Line Image Correction of the Positron Camera in the Secondary Beam Course of HIMAC

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ABSTRACT

A positron camera, consisting of a pair of Anger-type scintillation detectors, has been developed for verifying the ranges of irradiation beams in heavy-ion radiotherapy. Images obtained by a centroid calculation of photomultiplier outputs exhibit a distortion near the edge of the crystal plane in an Anger-type scintillation detector. The images of a ^{68}Ge line source were detected and look-up tables were prepared for the position correction parameters. Asymmetry of the position distribution detected by the positron camera was prevented with this correction. As a result, a linear position response and a position resolution of 8.6 mm were obtained over a wide measurement field.

Keywords: positron camera, positron emitter, gamma ray, range, radiotherapy

1. INTRODUCTION

A project using positron emitter beams such as ^{11}C is underway at the Heavy-Ion Medical Accelerator in Chiba (HIMAC) to verify the ranges of irradiation beams. For the measurements, a probing beam of positron emitters is injected into a position of interest in a tumor, e.g., quite close to a critical organ. A positron camera is a key device which determines the end point of the beam trajectory in the body by detecting pairs of annihilation gamma rays from the positron emitters. The positron camera consists of a pair of Anger-type scintillation detectors in order to be free from the sampling theorem. The positions where the gamma rays were deposited in a planar NaI(Tl) crystal are obtained by a centroid calculation of photomultiplier outputs. Since the number of photomultipliers used in the calculation is finite, the calculated positions of the gamma rays deposited near the edge of the crystal move toward the center of the crystal and the image is distorted. This distortion causes a nonlinear position response in the positron camera measurement and the position resolution decreases. Thus, it is important to correct the calculated position in each constitutive detector for high accuracy.

2. APPARATUS

The positron camera is required to measure the ranges with accuracy of less than 1 mm under the limitation of irradiation dose. Thus, the crystal size was optimized as a function of the range accuracy by numerical simulation[1]; 600 mm in diameter and 30 mm thick. For good spatial resolution, the surface of the crystal is diffusively reflective at the front and absorbent at the edge. 109 2-inch photomultipliers are mounted on a crystal as shown in Fig. 1. The effective detection area on each constitutive detector is inside of the diameter of about 500 mm. The distance between the two detectors is variable from 500 to 700 mm and now is set as 700 mm.

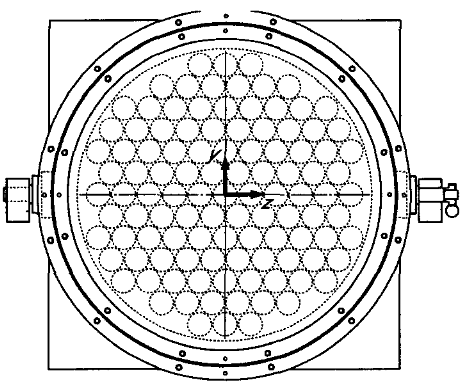


Fig. 1. Arrangement of photomultipliers on a detector

3. POSITION CALCULATION PROCEDURE

When the coincidence condition is satisfied for the constitutive detectors (Detector-A and Detector-B), the outputs of all photomultipliers are transferred and stored in the control computer. The position calculation procedure is as follows. Firstly, the gamma ray injection position is pre-evaluated by a centroid calculation on each detector. Next, the deposited energy on each crystal is calculated by a summation of photomultiplier outputs; the deposited energy is calibrated by using a previously taken function, dependent on the position. Then, the position correction (line image correction) is done. The 2-dimensional correction parameters (ΔY, ΔZ) are looked up in a table for each detector. Finally, the positron emitter position is calculated from the gamma ray incident positions on two detectors, (Y_A, Z_A) and (Y_B, Z_B), and the beam axis (X).

4. POSITION CORRECTION

4.1. Measurement of Position Correction Data

The data for evaluating the position correction parameters were obtained with a ^{68}Ge line source collimated by a 1-mm gap. The line source was mounted with a driving stage immediately in front of the crystal which was covered with a thin aluminum plate. The line images of the annihilation gamma rays were detected at intervals of 40 mm in the vertical and horizontal directions (on the y and z axes) for each detector. The line image is likely to depend on the deposited energy of the gamma rays because the depth where they deposit in the crystal depends on the energy. For simplification of the position correction, the data were taken for the deposited energy within $\pm$ 11% of 511 keV; here, the window width corresponds to the energy resolution of 11% in FWHM.

4.2. Position Calculation Expression

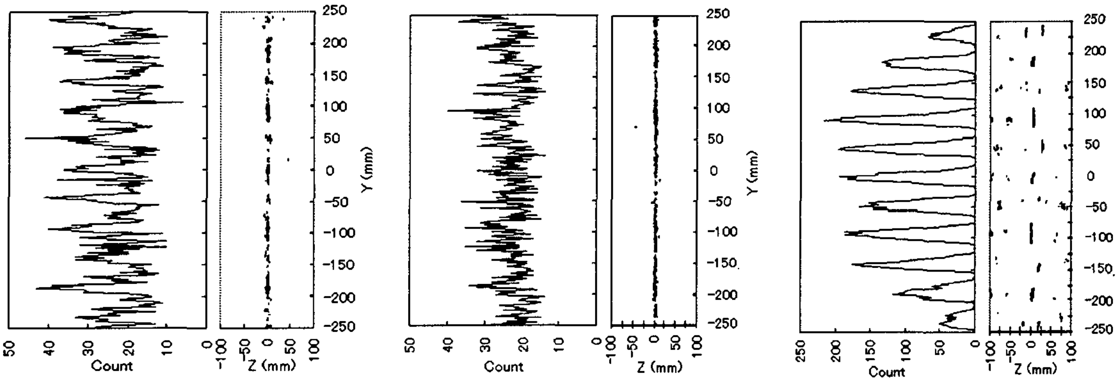
We examined three calculation expressions: (1) discrimination centroid calculation, (2) bias centroid calculation, and (3) local centroid calculation. These calculations are defined as follows.

Discrimination: $$Z_{\mathrm{d}} = \sum_{i}^{109}(z_i P_i) / \sum_{i}^{109} P_i, \quad \text{if } P_i < P_{\mathrm{d}},\ P_i = 0.$$

Bias: $$Z_{\mathrm{b}} = \sum_{i}^{109}\left[z_i (P_i - P_{\mathrm{b}})\right] / \sum_{i}^{109} P_i, \quad \text{if } P_i < P_{\mathrm{b}},\ P_i - P_{\mathrm{b}} = 0.$$

Local: $$Z_{\mathrm{l}} = \sum_{i}^{7}(z_i P_i) / \sum_{i}^{7} P_i.$$

Here, z_i is the position of the i-th photomultiplier and P_i is its output. The discrimination level (P_{d}) and the bias level (P_{b}) were set to 20% of the peak value of the output distribution of the photomultiplier for which the deposit position of the 511 keV gamma rays was the closest. The number of photomultipliers used in the local calculation consisted of the highest-output photomultiplier and 6 surrounding ones.



(a) Discrimination (b) Bias (c) Local

Fig. 2. Line images and projected distributions for three calculation methods

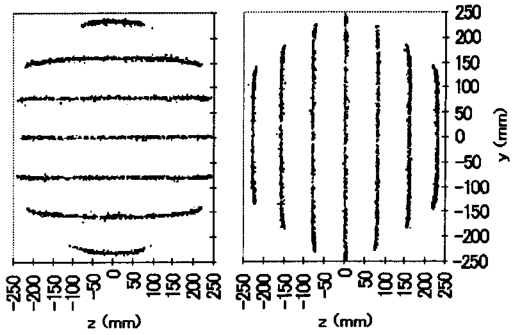
The line images and the position distributions projected onto the y-axis are illustrated in Fig. 2. The position distribution by the discrimination calculation has notches at the frequency of the photomultiplier arrangement, and furthermore, the position distribution by the local calculation separated completely. The distribution by the bias centroid calculation is the most uniform. Since one advantage of the Anger-type scintillation detector is freedom from the sampling theorem, we chose the bias centroid calculation.

4.3. Position Correction

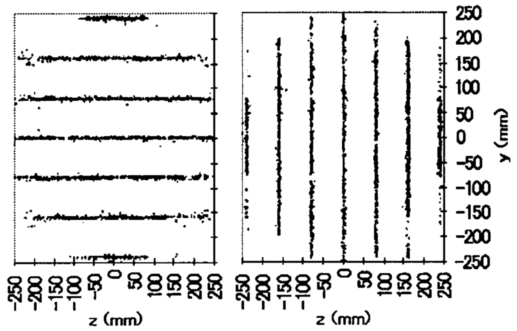
The position distortion is corrected by

$$Y_k = Y_{k,\mathrm{pr}} + \Delta Y_k, \quad Z_k = Z_{k,\mathrm{pr}} + \Delta Z_k,$$

where $Y_{k,\mathrm{pr}}$ and $Z_{k,\mathrm{pr}}$ are the pre-evaluated positions. The subscript k denotes Detector-A or Detector-B. The correction parameters (ΔY_k, ΔZ_k) were obtained as the difference between the setting position of the line source and their calculation points. The bias level was set to 7% of the peak output as mentioned above. The parameters in the area between each line were obtained by interpolation.
The change of the line images by the position correction is shown in Fig. 3. The curved lines near the edge were modified well and became straight.



(a) Before correction



(b) After correction

Fig. 3. Line images before and after correction

5. POSITION RESPONSE AND RESOLUTION

Position responses of the positron camera were measured for the cases with and without the line image correction. Here, the point source of ^{22}Na was moved on the central beam axis (the z-axis). The differences between the setting positions and the measured ones are shown in Fig. 4. Whereas the measured positions in the case without the line image correction moved toward to the center, those with the correction agreed with the setting positions in a standard deviation of 0.3 mm within ± 200 mm region. Figure 5 shows the dependence of the position resolution on the source position. The resolution was 8.6 mm in FWHM within ± 50 mm and was almost independent within ± 200 mm after the line image correction.

6. DISCUSSION AND CONCLUSION

Figure 6 shows the position distribution for the case when the point source was set 50 mm from the center. While the distribution before the line image correction extended toward the center, the distribution became symmetry after the correction. This improvement in the distribution led to good resolution and good linearity of the source position response. The position resolution is dominantly influenced by the parallax effect: a spread due to the large incident angle of the gamma ray pairs. When the gamma ray incident area on Detector-A was restricted within 50 mm from the source position to restrict the incident angle, the resolution was improved from 8.6 mm to 5.9 mm. These values of the resolution agreed with previous simulation results[1]. Thus, it has been found that the positron camera has the desired design characteristics. The positron camera has a linear response in a wide measurement region. This means that only an offset adjustment is necessary for application to range verification. Furthermore, the camera is useful to detect an irradiation field image because it has linearity within ± 200 mm.

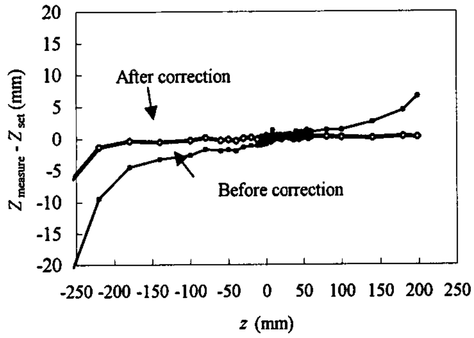


Fig. 4. Difference between setting and measurement positions.

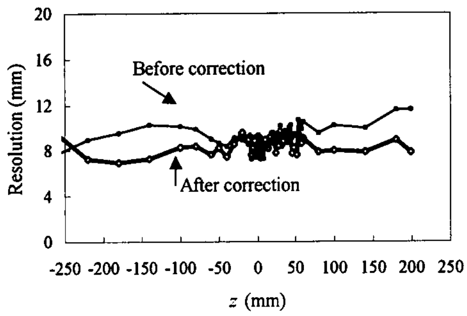


Fig. 5. Position dependence of resolution.

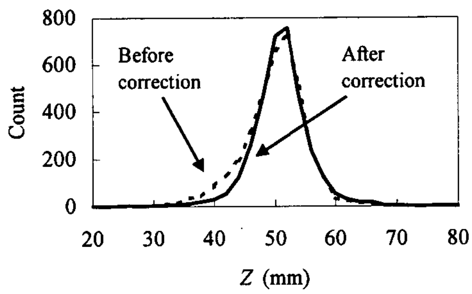


Fig.6. Position distribution before and after correction.

REFERENCE

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