A Solar X-Ray Detector aboard “TAIYO”

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An X-ray detector was mounted on the third Japanese scientific satellite “TAIYO” in order to search for solar X-rays produced by solar flares. This instrument is named “SXR,” an acronym for Solar X-Ray. It is sensitive to two X-ray energy ranges of 5.9–9.5 keV and 9.5–11.5 keV and has an area of 3 cm². Its time resolution is about 8 seconds. Since it is also sensitive to charged particles, it can investigate the charged particle intensity distribution in the radiation belt and the nature of precipitation particles in the orbit when TAIYO is at around the perigee.

1. Introduction

The main purpose of SXR is to examine the coronal high temperature and high density regions, which are generally called the sporadic coronal condensation and are probably produced by solar flares. We can investigate high energy properties of the sun by solar X-rays with data from radio waves and optical emissions obtained by ground observatories. The other objective of SXR is to clarify the effect of charged particles as well as of solar X-rays on the ionosphere and the thermosphere. This X-ray instrument can also detect X-ray emission from strong cosmic X-ray sources in the night sky.

The X-ray instrument consists of a small proportional counter whose sensitive energy ranges are set between 5.9 keV and 11.5 keV to detect X-rays from high temperature regions of about 3×10^7 °K.

Solar X-rays with energies below several keV are observed by ionization chambers and those with energies above 10 keV by scintillation counters. The X-ray detector aboard “TAIYO” can detect X-rays in medium energy ranges which are important for the observation of X-rays from the hottest coronal regions.

In the following sections we describe the functions of the X-ray instrument and properties of the proportional counter.

2. Functions of the Instrument

A cross section of the X-ray detector is shown in Fig. 1. In Fig. 2 is shown a photograph of the instrument without the cover.

In order to avoid saturation due to soft X-rays below several keV, absorbers of 4 mm thick Be and $50\ \mu$ Al cover the entrance window of the proportional counter. The box type proportional counter with the inner dimensions of $2 \times 2 \times 5\text{ cm}^3$ has a Be window 0.25 mm thick and is filled with Xe+3% CO₂ at a pressure of 500 mmHg. The X-ray counting efficiency for normal incidence is shown in Fig. 3 by the solid curve. The effective efficiency with absorbers is also shown in this figure by the dotted curve. We can observe X-rays from medium solar flares or those having greater energies.

As shown in Fig. 4 counting rates from each channel are sent to a scaler through a 1/4 scale down circuit. A 10-bit scaler and a 6-bit scaler are used for the low energy channel of 5.9–9.5 keV and for the high energy channel of 9.5–11.5 keV respectively. All of 16-bit data are sent to the 10th and 11th words of a PCM telemetry system.

Fig. 1. A cross section of the counter and the collimator.

Fig. 2. A photograph of the solar X-ray instrument.

Fig. 3. Efficiency of the proportional counter. The solid curve shows the efficiency of the counter itself and the dotted curve is its efficiency with absorbers.

Fig. 4. A block diagram of the observation system of solar X-rays.

A command signal from a ground station can calibrate the solar X-ray detector system. The method of calibration is to use 5.9 keV X-rays from Fe^{55} at the back of the proportional counter with a moving arm. Since the level of the lower discrimination of the low energy channel is adjusted to an energy of 5.9 keV of Mn K-X-ray, one half of the counts from the calibration X-rays are detected in the low channel. This counting rate per unit time is sensitive to a level shift. We can thus calibrate the level shift with an accuracy of about 1%.

We control ON/OFF of the scaler circuits by two sun sensors attached in front of the instrument. The field of view of the X-ray detector is $\pm 32^\circ \times \pm 45^\circ$

along the directions perpendicular and parallel to the spin axis. Two sun sensors are set to $+35^\circ$ and -35° in the direction perpendicular to the spin axis as shown in Fig. 1.

We can decide night- or day-mode by the presence or absence of signals from the sun sensors. In the night mode we can observe the background intensity for 3 seconds in every 8 seconds.

Even though SXR and the solar ultraviolet detector outputs share the 10th and 11th words of PCM telemeter, there is no serious trouble since two detectors are set on the opposite sides. SXR has a higher priority to the telemeter and the state of *all 1* data in the 10th word means that the 11th word is switched to the output of solar ultraviolet.

Protons with higher energies than 20 MeV and electrons with higher energies than 1.6 MeV are detected as background counts.

The total weight of the solar X-ray instrument is 1.8 kg and it consumes 1.6 W of electric power.

3. Characteristics of the Proportional Counter

We should take into consideration the following two characteristics of the proportional counter in the data analysis when it detects X-rays as intense as those from solar flares.

- (1) The pulse height decreases as the intensity of incident X-rays increases.
- (2) Incidence of intense X-rays on the proportional counter gives rise to the pulse pile-up phenomenon.

Since both are general properties of a proportional counter, we can not neglect these effects in the detection of intense X-rays with it.

We describe these two characteristics in the following sub-sections.

3.1 *Pulse height response characteristics*

We can obtain the following experimental results as a characteristic of a proportional counter in its pulse height response to incident X-rays.

- (1) The pulse height decreases when the intensity of incident X-rays increases, keeping the incident detection area constant as shown in Fig. 5.
- (2) When the detection area is decreased, keeping the incident counting rates constant, the pulse height also decreases.

These phenomena are due to the following causes.

An incident X-ray ionizes the gas in the counter and makes primary electrons and ions. These electrons are accelerated to the anode wire and finally

Fig. 5. Experimental data showing a decrease in pulse height as the intensity of incident X-rays increases.

an electron avalanche occurs. Ions created by this avalanche drift to the cathod, but the drift velocity is much slower than that of the electrons. Although the electrons get to the anode in several tens nano-seconds, ions drift to the cathod in several hundreds μ seconds. If the intensity of the incident X-rays increases, a number of ions drift in the counter. Since these positive space charges in the counter effectively weaken the electric field and the gas multiplication is suppressed, the pulse height decreases.

The electric field at a distant r from the anode wire in a cylindrical counter is expressed in the MKS system as

$$E = \frac{1}{r \ln(r_2/r_1)} \left\{ V_0 - \frac{Ne}{2\pi\epsilon_0} \ln(r_2/r_+) \right\} \quad (r_1 \leq r \leq r_+), \quad (1)$$

where r_1 and r_2 are the radii of the anode and the cathod respectively, r_+ radius of the ion cloud, V_0 the initial supply voltage to the anode, N the number of electrons per unit length and ϵ_0 is the dielectric constant of vacuum.

For example from Eq. (1) 5.9 keV X-rays with an intensity of 10^4 counts/sec effectively weaken the initial voltage by 6 V. They suppress the gas multiplication by about 6%. This is consistent with experimental data.

3.2 Pulse pile-up characteristics

Two X-ray photons make a pulse with a higher pulse height when they enter into a counter simultaneously or within a short time interval. This phenomenon is called the pulse 'pile-up' effect. When the counter is irradiated by

Fig. 6. A pulse height distribution obtained for intense X-rays entering into the counter. Peak 1 is the peak due to the pulse height distribution of 5.9 keV X-rays and peak 2 is that due to the pulse pile-up of 5.9 keV X-rays.

intense X-rays, the pulse pile-up will have an important effect on the pulse height distribution as shown in Fig. 6.

Assume that random X-ray photons enter into the counter with an average counting rate of λ counts/sec. The probability that the successive X-ray photon does not enter the counter till $T=0$ is given as

$$P(t) = e^{-\lambda t}. \quad (2)$$

Since the distribution function of incident X-rays is given as $f(t) = e^{-\lambda t}\lambda$, the probability that another X-ray enters into the counter between $T=0$ and $T=t$ is obtained as

$$P_1(t) = \int_0^t e^{-\lambda s} \lambda ds e^{-\lambda(t-s)} = e^{-\lambda t} \lambda t. \quad (3)$$

Generally the probability that n photons can enter into the counter within this time interval is given as

$$P_n(t) = \frac{1}{n!} (\lambda t)^n e^{-\lambda t}. \quad (4)$$

This function is known as the Poisson distribution.

If we substitute t_r , the pulse rise time of the X-ray detector system, for t in Eq. (3), we can obtain the probability for producing a pulse about twice as high as the normal pulse height. The probability obtained by Eq. (3) is reasonable for our experimental results as seen from Fig. 7. We must take into consideration the pulse-up ratio and the pulse height distribution shown in Fig. 3.

Fig. 7. Pulse pile-up ratio against incident X-rays. The solid curve is a theoretical one.

4. Conclusion

SXR aboard "TAIYO" is working without any trouble after launching. Since solar flares occur much rarely in the sun at present, we have not observed intense X-rays. We have obtained many data on the background around TAIYO's orbit. They can clarify the intensity variation in the radiation belt and precipitation particles. The results will be presented elsewhere.

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