HIRDLS TC-OXF-39

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ANALYSIS of LOS POINTING REQUIREMENTS

v0.0 920131 PV First draft
v0.1 920207 PV Replace scan mirror az uncertainty in across track grads
(previously removed as not tight requirement
on azimuth measurement).

Preliminary pointing requirement budgets. Outline jitter discussion taken mainly from DLS science requirements. Placement not yet included.

This document summarises the current HIRDLS pointing requirements. Total pointing requirements are specified, and an allocation of the requirements between subsystems suggested.

EOS

SCIENCE REQUIREMENTS.

The HIRDLS performs two distinct types of measurement; radiometric measurements of pressure, temperature and constituent profiles, and measurements of geopotential height gradients.

1. Radiometric measurements of P,T and constituent profiles.

These measurements require knowledge of the mean relative spacing of the detector elements over a single elevation scan.

The V1.2 HIRDLS Instrument Requirements Document SC-HIR-18 specifies the required accuracy as 0.5% over the scan range, 1.0% over any 100 arcsec segment. In azimuth, the requirement is stated to be 0.1 degree, corresponding to 2.5% of the nominal azimuth grid spacing.

The DLS Science Requirements Document SC-OXF-6 specifies 0.5% in pressure, corresponding to about 2.5 arcsec, and suggests that 5 times better than this would be advantageous particularly below 60km. In azimuth, the requirement is stated to be 0.2 degrees (3 sigma).

2. Measurements of geopotential height gradients.

These measurements require knowledge of the relative changes in tangent height for a given pressure between adjacent elevation scans.

The V1.2 HIRDLS Instrument Requirements Document SC-HIR-18 specifies this in terms of a gradient of 20m in 500km.

The DLS Science Requirements Document SC-OXF-6 specifies a gradient of 26m in 1000km. The gradient measurement also imposes a requirement on azimuth measurement to substantially better than 1.3% of the mean grid point spacing, that is 5km at the limb, for a grid separation of 400 km.

INSTRUMENT PERFORMANCE REQUIREMENTS.

The instrument pointing requirements are now derived from the science requirements summarised above. To do so, the baseline orbit (700 km altitude) and scanning pattern are assumed. The latter is based on a single sample time of 12ms, and a scan pattern of six successive elevation scans, each lasting 10s and covering about 140km (2.8 degrees) vertically, across an azimuth swath. The separation in azimuth between the elevation scans is about 13 degrees at the instrument (about 400km in latitude at the equator), reducing towards the poles. The extreme azimuth value is about 50 degrees. Azimuth swaths are repeated approximately every 60s, giving a swath separation of about 400km.

In the following, vertical and horizontal refer to the local vertical and horizontal at the tangent point. Angles refer to those subtended at the instrument.

1. Radiometric measurements of T,P and constituent profiles.

The vertical change in line of sight between any two 12ms samples in a single elevation scan (10s) should be known to 0.5 arcsec (DLS). The horizontal change in line of sight between any two 12ms samples in a single elevation scan should be known to 0.1degree (360arcsec).

2. Measurements of geopotential height.

Across track gradient measurements are made by comparing measurements on successive elevation scans, separated by about 10s in time and by about 400km horizontally at the equator.

Over such a time period, the change in vertical line of sight should be known to 0.77 arcsec (DLS 26m in 1000km). The change in horizontal line of sight which results in the same size of error in the gradient measurement is approximately 0.14 degrees (900 arcsec). A reasonable requirement might be that the knowledge of this change should be sufficient to result in an error no more than 20% of the vertical error, that is 180 arcsec (2.6 km at the limb).

Along-track gradient measurements are made by comparing measurements from elevation scans on successive azimuth swaths, separated by about 60s in time and by about 400km horizontally.

Over the along-track measurement period of 60s, the same requirements as for the across-track measurements must be met.

Orbit to orbit across track gradient measurements are also to be made, to meet the same requirements as gradient within a single orbit. Such measurements require that the change in vertical line of sight between the extremes of any one azimuth swath, and the opposite extreme of the swath one orbit later should be known to 0.77 arcsec, and that the change in horizontal line of sight should be known to better than 180 arcsec.

If the requirements for these measurements result in unreasonably tight requirements on the subsystem performance, then the azimuth scan range can be made sufficiently large so as to allow overlapping of adjacent scans, at some loss of horizontal resolution.

POINTING REQUIREMENTS.

The performance requirements are now broken down into budgets for the individual subsystems which contribute to the overall pointing.

The HIRDLS makes the following measurements in flight in order to calculate the direction of the line of sight:

> Measurement of the scan mirror orientation about an azimuth axis. The azimuth axis is nominally aligned nearly parallel to the spacecraft yaw axis, and nearly orthogonal to the elevation scan axis.

> Measurement of the scan mirror orientation about an elevation axis. The elevation axis is nominally aligned nearly in the plane of the spacecraft pitch and roll axes, and is thus nearly orthogonal to the azimuth scan axis.

> Three axis measurement of the change in orientation of the optical bench (OB) relative to inertial space. For an un-spun spacecraft in a sun synchronous orbit, the most significant constant input is the 360 degrees in 100 minutes (210 arcsec/sec) spacecraft pitch input (the precession of the orbit contributes yaw and roll components (in quadrature) of +-0.04 arcsec/sec (360 degrees/year)).

The following also affect the line of sight, but are not measured.

> Distortions of the optical bench resulting in a change in boresight direction relative to the gyro mounting feet.

> Motion of the optical bench outwith the gyro bandwidth, or within the gyro bandwidth, but exceeding the maximum rate.

To convert the line of sight into tangent point height, knowledge is required of the absolute spacecraft position in the orbit reference co-ordinate frame (ORCF), and of the position of the earth's surface below the tangent point.

The contribution of errors from each of the above sources to the overall uncertainty in pointing is now listed. Separate budgets are presented for each of the performance requirements. Separate budgets are required for initial placement, for within 1 vertical scan, for between adjacent grid points across track, for between adjacent grid points along track, and for between adjacent grid points orbit to orbit.

Vertical budgets are specified in an equivalent angle (arcsec) at the instrument, so that requirements on scanner elevation and azimuth measurement are 0.5 times the numbers below.

Horizontal budgets are expressed in km equivalent at the tangent point. The equivalent angles (arcsec) subtended at a radius of 2990km are given in brackets ().

The term line of sight (LOS) pitch is used to refer to the angle between the instrument LOS and a line from the spacecraft to the centre of the orbit (spacecraft z axis). The resolution of LOS pitch requirements into separate instrument pitch and roll requirements is not carried out in this document.

The term misalignment refers by default to misalignment relative to the orbit reference co-ordinate frame (ORCF).

A description accompanies each term in the requirements budget, in which the translation of the requirement into the relevant subsystem parameter is given. The majority of these translations are based on simple spherical trigonometric small angle approximations.

Allocation of the requirements between subsystems is at present based on historical (CDCR) best estimates of subsystem performance. Margin is not at present included in the requirements budget.

Requirements are for 1 sigma.

> SINGLE ELEVATION SCAN - vertical. Duration 12ms to 10s.
Arcsec at instrument.

Scan mirror total relative elevation measurement error 0.48
...the total uncertainty in the measured change in elevation angle, including (azimuth) gimbal wobble, structural deformations within the scanner subsystem.

Roll misalignment of the scan mirror elevation axis 0.05
...roll misalignment of the scan mirror elevation axis, resulting in a change in the conversion from elevation angle to height as cos(misalignment). Thus roll misalignment of the elevation axis must be known to about 144 arcsec to meet this.

Changes in the boresight direction due to OB structure changes 0.10
...the total change in the line of sight pitch component of the boresight (this is taken to exclude changes in the scanner subsystem).

Gyro LOS pitch measurement errors. 0.05

...total errors in the gyro relative line of sight pitch measurement

Height errors. 0.05
...errors in knowledge of changes in spacecraft altitude, and knowledge of mean (typical 500km along-track x 100km across-track) location of earth's surface at sub-tangent point
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TOTAL (RSS) 0.50

> SINGLE ELEVATION SCAN - horizontal. Duration 12ms to 10s.
In km, # across LOS, ! along LOS

Scan mirror azimuth measurement uncertainty (140 arcsec) 2.0
#
...the total uncertainty in the measurement of the change in azimuth angle (nominally zero) throughout the scan, including (elevation) gimbal wobble, structural deformations within the scanner subsystem.

Roll misalignment of the scan mirror elevation axis
...roll misalignment of the scan mirror elevation axis, resulting in an azimuth slew with elevation, proportional to sin(misalignment). This places a requirement on absolute roll misalignment of 0.85 degree, which is included in the placement error budget.

Changes in boresight yaw (OB structure changes) (140 arcsec) 2.0
#
...the total change in the spacecraft yaw component of the boresight (this is taken to exclude changes in the scanner subsystem)

Changes in boresight pitch (OB structure changes) (9 arcsec) 3.0
!
...the total change in the line of sight pitch component of the boresight (this is taken to exclude changes in the scanner subsystem)

Gyro LOS pitch measurement errors. (9 arcsec) 3.0
!
...total errors in the gyro relative line of sight pitch measurement result in errors in horizontal sub-tangent point location.

Gyro yaw measurement errors. (140 arcsec) 2.0
#
...total errors in the gyro relative yaw measurement

Spacecraft position errors 0.1
...this uncertainty in tangent point position is equivalent to an uncertainty

in spacecraft height of 0.25km, or in horizontal position of about 0.1km.

TOTAL (RSS) 3.5
#
4.2

> ACROSS TRACK GRADIENTS - vertical. Duration 10s (+13 degree azimuth slew). Arcsec at instrument.

Scan mirror elevation measurement error 0.70
...the total uncertainty in knowledge of the mean elevation angle between current scan and the scan 10 s ago, including azimuth gimbal wobble, structural deformations within the scanner subsystem.

Roll misalignment of the scan mirror elevation axis 0.16
...roll misalignment of the scan mirror elevation axis, resulting in a variation of LOS pitch angle with azimuth slew. This places a requirement on knowledge of roll misalignment of 0.6 arcsec.

Scan mirror azimuth measurement uncertainty 0.01
...the variation of LOS pitch with azimuth slew for a misaligned scan mirror elevation axis places a requirement on azimuth measurement. For a worst case roll misalignment of 0.6 arcsec this places a requirement on scan mirror azimuth measurement of 0.7 degrees for a 13 degree slew.

Changes in the boresight direction due to OB structure changes 0.30
...the total change in the line of sight pitch component of the boresight (this is taken to exclude changes in the scanner subsystem).

Gyro LOS pitch measurement errors. 0.05

...total errors in the gyro relative line of sight pitch measurement

Height errors. 0.05
...errors in knowledge of changes in spacecraft altitude, and knowledge of mean (typical 500km along-track x 100km across-track) location of earth's surface at sub-tangent point, equivalent to about 0.6 metre.

TOTAL (RSS) 0.77

> ACROSS TRACK GRADIENTS - horizontal. Duration 10s (+13 degree azimuth slew). In km, # across LOS, ! along LOS

Scan mirror azimuth measurement uncertainty (105 arcsec) 1.5
#
...the total uncertainty in the measurement of the change in azimuth angle including (elevation) gimbal wobble, structural deformations within the scanner subsystem.

Roll misalignment of the scan mirror azimuth (105 arcsec) 1.5
!
...roll misalignment of the scan mirror azimuth axis, resulting in a change of LOS pitch angle with azimuth slew. This places a requirement on knowledge of roll misalignment of 18 arcsec.

Changes in boresight yaw (OB structure changes) (105 arcsec) 1.5
#
...the total change in the spacecraft yaw component of the boresight (this is taken to exclude changes in the scanner subsystem)

Changes in boresight pitch (OB structure changes) (6 arcsec) 2.0
!
...the total change in the line of sight pitch component of the boresight (this is taken to exclude changes in the scanner subsystem)

Gyro LOS pitch measurement errors. (6 arcsec) 2.0
!
...total errors in the gyro relative line of sight pitch measurement result in errors in horizontal sub-tangent point location.

Gyro yaw measurement errors. (105 arcsec) 1.5
#
...total errors in the gyro relative yaw measurement

Spacecraft position errors 0.1

TOTAL (RSS) 2.6
#
3.2

> ALONG TRACK GRADIENTS - vertical. Duration 66s.
Arcsec at instrument.

Scan mirror elevation measurement error 0.70
...the total uncertainty in knowledge of the mean elevation angle between current scan and the scan 66 s ago, including azimuth gimbal wobble, structural

deformations within the scanner subsystem.

Scan mirror azimuth measurement uncertainty 0.01
...the variation of LOS pitch with azimuth slew for a misaligned scan mirror elevation axis places a requirement on azimuth measurement. For a worst case roll misalignment of 0.6 arcsec this places a requirement on scan mirror azimuth measurement of 0.07 degrees (250 arcsec) .CHK for a 1.3 degree change of azimuth between successive swaths.

Roll misalignment of the scan mirror elevation axis 0.16
...roll misalignment of the scan mirror elevation axis, resulting in a variation of LOS pitch angle with azimuth slew. This places a requirement on knowledge of roll misalignment of 6 arcsec, for a change in azimuth between grid points of 1.3 degree (0.1 of separation at equator).

Changes in the boresight direction due to OB structure changes 0.30
...the total change in the line of sight pitch component of the boresight (this is taken to exclude changes in the scanner subsystem).

Gyro LOS pitch measurement errors. 0.05

...total errors in the gyro relative line of sight pitch measurement

Height errors. 0.05
...errors in knowledge of changes in spacecraft altitude, and knowledge of mean (typical 500km along-track x 100km across-track) location of earth's surface at sub-tangent point, equivalent to about 0.6 metre.

TOTAL (RSS) 0.77

> ALONG TRACK GRADIENTS - horizontal. Duration 66s
In km, # across LOS, ! along LOS

Scan mirror azimuth measurement uncertainty (105 arcsec) 1.5
#
...the total uncertainty in the measurement of the change in azimuth angle including (elevation) gimbal wobble, structural deformations within the scanner subsystem.

Roll misalignment of the scan mirror azimuth (105 arcsec) 1.5
!
...roll misalignment of the scan mirror azimuth axis, resulting in a change of LOS pitch angle with azimuth slew. This places a requirement on knowledge of roll misalignment of 180 arcsec, assuming a change of 1.3 degrees in azimuth

between successive along track grid points.

Changes in boresight yaw (OB structure changes) (105 arcsec) 1.5
#
...the total change in the spacecraft yaw component of the boresight (this is taken to exclude changes in the scanner subsystem)

Changes in boresight pitch (OB structure changes) (6 arcsec) 2.0
!
...the total change in the line of sight pitch component of the boresight (this is taken to exclude changes in the scanner subsystem)

Gyro LOS pitch measurement errors. (6 arcsec) 2.0
!
...total errors in the gyro relative line of sight pitch measurement result in errors in horizontal sub-tangent point location.

Gyro yaw measurement errors. (105 arcsec) 1.5
#
...total errors in the gyro relative yaw measurement

Spacecraft position errors 0.1

TOTAL (RSS) 2.6
#
3.2

> ORBIT-ORBIT ACROSS TRACK GRADIENTS - vertical. Duration 6000s. Arcsec at instrument.

Scan mirror elevation measurement error 0.70
...the total uncertainty in knowledge of the mean elevation angle between current scan and the scan 6000 s ago, including azimuth gimbal wobble, structural deformations within the scanner subsystem.

Scan mirror azimuth measurement uncertainty 0.01
...the variation of LOS pitch with azimuth slew for a misaligned scan mirror elevation axis places a requirement on azimuth measurement. For a worst case roll misalignment of 0.6 arcsec this places a requirement on scan mirror azimuth measurement of 3.5 degrees .CHK for a 65 degree slew.

Roll misalignment of the scan mirror elevation axis 0.16
...roll misalignment of the scan mirror elevation axis, resulting in a

variation of LOS pitch angle with azimuth slew. This places a requirement on knowledge of roll misalignment to 0.15 arcsec for a 65 degree azimuth slew (at the equator).

Changes in the boresight direction due to OB structure changes 0.30
...the total change in the line of sight pitch component of the boresight (this is taken to exclude changes in the scanner subsystem).

Gyro LOS pitch measurement errors. 0.05

...total errors in the gyro relative line of sight pitch measurement

Height errors. 0.05
...errors in knowledge of changes in spacecraft altitude, and knowledge of mean (typical 500km along-track x 100km across-track) location of earth's surface at sub-tangent point, equivalent to about 0.6 metre.

TOTAL (RSS) 0.77

> ORBIT-ORBIT ACROSS TRACK GRADIENTS - horizontal. Duration 6000s
In km, # across LOS, ! along LOS

Scan mirror azimuth measurement uncertainty (105 arcsec) 1.5
#
...the total uncertainty in the measurement of the change in azimuth angle including (elevation) gimbal wobble, structural deformations within the scanner subsystem.

Roll misalignment of the scan mirror azimuth (105 arcsec) 1.5
!
...roll misalignment of the scan mirror azimuth axis, resulting in a change of LOS pitch angle with azimuth slew. This places a requirement on knowledge of roll misalignment of 4.5 arcsec, assuming a 65 degree azimuth slew.

Changes in boresight yaw (OB structure changes) (105 arcsec) 1.5
#
...the total change in the spacecraft yaw component of the boresight (this is taken to exclude changes in the scanner subsystem)

Changes in boresight pitch (OB structure changes) (6 arcsec) 2.0
!
...the total change in the line of sight pitch component of the boresight (this is taken to exclude changes in the scanner subsystem)

Gyro LOS pitch measurement errors. (6 arcsec) 2.0
!
...total errors in the gyro relative line of sight pitch measurement result in errors in horizontal sub-tangent point location.

Gyro yaw measurement errors. (105 arcsec) 1.5
#
...total errors in the gyro relative yaw measurement

Spacecraft position errors 0.1

TOTAL (RSS) 2.6
#
3.2

Jitter.

For the purposes of this document, jitter is defined as motions outwith the gyro bandwidth. It is implicitly assumed that the gyro bandwidth is not greater than the signal channel bandwidth. All motions within the gyro bandwidth will be tracked by the gyro to within set by the gyro transfer function. The numbers below are predominantly from the DLS science requirements document.

Vertical jitter results in an unwanted input radiance to the instrument as the product of the jitter amplitude and the atmospheric radiance gradient (which typically changes by 1% in 75m). In addition the vertical field of view is smeared and additional terms are added to the pointing errors.

> Unwanted input radiance (motional chopping).
This is divided into synchronous and asynchronous components, and refers to jitter within the chopper bandwidth.

Synchronous chopping will lead to a constant radiance error in the atmospheric view. To produce no more than 0.1% radiance error, this suggests a 0.5 arcsec peak-peak synchronous jitter requirement. Note that synchronous in principle includes 3rd and higher odd harmonics of the chopper frequency, attenuated by the band-pass filter characteristics.

Asynchronous chopping will result in increased noise in the atmospheric view. For a 0.2% maximum error, a figure of <1 arcsec peak-peak is required.

> Vertical field of view smearing.

For a smearing of the field by 5%, a requirement of 11.5 arcsec peak-peak is imposed.

> Pointing errors.

The total integrated jitter should not be a dominant contribution to the pointing uncertainty. A total figure of 10% of the 0.5 arcsec total short term vertical requirement seems reasonable, that is 0.05 arcsec. Similarly, a horizontal requirement of 18 arcsec seems reasonable.