ALIGNMENT MONITORING SYSTEM FOR ASTRO-H

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INTRODUCTION

High Energy Astrophysics (HEA) encompasses a broad range of astrophysical science, with sources that include stars and stellar clusters, compact objects (black holes, neutron stars, and white dwarfs), supernova remnants, the interstellar medium, galaxies and clusters of galaxies, Active Galactic Nuclei (AGN), and gamma ray bursters, as well as a variety of fundamental physical processes. The physics involved includes extremes of gravity, density and magnetic field and is often inaccessible via any other waveband. HEA investigates and answers crucial questions in all fields of contemporary astrophysics.

Unlike the focusing of radio and optical light, X-rays are brought to focus through shallow, grazing incident angles. The analogy of skimming a stone across a pond is appropriate in describing how X-rays are focused. The higher the energy of the X-ray photon the shallower the incident angle must be, thereby introducing the requirement of longer focal lengths for focusing high-energy X-rays (E > 10 keV). This technical challenge has hindered scientific advancement in the high-energy regime, while at lower X-ray energies the community has prospered immensely with spectacular data from focusing observatories like XMM-Newton, Chandra, and Suzaku. Now, with ASTRO-H, the community will reap similar rewards from the tremendous improvement in spatial and spectral resolution at high energies. ASTRO-H is a JAXA mission. More information can be found on the ASTRO-H web site [1].

Because of the grazing-angle optics, high-energy X-ray instruments have a long focal length. The Hard X-ray Imager (HXI) of ASTRO-H has its detector housed in a boom that will extend by about 6 m in orbit so that a focal length of 12 m can be achieved for that instrument. This long structure will inevitably oscillate and flex, especially when passing across the orbital day/night boundary. In order to retain the essential imaging resolution, it is important that the boom has a metrology system that measures this flexion in order to allow post-acquisition compensation in generating the science images. In the current paper, we describe a possible Alignment Monitoring System (AMS) to measure in real time the relative position of the boom. The AMS will be an important element to guaranty that the ASTRO-H observatory will meet its performance requirements.

The Canadian Space Agency has the intention of providing the AMS to the ASTRO-H mission. The current paper reports a study that was conducted to support that intention.

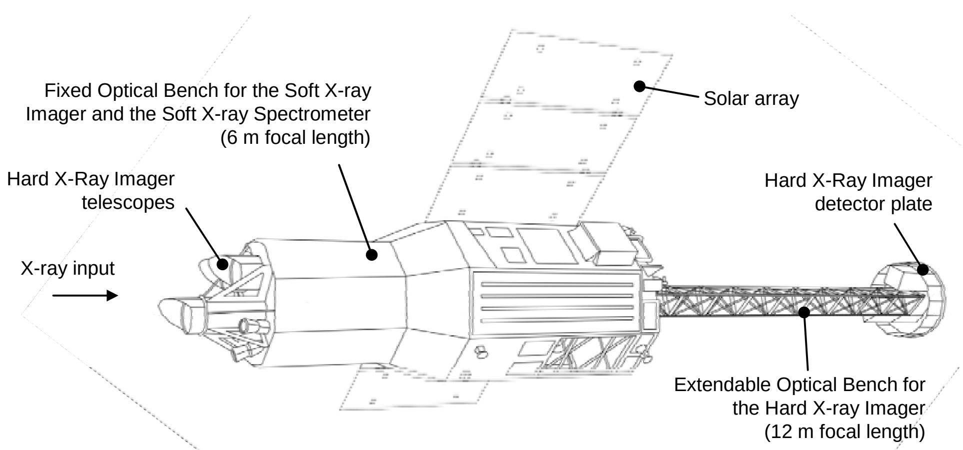

Fig. 1:ASTRO-H Observatory

ALIGNMENT MONITORING SYSTEM REQUIREMENTS

As mentioned previously X-Ray observatory does not rely on classical two mirror reflections such at those found in optical telescope. Another significant difference from optical observation is the fact that the X-ray detectors are not integrating such as a CCD or CMOS IR camera is. These detectors detect single incoming X-ray photons one by one by recording the time and position of detection thanks to the relatively low flux expected [2]. A raw acquisition thus presents itself as a series of detection accompanied with X,Y and time values. The image is then reconstructed by post-processing algorithms.

From this approach, it is easy to understand why relative movements between the detector and the telescope must be characterized with timing information more frequent than the frequency of the expected oscillations. Because of the long deployable boom of the HXI, low frequency oscillations are more susceptible to generate large displacement than high frequency one.

The proposed solution to this problem is to precisely measure the undesired displacement over time and append it to the data file for consideration in the post processing algorithms. The AMS is the module that will measure these transverse displacements (w/r to the optical axis) between the Fixed Optical Bench and the Extendable Optical Bench. Without the help of the AMS, the resulting images would be blurred with a magnitude that scales with the motion of the mast during the observation that can last more than one day. Also, many X-ray sources undergo spatial changes on time scales much less than a second for which the precise timing information of the AMS will be crucial.

It is proposed by JAXA that the AMS be segmented into two distinct modules: An active sensor head and a passive target. The Sensor Module is to be placed in the fixed optical bench structure, near the input. The Target Module is to be placed at the end of the deployable boom, near the detectors of the HXI. The two tables below give the main requirements of the two modules.

Table 1: AMS High Level Requirements

Number of modules	2
Position resolution (in X, Y)	< 60 µm (1-sigma) in X-axis and in Y-axis
Field of view (in X, Y)	wider than ± 10 mm
Sampling rate	> 5 Hz
Power consumption	< 5 W (Sensor Module) 0 W (Target Module)
Input voltage rail	unstabilized power supply (32V-52V DC).
Thermal	No heat transfer to mounting plate
Storage temperature	-30°C to 60°C
Data transfer I/F	Space wire
Mass	< 3 kg (Sensor Module) < 1 kg (Target Module)
Size	Cube with < 15 cm on a side (Sensor Module) Cube with < 5 cm on a side (Target Module)
Life time	> 3 years in LEO (550 km in altitude)
Operation Temperature in orbit	Bias (somewhere in the range -10°C to 40°C) Amplitude: ± 10°C

ALIGNMENT MONITORING SYSTEM CONCEPT

The concept that we propose for the AMS of ASTRO-H is very simple. It is based on components with high TRL. The goal is to achieve or exceed the required performance with a low risk and low cost system. The system has some elements of commonality with metrology system for NuSTAR described in [2].

The AMS Sensor Module has a solid state laser that is aimed at a cube corner reflector placed in the AMS Target Module. The returning beam is captured by a Position Sensing Detector (PSD) also placed in the Sensor Module. A PSD is a large area photodiode that returns a signal proportional to the position of the spot on its surface. A fibre optic taper is placed in front the PSD to extend its effective collection area. The module is shown on Fig. 2. The Sensor Module also includes the electronic board that drives the laser and the PSD.

The retroreflector of the Target Module is a trihedral prism (glass cube corner). That device returns the incoming laser beam at the same angle as the incidence angle regardless of the initial angle. The homogenous glass structure retains its characteristics over a very wide range of temperatures. The module is shown on Fig. 3. The Target Module is to be mounted at the end of the deployable boom near on the detector plate of the HXI, about 12 m away from the Sensor Module.

Depending on the relative position of the Target Module with respect to the Sensor Module, the returning beam will be more or less sheared. That shear is measured with the PSD in the Sensor Module. The displacement of the Extendable Optical Bench can be deduced from the measured shear.

The position of the beam on the PSD can be sensed with an accuracy of 5 µm (1-sigma) at a frequency of 5 Hz. Once the other sources of uncertainty are considered (high frequency jitters, thermal distortion, initial bias, etc.), the total position accuracy sensing of the AMS is 30 µm (1-sigma). The overall current best estimates of performances of the system are given in Table 2.

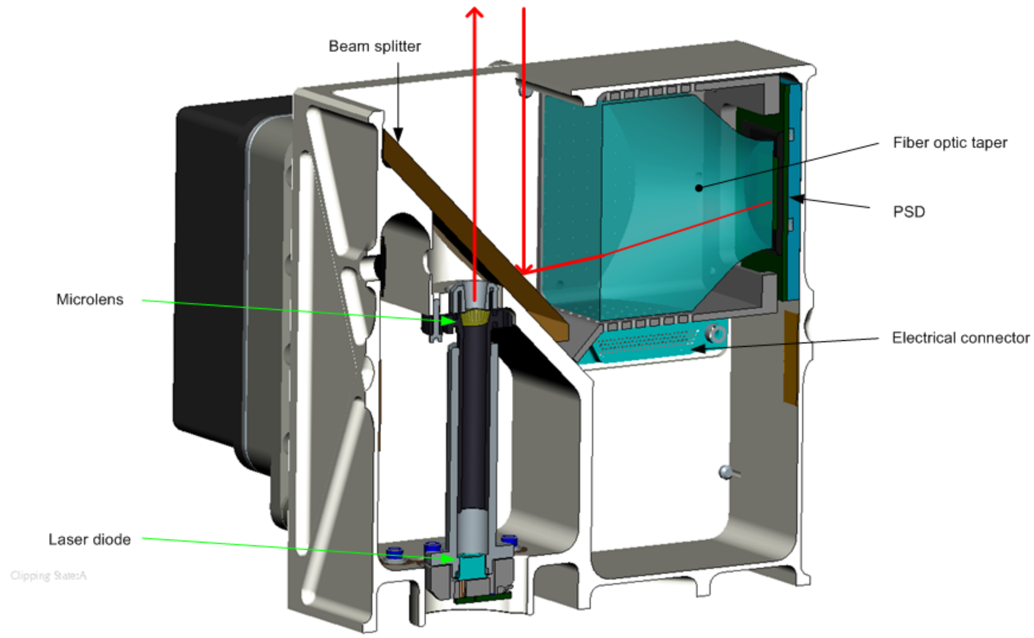

Fig. 2:AMS Sensor Module

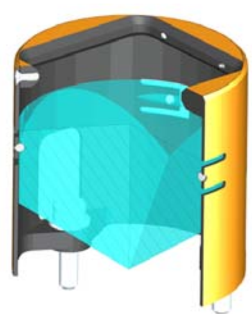

Fig. 3:AMS Target Module

Table 2: AMS Current Best Estimates of Performance

Position resolution (in X, Y)	< 30 µm (1-sigma) in X-axis and in Y-axis
Field of view (in X, Y)	± 13 mm
Sampling rate	5 Hz
Power consumption	3.3 W (Sensor Module) 0 W (Target Module)
Thermal transfer to mounting plate	250 mW (Sensor Module) 0 W (Target Module)
Mass	2.5 kg (Sensor Module) 0.2 kg (Target Module)
Size	$14.3 \times 14.3 \times 14.3$ cm^3 (Sensor Module) $5 \times 5 \times 5$ cm^3 (Target Module)

BREADBOARDING ACTIVITIES

In order to validate the concept and to verify the position sensing accuracy achieved with the PSD, a simplified breadboard of the AMS has been built. The breadboard was built with commercial components. The main elements of the AMS: PSD, retroreflector, beamsplitter, fibre optic taper, were present in the breadboard. The optical beam was folded to achieve a distance of 12 m in a smaller area.

The data from the PSD were acquired with an AD acquisition card in a PC. A Labview software was used to process and display the data. The data was sampled at a frequency of 12 kHz. Data averaged to a frequency of 5 Hz in order to improve the signal to noise ratio and the pointing accuracy.

100 measurements of the position (at 5 Hz) of the beam initially placed near the centre of the PSD were acquired. The PSD returns the position along the X and along the Y axis independently. Couples of X and Y positions were RSS'ed to obtain a single radial position value. Fig. 4 shows the histograms of the measurement sequence. The standard deviations of these distributions are 1.9 µm. The breadboard thus demonstrated that, when used as described above, the PSD can achieve a position accuracy better than 2 µm (1-sigma).

The breadboard showed that the approach is valid and that the PSD has the necessary accuracy to support the achievement of the overall accuracy of the AMS.

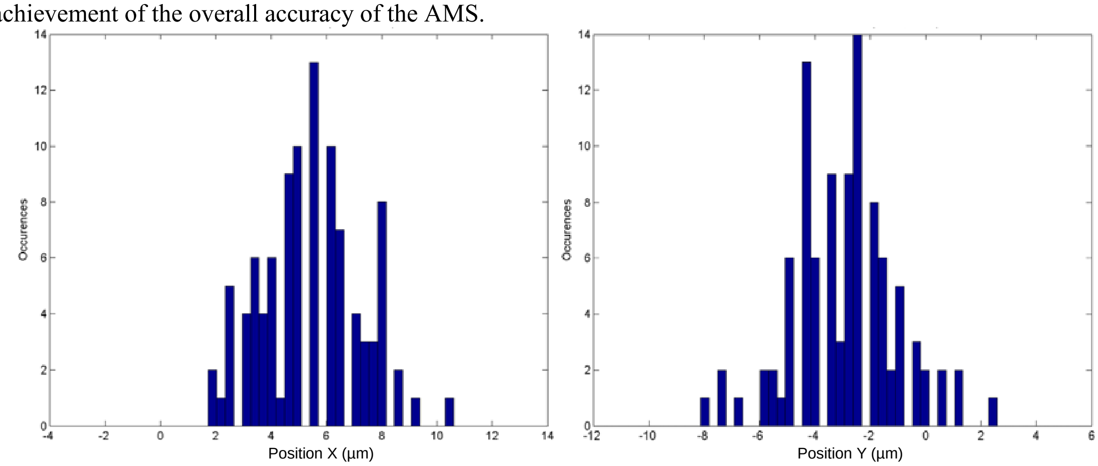

Fig. 4: Histograms of positions for a centred beam

CONCLUSION

We propose a very simple system, based on existing technology, to measure the transversal displacement of the Extendable Optical bench of the Hard X-ray Imager of ASTRO-H. The concept has been verified by breadboarding. The current best estimate of positioning accuracy is better than the requirement by a factor two.

ACKNOWLEDGMENT

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