. Both of these files are located in the calib directory. The program also updates the black level reference in the Gcor.cfg file as well (See Black Level Test Adjustment Theory).



PixTest – Blemish correction – Part II of the Photometric Adjustment

- The **PixTest** program was designed to compensate for correctable CCD blemishes in the camera
- Each pixel in the CCD has a slightly different response curve. Sometimes the response is so non-linear that it is basically ignored and assigned a value of the average of the pixels around it.

To do this, **PixTest** takes multiple image snaps:

- The program takes a snap of a flat field in open space at different X-ray tube current settings to simulate shading. It starts out at 100uA and decreased the current by 20uA until it reaches 20uA.
- Each image is analyzed and pixel gray levels are averaged in each quadrant of the image. Pixels that are beyond a threshold from the average are recorded and stored in a look-up table. When an inspection image is analyzed, the image is first corrected from the look-up table to remove the effect of the blemish. To make the correction, the gray level value of that pixel is ignored and the pixels around it are averaged. That average is assigned as the gray value for the bad pixel.
- This process is run on both the 512 and 1024 pixel resolution configurations of the X-ray camera and blemish information is appended to and stored in the cam_blem.cfg file in the calib directory.

Hard coded limits establish the threshold for “detecting” a bad pixel.

- Gray Level limit = 50 gray levels from average
- Sigma Noise Limit = 10 sigma(?)

PixTest - Column correction - Part III of the Photometric Adjustment

- A phenomenon that effect columns of pixels in the 4M15 camera were original detected with the development of the prototype. This is associated with the camera read-out strobe and affects the gray level of some columns of pixels in each quadrant of the camera.
- This can be seen as vertical stripes or lines in the corrected x-ray image. It is corrected with the third part of the PixTest program that does a column characterization.

To correct this, during the second part of the **PixTest** while the x-ray current was being changed and the images analyzed, the column gray level averages were also being calculated.

- Once the column average gray levels are calculated they are checked against a threshold. If the gray level average for the column exceeds the threshold, a gain correction value is calculated and mapped to that column.
- The correction is then applied and the column correction information is recorded in col_blem1.dat for 2X2 binning and col_blem2.dat for 4X4 binning in the calib directory.
- The **PixTest** program will then step the x-ray current down from 100uA to

10uA in 10uA steps and re-check for column linearity. This process is repeated if the threshold is exceeded again.

Hard coded limits establish the threshold for “detecting” a non-linear column.

- Column GL limit = 3.5

Black/White Level Test Adjustment Theory (Check Drift Average)

Another factor in the accuracy of the image gray levels is temperature drift. The Black Level Test/Calibration program was designed to address this issue on a short-term basis. Because the pixel response can quickly change with temperature (offset, and gain) another means of maintaining image system calibration was required. A quick method of checking to see if the gain and offset values were still valid after a configurable amount of time was required. Rather than adjusting the MBTable files as with Photocal, the Black level test quickly makes adjustments to the MBTable in memory as required.

To do this, The **Black Level test** takes multiple image snaps

- The first snap is a dark snap taken with the X-Ray beam being deflected onto the dump bank and the stage in the Photocal position. The image is analyzed and an average is taken. The average is compared to a value that was recorded in the Glcor.cfg file during the Photocal adjustment. If the average is below the threshold specified in the Glcor.cfg file then the time is recorded in this file and the

test is complete. If the average is beyond the threshold specified in the Glcor.cfg file then the program continues with the adjustment section of the program

- The second snap is taken at the same XYZ stage position, with X-rays on. This represents the brightest image the X-ray Image chain should typically see. The image is analyzed and an average of each quadrant is taken. .
- The average values for the black snap and the white snap are compared to the values in the Glcor.cfg file and a modifying constant is calculated. These modifying constants are then applied to the gain and offset values for the MBTable in memory. This is similar to Photocal except that the MBTable files are not modified; only the MBTable in memory is modified (Depending on the binning at the time of the test). Also, Photocal modifies the gain and offset of each pixel where as the black level test only modifies the gain and offset values with single constants.

Effects of Time

Over time, the photometric adjustment will become invalid due to several factors.

- Changes in the X-ray tube flux density.
- Changes in the scintillator screen.
- Changes in the pixel response of the CCD in the camera due to temperature and time.

All of these factors work against the stability of the x-ray image. To insure reasonable performance of the 5DX, it is

absolutely necessary that the photometric adjustment be accomplished **every 7-days** or less (more frequently under high temperature swings {+/- 10degrees F.}).

The Factory defaults for the Glcor.cfg file are set to a gray level threshold of 1.0 Gray level and a test frequency time of 15 minutes. These setting should be effective for most systems. If the system frequently sees rapid temperature shifts (Next to a A/C vent or by a outside door) then the frequency should be increased. Never turn OFF the Black level Test, as this will prevent the program from running and maintaining the correct gray level offsets and gains.

X-ray Scan Adjustment

Theory

Dump Ring

The Dump ring acts as a shutter for the X-ray Image Camera. It controls the amount of light that reaches the camera by deflecting the x-ray tube beam out far enough on the x-ray target in the tube that it hits the area of the target where the dump ring is located. The dump ring, made from a 1/8" thick piece of tungsten, is so dense that very few x-rays will be emitted from the accelerated electrons of the electron beam of the x-ray tube. This effectively shuts off x-rays very quickly and allows very accurate control of the amount of x-rays contacting the scintillator screen, and thus, light reaching the X-Ray Image Camera.

Dump Ring Calibration

The edges of the dump ring must be accurately located in order to create a dump ring for the X-Ray Scan Controller. The position of the edges of the dump ring are determined by the "Mapping the Collimator" menu selection in the Confirm & Adjust menu, and the results are stored in the FOVCAL.DAT file of the calib directory. These results are automatically used to create an interpolated the dump ring in bank 0 (sync0.dat) of the X-Ray Scan Controller. This process is not perfect and validation of the dump bank is sometimes necessary. The dump bank is verified automatically in the adjustment program. It does this by ensuring that the scanned beam in dump bank 0 remains on the dump ring, emitting no X-ray flux (light on the X-ray Image Camera). Please note that the dump ring is ***always*** loaded in the X-Ray Scan Controller in bank 0 of the memory. It should always be loaded in this bank or the image chain will never work properly.

FOV Creation

The XCALIB program creates the FOV banks for the X-Ray Scan Controller by first adjusting the XYZ stage height to get the correct magnification for the desired Field of View. Then the four quadrants of the scanned circle are measured/adjusted such that the 5-dot patterns from the C&A panel's X-ray image remains centered. Initially the user is asked to manually adjust the XYZ stage until a focused stage position is found.

Then the program makes continuous and automatic Digital to Analog deflection (DAC) adjustments in the X-Ray Scan Controller to maintain the position of the 5-dot pattern at each quadrant. Once the dot position is relatively stable, the entire FOV bank (each memory location with its deflection data) is interpolated and loaded in the X-ray Scan Controller. The axis and scanned beam are then moved to a various number of positions around a circle (usually 20) for confirmation and re-adjustment. The position of the 5-dot pattern is again measured and the results used to adjust the DACs in the X-Ray Scan Controller for each of the 20 positions. These adjustments are used to once again interpolate the entire bank. This measurement/adjustment process is repeated until the worst-case position in any rotation falls within a hard-coded tolerance in the program. The resulting X-ray Scan Controller DAC values are stored in SYNCX.DAT, where X is the FOV index for the bank. The user can create many different FOVs with this program including the standard FOVs of 200, 260, 320, 400, 650, 800, 850. Unfortunately, only the standard FOVs are currently supported in the Camera and Solder thickness adjustments. Please note that the 400 FOV is **always** loaded in bank 1 of the X-Ray Scan Controller. It should always be loaded in this bank or the image chain will never work properly. Caution: It is possible to load any FOV in any bank (0 -3) with the loadsync command.

The FOV can be verified in two ways:

- Image stability at slow rotational speeds, and
- Dynamic vs. static resolution.

When properly adjusted, an FOV should keep an X-ray image on the XYZ stage (assuming the right Z-height) very stationary. This is more easily seen at slower speeds. Incorrect FOV banks (or incorrect Z-heights) will result in the X-ray image moving in circular/elliptical patterns. At higher rotary speeds, even slight image shifts will result in a blurring of the X-ray image, decreasing the dynamic resolution of the image. Theoretically, the best dynamic resolution can only be as high as the static resolution.

Phase

Phase is an adjustment to compensate for mechanical drag in the rotary axis. Because a mechanical belt drives the scintillator on the rotary motor, there is a small amount of stretch in the belt when driving the scintillator at 1000 RPM. This is caused by windage and friction in the assembly. The phase adjustment was designed to compensate for this lag in time by advancing the address count in the X-Ray Scan Controller. It accomplishes this by adding an address offset to the address buss in the scan controller. This effectively shifts the memory location of every x-y deflection values stored in the memory. Its effect is like adjusting the distributor on a car

engine to advance or retard the ignition timing.

Effects of Time

Several factors can affect the accuracy of the FOV files loaded in the X-ray Scan Controller, which will require the FOVs to be re-adjusted over time. Changes in the X-ray tube electron beam generation or changes to the focus current will have a major impact on the adjustment.

Mechanical changes to any of the components of the Image chain will require also re-adjustment of the FOVs. Even changes in the analog circuit of the X-Ray Scan Controller will affect the image quality and necessitate re-adjustment. The Division recommends that all FOVs be re-adjusted at least every **two months**.

Camera Index Adjustment (FGCALC) for Digital Cameras

Theory

The FGCalc program is used to adjust the different black/white, gray level reference values (Gain and Offset) for different camera index settings (Index settings correlate to the aperture adjustment on a regular camera, controlling the darkness or brightness of the image). These adjustments are strictly for the benefit of enhanced display images. It serves no other purpose, the algorithms do not require it. The camera indexes assist the application programmers and the repair operators by making the x-ray image easier to view. The program does this by:

- "Opening" the FG settings to known black/white levels (Default values of 0 and 4095).
- Running an inspection of the C&A panel with these default values.
- Using the results of the inspection (background gray levels and foreground gray levels) to calculate the new black/white reference levels.
- Modifying NFG*.dat files (Camera Index files) to use the new black/white reference levels.

When the 5DX analyzes an image for measurement information, the gray levels are converted back to what they would be for camera index 0. All thickness measurements are based on gray level values of Camera index 0.

On a 5DX Series 3 & 5000 Systems with a digital camera, the raw Digital Frame Grabbers gain and offset values are kept constant, and all gain and offset adjustments are simulated in software as black/white gray reference values (MXB corrections, Scale and Offset).

How it works: A full inspection of the C&A panel is run with known FG settings. The inspection is run at all possible integration cycles (1 – 4). The program looks at the result files and the resulting gray levels. The program then chooses a gain and offset to adjust the gray levels to match the target values stored in the Fgcalc.cfg reference file. The program adjusts these gain and offset values for each target set in the reference file. These different target values represent the different camera indexes (Gain, offset

and integration cycles). This stretches the image gray levels to enhance the image for shaded camera views. This does not improve the date for the image analysis; it just makes the image brighter. The specified "target" components and desired gray levels are found in CALIB/FGCALC.CFG These values should not be modified, as they are used by FGALC to calculate the correct black/white reference levels for each camera index and correlate them to a common standard for all 5DX systems.

NOTE: The resulting Frame Grabber setting files, NFG*.dat, should be fairly consistent on a system-to-system basis. This is because Photocal MXB "normalizes" camera variations between systems.

Effects of Time

The NFG*.dat files are less sensitive to time because the only thing that will affect their accuracy is a change in the camera pixel response. This is a characteristic of the camera and as long as the camera is not replaced, the gain and offset values should be fairly stable. To insure that the camera pixel response has not changed, the Camera Index adjustment could be accomplished every **two months**.

Thickness Table Adjustment Theory

SolderCal

Solder Thickness table adjustment is one of the most important calibrations on the 5DX.

First step is to look at how shading effects thickness by looking at the same thickness dots under different copper filters and then develop a curve plot that describes the variation. Fit delta gray level vs. background.

Second step is to take the corrected delta gray level and match it to a thickness. Fit to curve.

Notes:

1. Test inspects the cal panel and takes measurements, no camera index adjustments, only camera index 0.
2. Compares measurements with reference file (6337_CU.dat)
3. Calculates a corrected gray value
4. Writes gray value to thickness relation to a file for that FOV

Effects of Time

Adjustment should be accomplished every **two months**.

Surface Mapper Adjustment Theory

Lasers

X-ray to Laser Offset

The Laser offset adjustment was created to insure that the offset between the laser spot source and the center of the X-ray image screen was accurately known. Knowing this offset allows the system to move to the exact position where a laser spot and the center of the x-ray image are in common. For portability purposes, this offset value is critical. Without it, the laser spot would not be located at the same coordinates of a board on different 5DX systems.

Laser Spot Region Setup

The Laser Spot Region adjustment was created to detect the location of the laser spot in the laser camera image. Because the laser camera is tilted at about 30 degrees from perpendicular, as the z-axis translates up or down, the laser spot appears to transition across the laser camera image. The Laser spot region adjustment will move the stage up and down to track the laser spot position in the image and record its pixel locations. This helps to reduce the search region for the laser spot and help define upper and lower limits for the laser range when the optical laser mapping technique is being used.

Laser Z Measurements

Lasercal creates a conversion table between the laser spot location (on the laser view camera image) versus the Z-axis position. This conversion is used to make accurate optical-mode laser readings during surface mapping.

Lasercal performs the following steps:

1. Sets default Black/White image settings.
2. Sets the laser for galil mode.
3. Moves the XYZ Stage to the laser hole on the Calibration Coupon (HOLE_X, HOLE_Y, HOLE_Z of CALIBXXX.CFG).
4. Requests the user to adjust the axis position and do a manual X-ray focus.
5. Turns laser camera lights off.
6. Moves the XYZ Stage under the laser (instead of the X-ray) with LaserXOffset and LaserYOffset.
7. Moves the Y Stage by +50 mils to be near the laser hole.
8. Reads the Laser distance to the probe focus coupon (Zdist1).
9. Moves the X Stage by +800 mils to the bare board beside the calibration Coupon.
10. Reads the Laser distance (Zdist2).
11. Moves the Z-Axis so that the bare board reading is at the probe focus height reading.
12. The laser reading at this Z-height is the Galil laser reference reading.
13. Sets the laser for optical mode.
14. The edges of the laser viewer are found by moving the Z-Axis up and down.

15. The Z stage is stepped in 2 mil steps over the entire laser viewer range.

16. Laser spot pixel locations are recorded over this range.

The resulting array of pixel location versus Z-height is stored as LASERn.DAT, where *n* is the laser number.

Laser*n*.Dat has the following format:

Adjustment Data for Laser 1
100 ; Number of points
300 ; First Reading (laser)
1 ; Increment between Readings
pixelvalue0
pixelvalue1
pixelvalue2
pixelvalue3

Set Laser Reference Measurement

Nulls out the difference between the two laser reference measurements (Laser units) when the second laser is installed into a system.

It does this by:

Moving the cal panel under the x-rays so as to image the laser target (1.0" X 1.0" tungsten square).

Adjusting the Z-axis until center hole is in focus.

Moving the cal panel under the front laser (Laser #1) and taking a Laser unit reading.

Moving the cal panel under the rear laser (Laser #2) and taking a laser unit reading. Calculating the difference between laser #1 and laser #2 and stores this value.

Every rear laser reading has this offset added to its laser measurement.

Effects of Time

Because the laser map basically references the POF, anything that happens to the X-ray image calibration over time will also affect the laser POF calibration. As long a Selftest is allowed to run, the POF height value will be corrected. The position of the fixed rail can also affect the Selftest results. Due to the design of the earlier 5DX's (Pre series 3s) the fixed rail could be misadjusted by a stage slam or a board jam. Movement of the fixed rail after a Selftest set-up would change the true coordinates of the Selftest features. (Reviewing the Dot-X and Dot-Y values in the Selftest log can monitor this)

To insure that the Laser Mapper provides accurate information, the Selftest set-up adjustment should be accomplished at a minimum of every **two months**.

Stage Adjustment Theory

Portability adjustments

Rail and Stage Measurements

The Rail and Stage measurement is a suite of small tests that were designed to improve system to system portability. These tests center on the physical adjustments of the XYZ stage and particularly the fixed and moveable rails

in relation to the x-ray image camera. After running this suite of tests, information about the state of the XYZ stage is available that will inform the user if adjustment is required to correct any physical misalignment. By correcting these miss-alignments, the portability of applications can be greatly improved.

- The first test checks that the Fixed Rail is parallel to the Y-axis. This is necessary because the panels are indexed by the rail and depend on the boards to be orthogonal to the CAD data.
- The second test checks the rotation of the camera image. This is required for the same reason as that of above.
- The third test checks that the Moveable Rail is parallel to the Y-axis and the Fixed Rail. Again, this is required to keep the panel index orthogonal to the CAD data.

After the Rail and Stage program has run, information about the Stage rails and Camera Orthogonal alignment is written to a log file. The log file provides Pass/Fail information as well as adjustment instructions if required.

Autowidth Adjustments

This test and adjustment is used to measure and adjust the stage rails board width. By using the X-ray Imaging tools in combination with the Stage positioning information, the board rail width can be accurately determined. Once measured,

the program writes the actual measured width to the Machine.cfg file. This assumes that the X-Y Rail portion of the test has been run and any required adjustment been applied.

PIP Position Setup

The PIP location is key in referencing the Stage mechanical coordinate system to the CAD coordinate system. This is how the Machine and CAD coordinate systems are tied together. This allows the Stage to move to a specific feature described in the CAD data of the board program. The Calibration panel has a design feature of a know size and location built into the panel. With this information and the panel loaded into the 5DX, the stage moves to a default location and searches for this feature (A rectangular lead feature 0.30" By 0.30", 0.300" from the edge of the panel (In X and Y)). Once located, it references the machine coordinates, subtracts the position offset of the feature from the edge of the panel and obtains an offset constant that is written to the CalibXXX configuration file.

Effects of Time

Because some aspects of the XYZ table and the Camera are adjustable, there is a possibility of the Stage or the Camera being "bumped" out of adjustment at any time. This could be caused by a board jam or a mechanical failure on the stage or simply the replacement of one of the components. Again, the Selftest data rely heavily on accurate feature location and

are affected anytime the fixed rail in the system moves unexpectedly. In addition to the stage position, the alignment of the Image camera is important to maintain. During a field replacement, the Camera rotation and alignment with the stage is a critical factor in maintaining the optimum performance in the locator algorithms (By maintaining the maximum tolerance budget, i.e. starting out with an orthogonal image and cad data). Therefore, adjustment should be accomplished every **two months or anytime a Camera or Stage component has been adjusted or replaced.**

