HFOSC: Basic Aligment and Centering Tests at Copenhagen

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1 Basic optical considerations

The basic optical setup is the following:

Mount the CCD camera on the HFOSC, make sure the distance between the CCD and the field lens is correct.

Place the spectrograph camera in its nominal position, adjusting the hall switches so that the camera is in its middle position.

Find the correct camera position by obtaining sharp images of stars.

Place the collimator in its nominal position using mechanical distance pieces.

Finally, adjust the distance between the aperture wheel and the collimator to obtain sharp image of a pinhole mounted in the aperture wheel on the CCD.

Small mechanical "zero-point" blocks are mounted against the collimator and the camera.

2 Focus of HFOSC camera

The CCD camera, the spectrograph camera and the grism and filter wheels were mounted. V filter was used to avoid lateral colour aberrations in the camera. The camera was then focussed on some nearby objects (at a distance 10-15 m). Using the thin lens formula, the camera position to obtain focussed images of stars was computed. Short exposures (maximum of 2 sec to avoid trailing) of stars were obtained at several camera positions. The FWHM of the stellar profile was obtained in thses images to estimate the best camera focus.

Another method to obtain the camera focus is to obtain star trails using two Hartmann masks (H1 and H2) without reading the image in between. A focus position was chosen and exposed for a few seconds through H1 and then through H2. Several such sequences were made before reading out the CCD. (Note that the Hartmann masks should be oriented perpendicular to the direction of the star trail.) When the trails in H1 and H2 match and are in a straight line, the correct focus is obtained.

Both methods gave the same focus position of 1285, with an accuracy of 5 focus steps.

3 Alignment and centering

Alignments come in two groups: directional alignment and centering. The reference for all alignments is the central hole in the mounting flange.

A reference axis was set up using a laser source kept at a distance of 8 m. The light from the laser was reflected from a mirror on to a flat glass plate mounted on two distance bars placed parallel to the mounting flange, and adjusted to reflect the spot back into the laser exit hole. This method gives a reference point with respect to the mounting flange.

3.1 Collimator

The laser spot was reflected from the flat, front surface of the silica prism (first element of the collimator). The tilt and rotation of the collimator was obtained by tilting the entire optical bench and adjusting such that the laser spot reflected back to the exit hole. An accuracy of 2 arcmin was obtained. The centering was done using a specially made mechanical tool which was centered in the central hole of the mounting flange.

3.2 Aperture wheel

The aperture wheel is to be aligned with respect to the optical axis and also with reference to the mounting flange. A mirror was mounted on the defining surface of the aperture wheel (the side facing the collimator), and the laser light reflected back. The position of the spot center of the reflected beam was then measured with reference to the reference point estimated earlier. This measurement was repeated for three different positions on the aperture wheel. In the worst case, the reflected spot was at a distance of 12mm from the reference point. This implies that the aperture wheel is aligned normal to the laser path (and optical axis) to ≤ 2.6 arcmin (60*12/16000).

The centering of the aperture wheel with respect to the center of the mounting flange hole was obtained using a plastic block of diameter exactly matching the size of the aperture hole (54 mm) placed in another block with an outer diameter exactly matching that of the mounting flange hole. This tool was then placed through the mounting flange hole into one of the holes in the aperture wheel. This was repeated for two other aperture positions. The centering was found accurate to 0.1 mm.

3.3 Camera

In principle, the camera should be aligned when the collimator is aligned since both are placed on the same optical bench, and have the same outer diameter of the housing. However, this was also tested by setting up the laser beam entering from the 'back end' of the camera, i.e. the side facing the detector. The laser light was reflected from a glass plate placed parallel to the end flange of the collimator and the reference axis set. The glass plate was then held against the front end of the camera and the position of the reflected spot measured relative to the reference set by the collimator. The alignment of the camera was found accurate to 1 arcmin.

3.4 Filter wheel

A plane mirror was placed parallel to the defining surface of the filter wheel, which is the surface facing the collimator, and the laser beam reflected. The alignment of the filter wheel (wrt to camera) was found accurate to about 2-3 arcmin.

The centering of the filter wheel was acheived by using a cylindrical aluminium block that had an outer diameter similar to the outer diameter of the camera/collimator housing, inside which was placed a plastic block having a diameter matching the holes in the filter wheels (36 mm). This tool was placed on the optical bench in the camera position (after removing both the camera and the grism wheel) and the inner plastic block inserted through the filter hole. The centering was found accurate to 0.2 mm.

3.5 Grism wheel

The camera and grism wheel were mounted back. The alignment of the grism wheel was done with respect to the filter wheel. The reference axis was determined by reflecting the laser off a plane glass placed parallel to the filter wheel. Note that in this test the glass was not placed in the optical path of the instrument, but at the opposite end of the wheel. It does not affect the tests, since measurements of the reflected spot from three different positions of the filter wheel were accurate to about 1 arcmin (relatively).

The mirror was then placed parallel to the defining surface of grism wheel, which is the surface facing the camera, and position of the reflected spot measured wrt to the reference position. The measurements were repeated for three different positions of the grism wheel. It was found that the alignment was about 7 arcmin and also the grism wheel was slightly tilted with respect to the filter wheel by $\sim 4-5$ arcmin. This was corrected for by shimming the grism wheel with a 0.2 mm foil. Repetition of the laser measurements indicated the alignment had improved to about 2 arcmin.

4 Camera focus and repeatability

A pinhole plate was placed in the aperture wheel, which was illuminated using a continuum source. It was ensured that a nearly f/9 beam illuminated the collimator by placing a hollow block, of height 30 mm and an opening of 2.8 mm at the other end (facing the collimator), on the pinhole plate. Two Hartmann masks were placed in the grism wheel, and a V filter in the filter wheel.

The camera was kept at the focus position obtained earlier using stars, which corresponded to a focus position of 1285. The pinhole was then imaged onto the CCD and the position of the images with the two Hartmann masks estimated. At the best focus position, the centroid of the two pinhole images should coincide. The best focus was thus estimated. At this position, the difference between the centroids was found to be about 0.02 pixel.

The repeatability of the focus position is found by

(a) initializing the camera position and returning to the best focus position. The centroid of the pinhole images with the two Hartmann masks are then measured. This is to be repeated several times.

(b) moving the camera in several steps in one direction towards the limit in that direction and returning back to the best focus position, again in several steps. Measure the pinhole positions through both the Hartmann masks. Repeat for several times. Next move the camera towards the other limit in several steps and return back to the best focus position, again in several steps and measure the pinhole positions through both the Hartmann masks. Repeat for several steps.

When (a) described above was performed, it was found that the best focus had changed by nearly 15 μm after a few steps. The error was detected to be due to the size of the pinhole being too large for a good estimation of the centroid. The pinhole was replaced by one with a smaller hole and the tests repeated. Both the tests (a) and (b) described above indicated the camera focus repeats to an accuracy of ≤ 0.05 pixel (7 μm).

NOTE: 1 step in camera movement corresponds to 1 μm. Total travel available is 3.4 mm. A difference of 1 pixel (in Y-position) in the centroids of the pinholes through the two Hartmann masks corresponds to about 143 camera steps.

5 Repeatability of aperture wheel

The camera was kept at the best focus position. A pinhole plate was placed in aperture wheel and imaged, and the centroid measured. The aperture wheel was then moved by half a turn in arbitrary steps in one direction and back to the original position (in one go), and the pinhole image obtained and centroid position measured. This was repeated several times. The wheel was then moved by a half turn in the opposite direction as before and the pinhole image obtained and centroid position measured. Once again this was repeated several times.

The aperture wheel was then initialized and the pinhole brought back in the optical path. It was imaged and the centroid measured. This was also repeated several times.

The accuracy of the positioning of the aperture wheel, during both tests, was found to be ≤ 0.1 pixel, which corresponds to an accuracy of 1 step in the wheel movement. (Total number of motor steps corresponding to one full turn of the aperture wheel is 320,000. The center of the aperture is at a distance of 110 mm from the center of the wheel, which implies a circumference of $2 * \pi * 110$. Hence, each step corresponds to $2 * \pi * 110/320000 = 2.2\,\mu$m).

6 Alignment of the CCD camera

A plate with three pinholes in a straight line was placed in the aperture wheel and imaged. The image of the pinholes should be aligned along the CCD column pixels. The (X,Y) position of each of the pinholes was measured. The $(\Delta X,\ \Delta Y)$ in the position of the extreme holes gives the angle of rotation ($\tan\theta = \Delta X/\Delta Y$). The laser beam was placed at a distance of 3.2 m and reflected off a mirror fixed onto the CCD mounting flange. The angle of rotation then corresponds to a deflection of the reflected spot by a distance given by $\Delta d = 6200 * \tan\theta$ mm.

The CCD was aligned to an accuracy of 0.4 pixel in X, or an accuracy of 2 arcmin.

7 Alignment of grisms and slit

7.1 Grisms

The grism is mounted in the grism wheel. The grism is rotated (within its mount) such that the dispersion axis is normal to the rulings. A coarse alignment is achieved by a visual inspection. A pinhole is then placed in the aperture wheel, and a spectrum of the continuum source obtained (note: use the f/9 beam). The (X,Y) coordinates of the extreme ends of the spectrum gives the angle by which the grism is to be rotated. (The spectrum is aligned along the column similar to the pinholes). This is acheived by mounting a small mirror on the grism tube, shining a laser on it and estimating the displacement of the reflected spot corresponding to the angle of rotation. The grism tube is then carefully rotated (after loosening the three screws that hold the grism tube in its mount) by the required amount.

Grisms HFOSC5, HFOSC7, HFOSC10, HFOSC11, HFOSC14, HFOSC15, HFOSC16 and HFOSC17 were aligned with an accuracy, respectively, of 9.5, 4.0, 2.3, 3.3, 2.8, 18, 2.9 and 5.0 arcmin. Note that this process need not be repeated as it is a one time process. Finer alignment is to be done with the align tool in the FOSC control software each time the grisms are changed. The worst case of 18 arcmin corresponds to 267 motor steps, while corrections upto a 1000 motor steps are possible with the align tool.

7.2 Slit

The 100 μm wide slit was placed in the light path and imaged. As before, the angle of rotation was estimated using the extreme ends of the slit. (The slit is aligned along the rows). It was found that the slit was aligned to better than about 200 motor steps, which was corrected using the align tool.

8 Flexure tests

The flexure of the instrument was measured with a pinhole (with f/9 beam) mounted in the aperture wheel and the V filter. The camera was kept at the best focus.

(a) The instrument was kept in an orientation that corresponed to its being mounted on one of the side ports of the instrument mount cube with the long axis of the instrument perpendicular to the telescope. An image of the pinhole was obtained and its centroid measured.

(b) The instrument was rotated by 90°. This orientation corresponds to the telescope pointing horizon (in one direction). The pinhole was once again imaged and its centroid measured.

(c) The instrument was rotated by 180° from the previous position, an orientation corresponding to the telescope pointing the horizon in the opposite direction. Once again the pinhole was imaged and its centroid measured.

(d) The instrument was brought back to its original position (a), the pinhole imaged and its centroid measured.

The deviations (in pixel) $(\delta X, \delta y)$ relative to position (a) were, respectively, (2.35, −0.45), (2.14, −0.04) and (0.10, −0.30) for positions (b), (c) and (d).

(e) The instrument was mounted in the same orientation as (a), but such that the long axis would be parallel to the telescope. An image of the pinhole was obtained and its centroid measured.

(f) The instrument was rotated by 90° such that it corresponded to telescope pointing horizon. An image of the pinhole was obtained and its centroid measured.

(g) The instrument was rotated by −90° relative to (f) such that it corresponded to position (e). The pinhole was imaged and its centroid measured.

(h) The instrument was rotated by −90° relative to (g) such that it corresponded to telescope pointing horizon in the direction opposite to (f). The pinhole was imaged and its centroid measured.

The deviations (in pixel) $(\delta X, \delta y)$ relative to position (e) were, respectively, (−0.50, −1.30), (0.01, −0.10) and (−1.03, −0.80) for positions (f), (g) and (h).

Position (b) is when the effect of gravity is at its maximum, and the effect of flexure noticed corresponds to 0.7 arcsec in X and 0.13 arcsec in Y.