System Engineering Report

Project: AXAF SIM/ GSE
Title: FAM installation and alignment at XRCF
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Abstract:

An earlier SER, *FAM coordinate conversion, alignment and calibration,* gave the mathematics of HRMA angle to FAM actuator mapping, as well as one concept of FAM alignment at XRCF.

This SER gives the FAM installation and alignment process in more detail. It deletes a portion (the alignment cube on the FAM rear rail) of the FAM alignment concept offered in the earlier SER, and replaces it with one consistent with other alignment tools now known to be used (the OBASIM Alignment Reference Mirror, and XRCF's Alignment Telescope Assembly) . This SER clarifies some earlier ambiguities, distinguishing between FAM positions given with respect to (w.r.t.) *home*, and HRMA positions w.r.t. *boresight*. It uses the coordinate system naming convention (e.g. **F1**, **F3**, **x1**, ...) developed in the previous SER.

Last, this SER gives algorithms and important variables associated with basic FAM processes such as going home, moving w.r.t. home, moving w.r.t. boresight, and reporting actual positions as compared with commanded positions.

FAM installation on the DETB:

At this time, the FAM is located in the XRCF clean room. Operating the FAM in the clean room entails placing the Remote Electronics Unit, a 19"rack of FAM electronics, nearby in the clean room without contaminating the room.

The six FAM actuators are denoted Ax, Ay, Az (FAM foot A x,y,z) ; Bx,Bz; and Cz. There is no By, Cx nor Cy actuator.

If not already at home, drive the FAM to home - this is the position where each of the six linear encoders distributed amongst the three FAM feet are at a precise index mark, "home", nominally centered in their range of travel. Since actuator position on power up is unknown, ordinarily homing requires

1. Driving each actuator to one limit (at high speed), say the left limit. NEAT's controller runs the actuator into the limit, then backspaces (at low speed) until the limit is no longer seen.
2. Backspacing (at high speed) to a position just short of home. The limit-to-home distances (here denoted Axllhm, Ayllhm, ..., Czllhm; six left-limit to home distances) must be known a priori; they will probably be supplied by NEAT at the factory, although they can certainly be found in the field.
3. Searching (at low speed) for the index mark. The stepper controller notes the exact moment at which the index mark is seen, and clears the encoder counter at that instant. The actuator comes to a stop soon after.
4. Read the encoder count, and if necessary forward space the actuator until the encoder reads zero within some tolerance. Iteration should not be necessary.

Place the FAM on the DETB so that

1. The rail that extends from foot A to B (the two rear feet) is parallel to Y, i.e. parallel to the hole pattern in the DETB. This is a rotation about the Z axis.
2. The center of the FAM aperture is at Y=0. This is a translation along Y.
3. The -X side of the payload mounting plane is 30.625" (28.5 SI to OBA I/F + 2.125 OBA I/F to payload mounting plane) in the +X direction from the SI focal plane. The SI focal plane datum in X is marked on the top of the DETB.

Precise placement is not required, since the FAM can accomodate mounting variability. Note that the FAM attitude w.r.t. the facility **R32** is fixed at this time, but not yet known.

ISIM installation on the FAM:

Upon arrival at XRCF, the ISIM and OBASIM are already bolted together as one integral piece, as they will remain for the duration of tests at XRCF. Fig. 1 shows the arrangement.

The OBASIM contains an Alignment Reference Mirror (ARM), shown in detail in Fig. 2. Details of the reticle pattern are shown in Fig. 3. When FAM alignment is complete and before XRCF tests proper begin, the ARM will be removed from the OBASIM's -x side, leaving the ISIM in place.

Bolt the OBASIM/ARM/ISIM to the FAM. Pins provide precise roll registration.

Boresight:

After FAM installation, our initial objective is to find the FAM rotations and translation required to place the SI's at "boresight", our term for the on-axis, focussed position of the SIs. Subsequently, once boresight is found and the FAM distances required to get there from home recorded, each time the FAM is put in operation the first step (after going home) is to go to boresight.

Finding boresight attitude:

The following steps may be performed with the DETB on rails in the clean room, or for better accuracy with the DETB in the IC, supported by four jacks in its final position. In the IC, the "standard" FAM cabling arrangement is used, with the REU on the second floor south east side of the IC. In either case, the ARM aperture is big enough to support the 3" height (Z) difference between the rail position and the jacked position.

One objective is to rotate the FAM about Y and Z until the OBA interface plane, i.e. the OBASIM ARM reference surface, is normal to the Facility Optical Axis (FOA), **x1**. A course alignment may be made as shown in Fig. 4, using a 1" diameter laser beam at the X-ray source, and observing the position of the reflection off the ARM back at the X-ray source. Note the ARM's refererence suface has 20% reflectance.

A fine alignment alignment requires the Alignment Telescope Assembly (ATA), which is positioned near the center of the HRMA aperture as shown in Figure 5.

A second objective is to roll the ARM about **x1** until its Z axis is parallel to the ATA Z axis, as shown in Fig. 6.

Finding boresight translation:

So far we've discussed how to align the ISIM (or ARM) to the facility in three of six possible degrees of freedom, i.e. rotation about Y,Z and X. Rotations should be done first for convenience, since rotations and translations interact at the ARM (whereas they are independent at the FAM (or SI) origin). Three more degrees of freedom remain, to wit, translation in Y,Z and X.

The laser may be used as a coarse check on the ARM's position in Y and Z. If the DETB is on the rails, the beam should be centered (i.e. should illuminate a card near the OBASIM ARM) at Z = + 3" and Y = 0" on the ARM. If it is on the jacks, the beam should be centered at Z = 0" and Y = 0" . Again, the ATA may be used for better accuracy, by translating the ARM in Y and Z until its reticle is coincident with the ATA reticle.

Final alignments in Y and Z, and alignment in X depends on observation of images taken with the ACIS imaging array. Remove the ARM from the OBASIM on the -x side, leaving the ISIM in place. With the SIM focussing assembly at X=0 (i.e. the center of its travel range) , and the SIM TSC at Z=0 (the launch position), the ISIM is translated in X until a well focussed image is seen, and translated in Y and Z until the image is seen at the center of ACIS imaging array.

Alignment then results in six numbers, three FAM rotations and three translations, distances from home to the "aligned" or "boresight" position.

Moving the FAM from home to boresight:

Moving from home to boresight takes place for three reasons:

1.general purpose movement w.r.t home (e.g. for performance test or non-orthogonality measurement), in which case *boresight* has no particular meaning .
2. trying to find where boresight is,
3. and going there after it is found.

In any case, Fig. 7, taken from Fig. 6 of the *FAM Coordinate Conversion* SER, shows the calculation sequence. While finding boresight, **R32** is not yet known (unless it was found by virtue of an earlier search), but it can be set to **I**, the identity matrix. This declares the FAM coordinate system **F3** parallel to the facility system **F1**, a useful and convenient approximation. Having found boresight once, **R32** is known (per procedure below).

In either case, the three commanded angles are $y1bshm_y$ (rotation about Y, or elevation) , $y1bshm_z$ (rotation about Z, or azimuth), and $y1bshm_x$ (rotation about X, or roll) . The three commanded translations are $S1bshm_y$ (along Y, or azimuth) , $S1bshm_z$ (along Z, or elevation), and $S1bshm_x$ (along X, or focussing) . All six variables are distances from home to boresight. Fig. 7 shows the various intermediate products that are generated, finally resulting in six home to boresight actuator displacements $uAbshm_x$, $uAbshm_y$, $uAbshm_z$, $uBbshm_x$, $uBbshm_z$ and $uCbshm_z$.

Calculating R32 after boresight is found:

The FAM coordinate system **F3** is defined by (not the OBASIM ARM, regrettably, due to the location of the SI origin and practical contraints when measuring FAM non-orthogonalities, but rather) a cube that resides on the SIM mass simulator (SIMSIM) at the FAM (and SI) origin, with the FAM at home, as shown in Fig. 8.

The SIMSIM cube has an azimuth, elevation and roll offset w.r.t. the OBASIM ARM (**xRAM**,**yARM**,**zARM**) of fso, qso and yso, shown in Fig. 9. These offsets are found with a theodolite at the time FAM non-orthogonalities are measured.

Fig. 10 shows the azimuth portion of the composite situation, similar geometry holds for elevation and roll offsets. With the FAM at home, an unknown offset f_{31}exists for the FAM axis **x3** w.r.t. the facility axis **x1**. $f_{31}$is found by moving the ARM to boresight, where **xARM** is parallel to **x1**. Then

Eq. 1a $f_{31} = fso - y1bshm_z$, the facility to FAM azimuth offset, and similarly
Eq. 1b $q_{31} = qso - y1bshm_y$, the elevation offset,
Eq. 1c $y_{31} = yso - y1bshm_x$, the roll offset

Then **R32** = **E321**(f_{31} , q_{31} , y_{31}) is found from Eq. 61b of the *FAM coordinate conversion* SER.

Moving from boresight to a HRMA field angle position:

Fig. 11, taken from Fig. 6 of the *FAM Coordinate Conversion* SER, shows the calculation sequence. Note that these calculations are similar to those of Fig. 7:

1. HRMA azimuth and elevation is specified from boresight, not home.
2. **R32** must be known and installed, otherwise the SIs will defocus with large azimuth or elevation.
3. Home to boresight motor displacements **uAbshm,uBbshm,uCbshm** must be known by virtue of an earlier boresight.
4. The end product is FAM motor displacements from home, the values sent to the FAM controller.

Reporting actual HRMA field angle position relative to boresight:

Fig. 12, taken from Fig. 7 of the *FAM Coordinate Conversion* SER, shows the calculation sequence. **uA',uB',uC'** are the actual FAM motor displacements in units of length, say inches, as measured by the encoder associated with each motor. Any encoder reads zero when its "motor displacement" is zero, i.e. when that actuator is at home. Each (of six) encoder has an associated gain in counts/inch. $\mathbf{M66}^{-1}$ maps differences between actual and commanded positions into differences between actual and commanded SI angles and translations. Errors in SI angle are ignored, errors in SI defocus are ignored, and errors in SI translation Z and Y correspond to errors in HRMA field angles.

FAM algorithms:

Fig. 13 shows the process of going home, and some of the variables (the ones discussed in this SER) associated with it.

Fig. 14 shows the process of "moving to boresight", and some of the variables (the ones discussed in this SER) associated with it. Intermediate products, e.g. **DA3bshm**, are not listed here. This same routine is also used for general purpose FAM movement w.r.t. home, e.g. at FAM performance test time and non-orthogonality test time.

Fig. 15 shows the process of "moving to HRMA field angle position", and some of the variables (the ones discussed in this SER) associated with it. Intermediate products, e.g. **DA3bs**, are not listed here.

Fig. 16 shows the process of "reporting actual HRMA field angle position", and some of the variables (the ones discussed in this SER) associated with it. Intermediate products, e.g. **DuA**, are not listed here.

Fig. 17 shows the process of "reporting actuator position", and some of the variables (the ones discussed in this SER) associated with it.