3P4-10

Visualization of Charged Heavy Particle Tracks in Water with Ultrasonic Imaging

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1. Objectives and background

In this study, experiments have been conducted to investigate the mechanism of the phenomenon that the trajectories of heavy ion particles particles are visualized by ultrasonic echoes when those particle beams are irradiated into water.

In the field of medical physics, research on the detection and measurement of "acoustic waves" generated from the position of the Bragg peak of a water phantom (a tank filled with water) after irradiating it with particle beams has been actively conducted both in Japan and abroad.[1-4] This study, on the other hand, attempts to detect the position of the source of the "acoustic waves" rather than the "acoustic waves" themselves in water irradiated with particle beams. The idea is that if there is a local temperature increase or density change due to the loss of energy of the particle beam in the water, then changes in acoustic propagation may be observed.

For example, if bubbles in the water are so small that they are invisible to the eye, they will reflect and scatter ultrasound waves and show up clearly in the ultrasound echo image. To detect such "changes" in water at room temperature, we decided to use ultrasonic echoes, which actively transmit ultrasonic waves and image the scattering and reflection of the ultrasonic waves, using a diagnostic sonograph system.

2. Experiments

The experiments were conducted using the Heavy Ion Medical Accelerator in Chiba (HIMAC) at the National Institute of Radiological Sciences of the National Institute of Quantum Science and Technology (QST-NIRS).

The irradiated particle beam was 500 MeV/n of Fe and was irradiated against water in a 30 cm x 30 cm x 30 cm acrylic tank. In HIMAC, heavy particle ion beams in the form of time-width pulses of about 0.7 s are delivered with a repetition rate of about 3 s. Ultrasound echo images were acquired while irradiating the Fe ion particle beam with the probe of an ultrasonograph (Honda Electronics Co. Ltd.,) placed just above the water's surface in the tank.

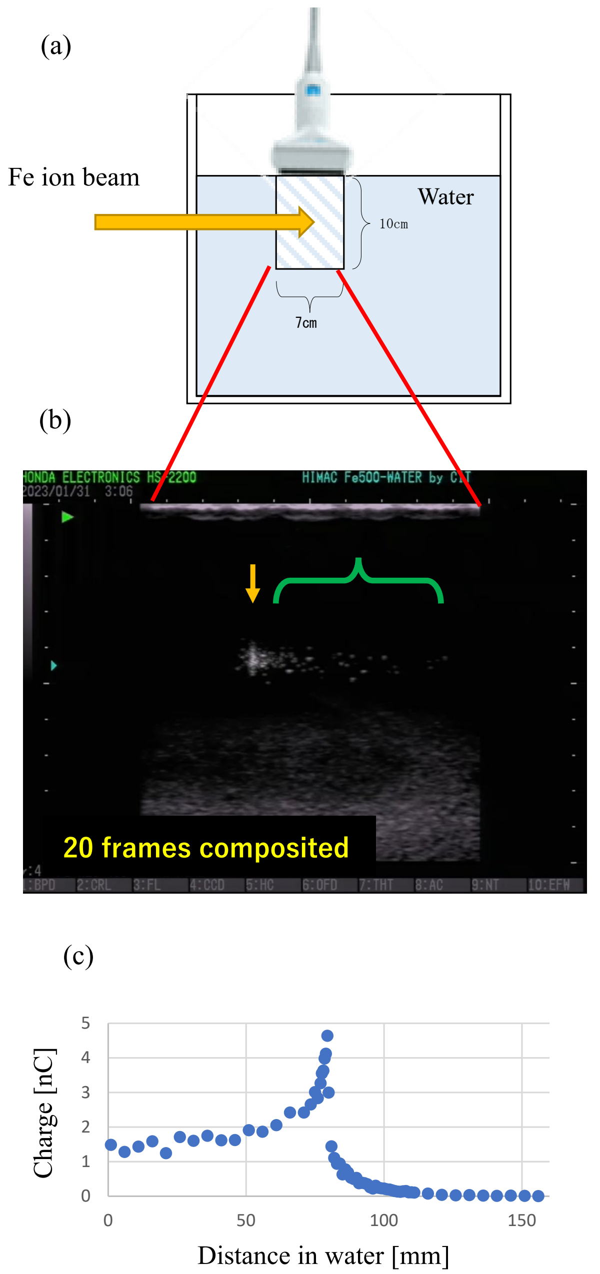

Fig. 1: Illustration showing an overview of the experimental setup (a), a frame composite of the ultrasound echo animation of the Fe beam irradiation (b), and the results of the dose measurements taken with the Marcus ionization chamber against the beam (c).

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3. Experimental results obtained so far

3.1. Correspondence with the Bragg peak

The screen of the sonograph system and the corresponding particle beam are shown in Fig. 1. With the particle beam conditions fixed, the Marcus ionization chamber and the ultrasound probe were mounted on the same X-axis stage, and the dose distribution and "bright spots" measured by the ionization chamber were compared, respectively. Bright spots only appear on the screen when the particle beam is pulsed, and no bright spots appear during the time when the beam is not emitted until the next beam pulse. The bright spots that appear currently are microbubbles that only occur during beam irradiation.

The orange arrows indicate the location of the Bragg peak, where the particle beam loses the most energy, and coincide with the bright spots (white dots on the black screen) that only appear when the particle beam irradiation is taking place.

3.2. Correspondence with the beam spot

For the experimental configuration shown in Fig. 1(a), the ultrasound probe was rotated by 90° to acquire ultrasound echo images that monitor the cross-section of the particle beam. An example of the experimental results is shown in Fig. 2. (The beam intensity was fixed at 1.0×10^8 ppp and three patterns of beam spot diameters of ϕ5 mm, ϕ10 mm and ϕ20 mm are shown).

Otherwise, the number and brightness of the "bright spots" increased with respect to the increase in beam intensity, and the distribution of the "bright spots" on the ultrasound echo image was found to be distributed only in the range of the beam spot when the beam spot diameter was changed. In other words, it was found that the spread of the "bright spots" amplitude was approximately equal to the size of the beam spot diameter.

3.3. Generation of large bubbles

When the spot diameter was fixed to the minimum (ϕ 5 mm) and the beam intensity was made even higher, an artifact (an imaginary image that does not actually exist) in the sonograph system called a "side lobe" was visible. When the beam intensity is further increased, this is an event that appears when there is a solid reflected echo source, which is larger bubbles (several hundred micrometers) comparable to the beam diameter. In addition, the bubbles remained after the beam pulse ended.

The appearance of large bubbles was found to be facilitated not only by increasing the beam intensity but also by increasing the concentration of dissolved carbon dioxide in the target water.

Fig. 2: An image of one frame of the ultrasound echo image when the beam intensity was fixed at 1.0×10^8 ppp and the spot size of ϕ5 mm and cropped images of the spot size of ϕ10 mm (red frame) and ϕ20 (green frame) mm are superimposed for comparison.

4. Concluding remarks

The previous chapters have described experiments in which ultrasonic echo imaging was performed on water irradiated with a particle beam. The mechanism of this phenomenon is not yet understood, but it is thought that the energy of the particle beam and the ultrasound may have induced the dissolved gas. The mechanism for generating the "microbubbles" identified in the experiment is unknown, but it seems certain that it is an action other than an ionization interaction. The visualization of particle trajectories is of great significance for particle therapy. Continuing clarification of the bubble generation mechanism should lead to the practical application of particle beam trajectory visualization.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number JP21K18148. The study was conducted as part of Reserch Project with Heavy Ions at QST-HIMAC.

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