PB06

3D Visualization of Fast Light Emission Phenomena by Dynamic CT

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Abstract

3D visualization of Cherenkov radiation in water generated by an electron beam from the 28 MeV linac of University of Tokyo was performed. We introduced the light emission computed tomography theory. We adopted the fan beam projection using a rotating mirror, a collimator, an optical fiber and a photo-multiplier. Cherenkov radiation passing through the collimator enter a photo-multiplier via an optical fiber. The optical fiber should be shielded against X rays. At the first stage, we succeeded in reconstructing the image of distribution of Cherenkov radiation in water, with the nanosecond time resolution.

1.Introduction

Recently, Computed Tomography(CT) is progressing remarkably in the field of the diagnostic technology and medical treatment technology. Dynamic light emission CT is the way of 3D visualization of a luminous body using the algorithm of CT. For now, it had obtained the distribution of the emission that was emitted from a fluorescent tube or a discharge tube, with the millisecond time resolution. The purpose of this research is to enhance the time resolution of this CT and to get the dynamic image of distribution of light emission phenomena in nano- and picosecond time domains. At the first stage, we measured Cherenkov radiation in water generated by an electron beam from the linac of University of Tokyo, and reconstructed the image of distribution of the emission by the light emission CT theory.

2.Theory of CT

In order to obtain the CT image of a body, we need to get projection data in all directions. Assuming that f(x,y) is the distribution of light emission from the body, the projection data in the θdirection, p(r, θ), in the r-s coordinate which rotate θ angle from the x-y coordinate are given as follows (see Fig.1),

$$
\begin{aligned}
&p(r,\theta)\\
&= \int_{-\infty}^{\infty} f(r\cos\theta - s\sin\theta, r\sin\theta + s\cos\theta)ds\\
&= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\delta(x\cos\theta + y\sin\theta - r)dxdy
\end{aligned}
$$

where $r = x\cos\theta + y\sin\theta, s = -x\sin\theta + y\cos\theta$.

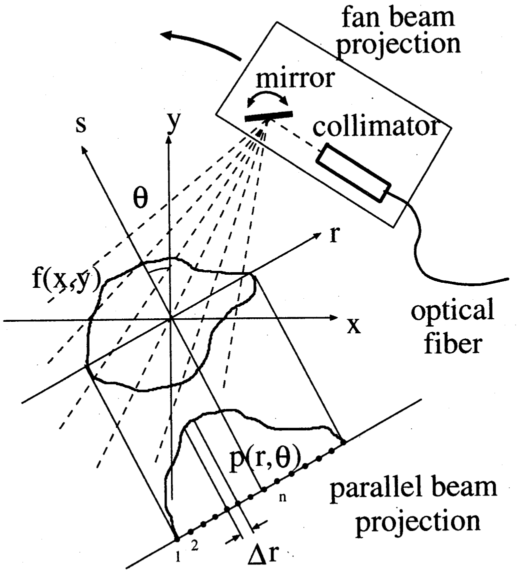


Fig.1: Parallel beam projection and Fan beam projection

This equation is called the Radon transformation. Applying this transformation to the angle range $0 \leq \theta < 2\pi$, the projection data are made. This projection method is called the parallel beam projection (solid lines), while there is another method, the so-called fan beam projection(broken lines). To reconstruct the image from projection data, we backproject the projection data in all directions. Actually we perform Radon inverse transformation discretely. There are three methods for the backprojection such as the 2D-Fourier transform method, the filtered back projection method and the convolution method. Here, we use the convolution method since we can choose an appropriate filter function to get a clear image. The projection data are multiplied by filter function h(r) and we carry out the convolution to get corrected projection data. We can reconstruct the image of f(x,y) by backprojecting this corrected data $^{(1)}$.

$$
\begin{aligned}
&f(x,y)\\
&= \int_0^{\pi}\int_{-r_{max}}^{r_{max}} p(r,\theta)h(x\cos\theta + y\sin\theta - r)drd\theta\\
&= \sum_m\sum_n p(n\Delta r, m\Delta\theta)h(n\Delta r)
\end{aligned}
$$

We use the Shepp and Logan filter function as follows,

$$h(n\Delta r) = 2/\pi^2(\Delta r)^2(1-4n^2)$$

3.Experimental setup

The experimental setup is shown in Fig.2. The energy of an electron beam is 28MeV, macro pulse width is 2.5ns, electric charge is 3.2nC/pulse. The electron beam passed through a glass tube. The glass tube is filled with water and the water is shielded by Ti windows at the both ends. When the electron beam passes through it, we take Cherenkov radiation in water from the side of the glass tube through a collimator. The light signal passes through the collimator, an optical fiber, a photo multiplier with multi channel plate(MCP-PMP), and is measured and processed at a transient digitizer. The diameter and the length of the glass tube are ϕ50mm and 175mm, respectively. The inner diameter of the collimator is ϕ1mm and the outer diameter and the length of the fiber is $\phi 600\mu$m, and 10m respectively. We applied -2kV to the photo multiplier. The xyz coordinate is defined as shown in Fig.2. The measurement plane is vertical to the z axis, and we carried out the fan beam projection by using the rotating mirror. Then, we move the optical equipment along the z axis, to obtain the data for 3D reconstruction. The mirror area is a 18mm square, and the mirror is fixed and centered at the axis of the rotation stage to reflect the light into the collimator. By using this mirror, we could avoid that the optical fiber faces directly, the water tube where X rays are generated, so as to reduce the light noise generated by X ray irradiation in the optical fiber. By taking account of axisymmetry of the water tube, we didn't scan the collimator in the azimuthal direction and scanned the mirror only in the range of 24° at a half side of the fan beam projection. The step angle is 3°, and the measurement plane is changed by 10mm step from the point of z=19mm to z=119mm. We measured the light noise data by cutting the visible light at the entrance of the collimator by a paper beforehand and subsrtucted them from all measure data.

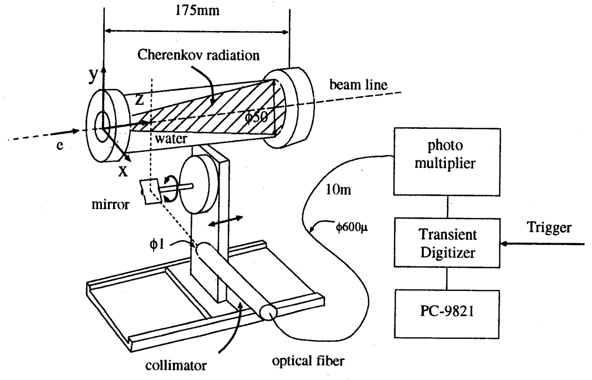


Fig.2:Experiment setup

4.Result

Because of axisymmetry of the configuration, we measured only the least necessary data, and assigned them to 31 fan beam projection data in the mirror angle range of ±45° at 72 azimuthal angles around the water tube. Under this assumption, we calculated the reconstruction image. We show the reconstruction image of the distribution of Cherenkov radiation in water as shown in Fig.3. It is the view in the x-y cross section at z=29mm After we reconstructed in the x-y image at each z position, we integrated them with respect to the x coordinate and time, the y-z image as shown in Fig.4. For comparison, we show the picture of Cherenkov radiation taken by a CCD camera as shown in Fig.5. It looks that strongly radiated area in the reconstruction is more widely distributed than in the photograph. It can be attributed to lack of spatial resolution in the x-y plane due to the large radius of the the optical fiber.

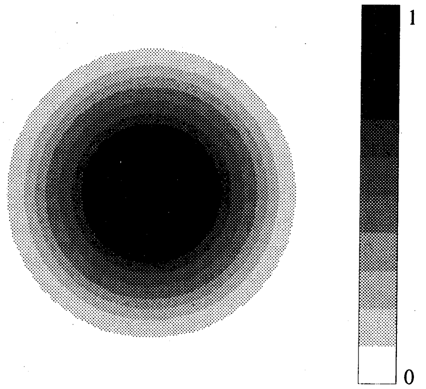


Fig.3:x-y cross sectional image (z=29mm)

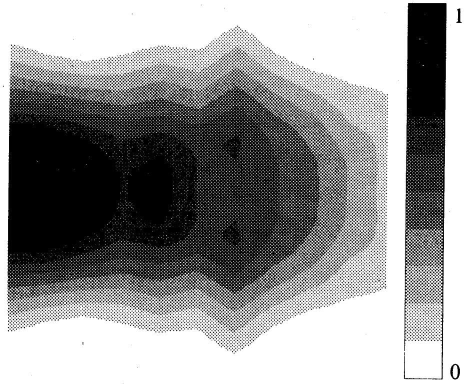


Fig.4:Image of reconstruction integrated data along x axis and about time.

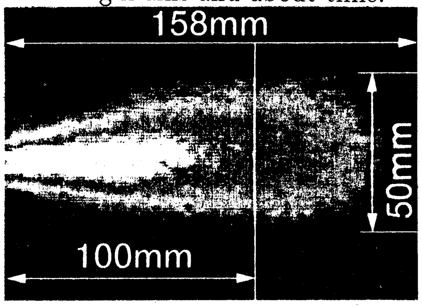
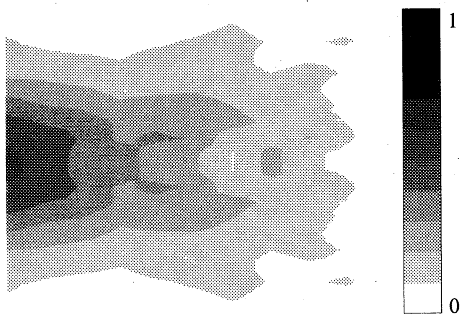
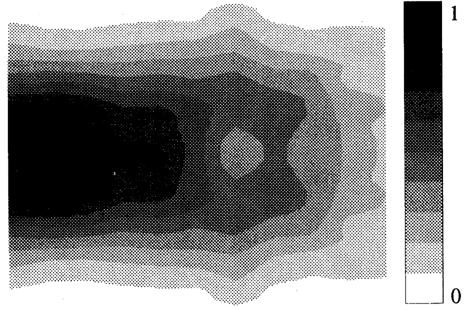


Fig.5:Picture of Cherenkov radiation in water

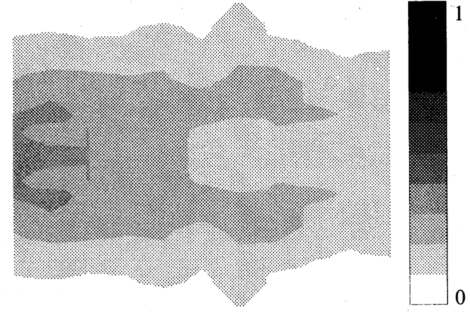
Next, we show the time variation of Cherenkov radiation in the y-z plane at x=0 as shown in Fig.6(a)~(c). Fig.7 shows the time variation of maximum projection data at z=19mm. It is clear that the electrons lose their energy near the entrance of the electron beam and the resultant emission area is localized there.



(a):t=1.0ns



(b):t=2.0ns(peak)



(c):t=4.0ns

Fig.6:Time variation of Cherenkov radiation in the y-z plane.

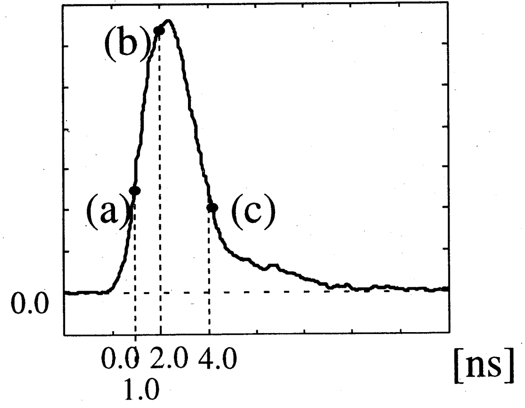


Fig.7:Time variation of maximum projection data at z=19mm

In this experiment, we manually positioned the mirror and other optical equipments and it is thought that there are rather position errors. But now we are manufacturing a automatic measurement system as shown in Fig.8. The system has a column made of Pb to cover the body to shield the optical fiber against X rays, and the column has a small window for light extraction into the collimator. It rotates keeping the window to face the mirror. By using this system, we can get fan beam projection data with high spatial resolution quickly. Now, because we use the photomultiplier as the detector of light, the time resolution is limited to nanosecond, but we will introduce a streak camera to enhance the time resolution to picosecond soon.

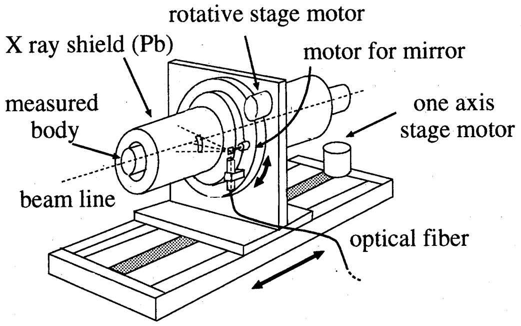


Fig.8:3D Automatic Measurement System

5.Conclusion

A 28 MeV electron beam generated by the linac passed through the glass tube filled with water. Then we took the Cherenkov radiation in water by the collimator with the rotating mirror, the optical fiber and the photo multiplier. Using the measured data, we calculated the reconstructed image of each section which is vertical to the beam line by the light emission CT theory. Finally, then we succeeded in getting the 3D image of the radiation distribution with the nanosecond time resolution. We used the convolution method for numerical reconstruction where the Shepp and Logan filter function is used. Hereafter we attempt to enhance both spatial and time resolutions by introducing the 3D automatic measurement system and the streak camera.

Reference

(1)Tsuneo SAITO : "Image Processing Algorithm" ,Ohmikagakusha,1993.