

Thomson X-ray Polarimeter for a Small Satellite Mission

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ABSTRACT

We describe the current status of the design and development of a Thomson X-ray polarimeter. The experiment has been proposed to the Indian Space Research Organization for a small satellite mission. Currently, development of a laboratory model and design of an engineering model has been completed and the fabrication of the engineering model is in progress. We also present the development of a polarimeter test and calibration facility. This experiment will be suitable for X-ray polarisation measurement of hard X-ray sources like accretion powered pulsars, black hole candidates in different spectral states, etc. For about 50 brightest X-ray sources a Minimum Detectable Polarisation of 2–3% will be achieved.

KEY WORDS: polarization — instrumentation: detectors — instrumentation: polarimeters — techniques: polarimetric: thomson scattering — X-rays: binaries

1. Introduction

X-ray polarimetry is an unexplored area in high energy astrophysics. In the whole history of X-ray astronomy, Crab nebula is the only X-ray source for which a definite polarisation measurement exists (Weisskopf et al. 1976). Emission of X-ray photons involving magnetic field, scattering or beaming can give rise to linear polarisation and X-ray polarisation measurement can correctly identify the emission processes and geometry of the sources and their orientations. Polarisation measurement will give insight about the strength and the distribution of magnetic field in the source, geometric anisotropies in the source and their alignment with respect to the line of sight, as well as the nature of the accelerator responsible for energizing the electrons taking part in radiation and scattering. With this mission, X-ray astronomy research, and in a broader context, high energy astrophysics research will strongly enrich from X-ray polarisation measurements in many kinds of astrophysical objects.

This experiment will be suitable for X-ray polarisation measurement of hard X-ray sources like accretion powered pulsars, black hole candidates in different spectral states (Maitra et al. 2011), etc. For about 50 brightest X-ray sources, a Minimum Detectable Polarisation of 2–3% will be achieved.

2. Principle of operation

The instrument is based on anisotropic Thomson scattering of X-ray photons. X-rays from the source are made to undergo Thomson scattering and the intensity distribution of the scattered photons is measured as a function of azimuthal angle as shown in Figure 1. Polarised X-rays will produce an azimuthal modulation in the count rate. The total configuration will be rotated about the viewing axis.

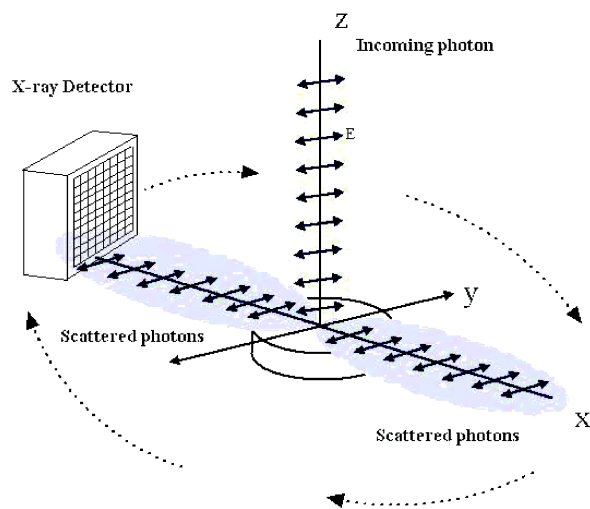


Fig. 1. Principle of operation of a Thomson X-ray Polarimeter

3. Instrument configurations

Two configurations are considered based on the geometry of the detector element (Rishin et al. 2010), (1) Rectangular and (2) Cylindrical detectors.

3.1. Rectangular detectors

Figure 2 shows the configuration of the Thomson Polarimeter with rectangular detectors. Here the detector elements are flat multi-wire proportional counters placed on four sides of a disk-like scattering element made of Be or Li. The geometry of the scatterer will be optimized using Geant4 simulation to get highest sensitivity (Vadawale et al. 2010). The instrument will have a photon collecting area of 1018 cm². Energy range covered will be 5–30 keV. Figure 3 shows the fabricated rectangular detector used for the lab model.

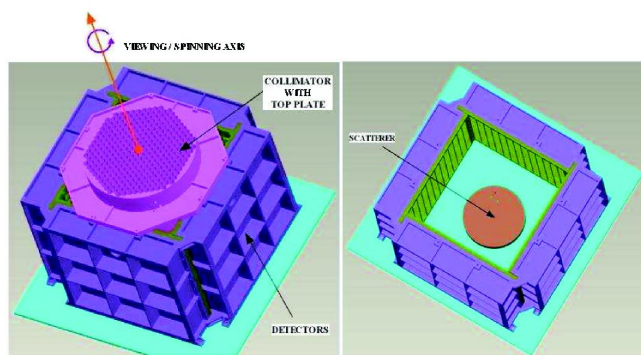


Fig. 2. Complete assembly design of the Thomson polarimeter with rectangular detectors. The inside view with the collimator removed is also shown

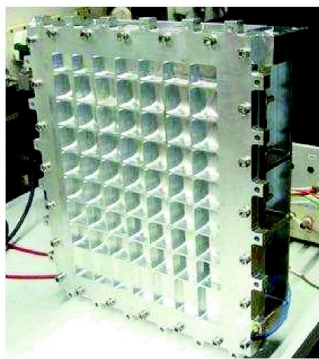


Fig. 3. The fabricated rectangular detector

3.2. Cylindrical detectors

The second configuration uses cylindrical detectors (Cowsik et al. 2010) as shown in Figure 4. In this configuration, we have a 360° coverage of the scattered photons which is an advantage compared to the rectangular detectors. The experiment will have two such detectors and each unit will weigh about 25 kg with a

photon collection area of 314 cm² each. In a cylindrical detector, we also expect to have uniform gain and quantum efficiency in all directions which will help to reduce systematic errors while searching for faint signal (i.e small fraction of polarised photons).



Fig. 4. Fabricated parts of the cylindrical detector and the total assembly

The detectors will be filled with xenon gas, with a few percent of quench gas, at a pressure of about 800 Torr.

4. Collimator

In order to restrict the field of view of the instrument, a collimator with field-of-view (FOV) 3° x 3° is designed. To compensate for inaccuracy in satellite pointing and to attain constant effective area over a range of offset pointing, a collimator with a flat topped response is required.

For the lab model, we have developed a honeycomb based collimator. In this construction, aluminium honeycomb is sandwiched between copper plates with circular holes. The holes on the front plate has slightly smaller diameter than the holes on the back plate which leads to a flat topped response. For the engineering model, we plan to fabricate the collimator from a solid aluminium block, with tapered hexagonal slots, thereby giving a flat topped response. Since aluminium does not provide enough X-ray absorption above ~ 15 keV, a silver coating will be provided on the Al surface to increase absorption. Figure 5 shows the honeycomb based collimator developed for the lab model and the hexagonal tapered holes machined on a sample piece for the engineering model collimator.

5. Test and calibration system

In order to test and calibrate the polarimeter, the following systems (shown in Figure 6) are at various stages

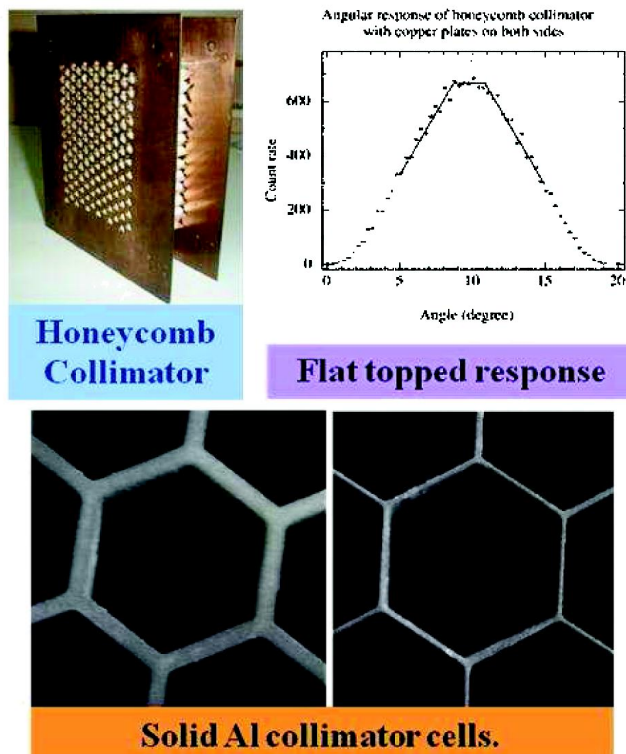


Fig. 5. Honeycomb based collimator developed for the lab model and the hexagonal tapered holes machined on a sample piece for the engineering model collimator. The flat topped response achieved for the honeycomb collimator is also shown

of development.

(1) A double crystal monochromator/polariser working in the energy range 2–60 keV to facilitate calibration of detectors over the entire energy band of interest. The total energy range will be covered using three pairs of crystals with $d = 1.15, 1.9$ & 3.1 Å. The first crystal plate has been fabricated with the 3.1 Å crystals parallelized to arc sec level. The crystal plate has been tested in the energy range of 7–11 keV and has energy FWHM of $\sim 2\%$ in this range.

(2) A polarised source based on Thomson scattering of X-rays from a low Z scatterer.

(3) A polarised source based on filtering out the highest energy (last 5–10%) photons from an electron beam X-ray generator (Tanaka et al. 1997).

(4) A rotary stage to simulate the spinning satellite platform during polarisation measurements.

6. The electronics developed and the test results

For the lab model, the detectors consisted of 6 proportional counter cells, grouped into two. The electronics consisted of charge sensitive amplifiers followed by simple anti-coincidence counters. Figure 7 shows the test results from the lab model using polarised and unpolarised sources. In the 9–23 keV range, we obtained a

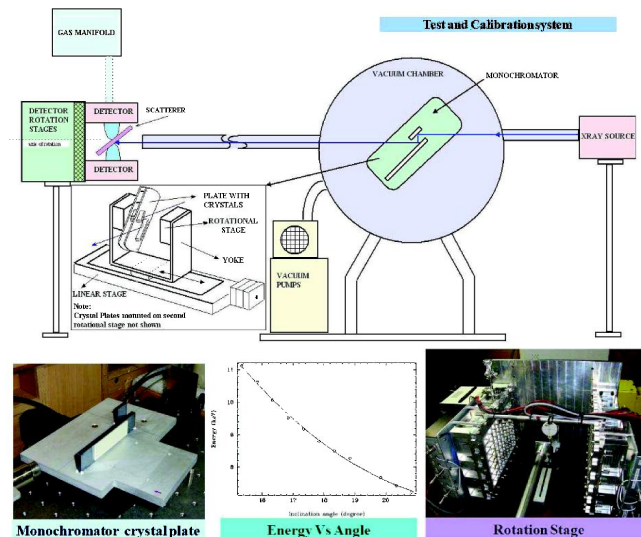


Fig. 6. Test and calibration system showing the vacuum chamber, the beamline, monochromator and the rotary stage

modulation factor of up to 44%.

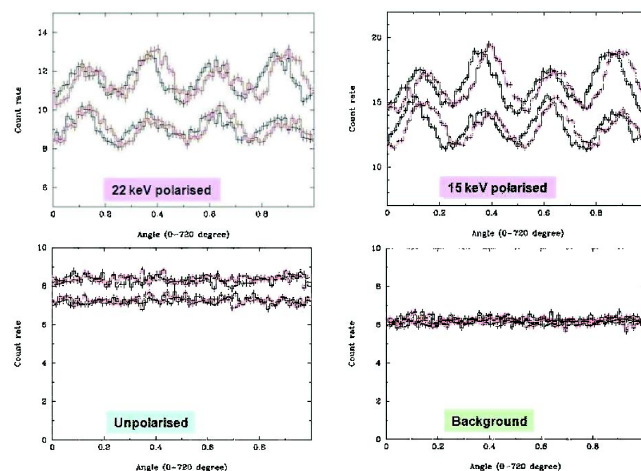


Fig. 7. Test results of X-ray polarisation measurement from the lab model

In the lab model detectors, each group of cells subtended about 30° angle to the scattering element. The modulation factor of the instrument can be improved by reducing the angle to less than 10° . Therefore, in the engineering model, we are using position sensitive proportional counters employing resistive Nichrome wires. The position sensitivity is achieved by charge division method. In addition to improving the modulation factor, it will also help to achieve better background rejection at the edges of the detector. The processing electronics logic is implemented in Field Programmable Gate Array (FPGA).

Taking into consideration, the requirements for modularization and redundancy, the polarimeter electronics is

made in the following five subsections as shown in Figure 8.

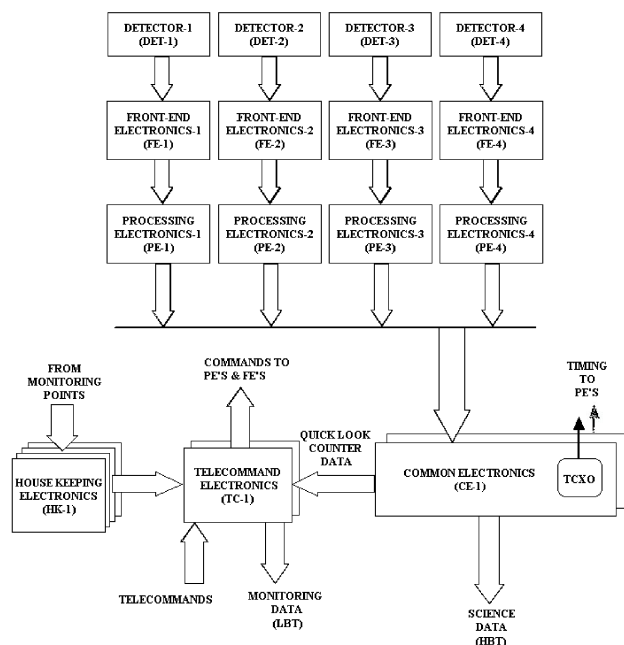


Fig. 8. Basic block diagram of the polarimeter electronics showing the five subsections

- (1) The front end electronics (FE) which provides controlled and stable high voltage bias to the detector, collects the charge pulses from the detector anodes and amplifies it to a proportional voltage pulse.
- (2) The processing electronics (PE) which selects or rejects the voltage pulses from the front end electronics using anti-coincidence logic and measures the peak amplitude of the pulses at both ends of the resistive wire.
- (3) The common electronics (CE) which collects the pulse peak information from the four processing electronics, adds timing information, produces data packets and transfers it to the satellite solid state recorder.
- (4) The house keeping electronics (HK) which acquires and monitors important payload parameters and
- (5) The tele-command electronics (TC) which acts as a command interface between the polarimeter electronics and the satellite bus and also passes on monitoring data (quick look data) from HK to the satellite bus.

Figure 9 shows the test results for the rectangular and cylindrical detectors employing charge division concept.

7. Conclusion

A Thomson X-ray polarimeter in the 5–30 keV energy band is being developed for a small satellite mission. A laboratory model has been made and tested successfully. The experiment has been proposed to the Indian Space Research Organization for a small satellite mission. Design of the engineering model of the instrument has been

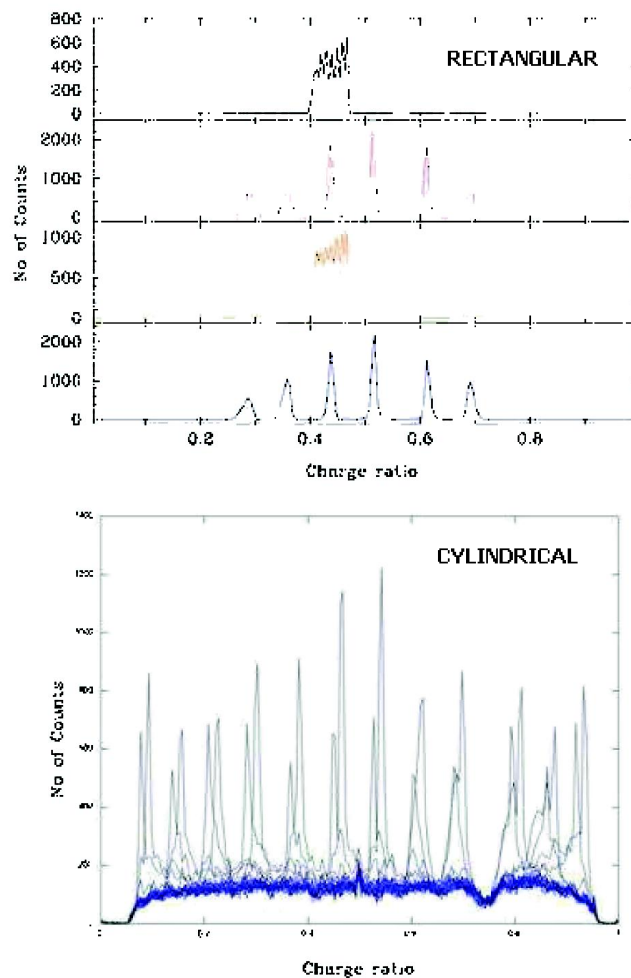


Fig. 9. Test results for the rectangular and cylindrical detectors employing charge division concept. The peaks are obtained by shining 22 keV X-rays from a Cd source in different wire segments and taking the histogram of the peak ratio

completed and fabrication is in progress.

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