Development of an ion-acoustic dose-deposition mapping system for LhARA

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Introduction

LhARA, the Laser-hybrid Accelerator for Radiobiological Applications [1], has been proposed as a facility dedicated to the study of radiation biology. LhARA has been designed to deliver a variety of ion species over a wide range of spatial and temporal profiles at dose rates up to and significantly beyond the FLASH regimen. The automation of sample handling in LhARA requires the measurement of the deposited dose distribution in real time at a repetition rate of 10 Hz. The LhARA collaboration has embarked on the development of an ion-acoustic system for this purpose. Development of the LhRA proof-of-principle system has the potential to allow real-time monitoring of the position of the Bragg peak during ion-beam therapy.

Ion-acoustic dose mapping is based on the ultrasound waves generated from the energy deposited by the passage of the proton or ion beam [2,3]. Due to the short pulses (10—40 ns) delivered by LhARA, the thermal expansion generated by the almost instantaneous energy deposition satisfies the stress confinement criterion necessary for efficient generation of acoustic waves. An experiment to demonstrate the feasibility of the technique to provide the energy-deposition profile within the timeframe required by LhARA is being developed and its performance is being evaluated using Geant4 [4] and k-Wave [5].

Methods

The SmartPhantom, a water phantom instrumented with planes of scintillating fibre, has been simulated using Geant4. The simulation takes beams with energies in the region of 200 MeV and calculates the energy deposited as a function of position and time. The time-dependent energy spectrum output from Geant4 has then been used as the source acoustic input for k-Wave to simulate the ion energy transfer to the medium, the generation of the acoustic waves and their propagation in the three-dimensional space. A hemispherical sensor array composed of several voxels was also simulated in k-Wave. The performance of the sensor array was evaluated to test the reconstruction of the pressure distribution.

Results & Discussion

The k-Wave reconstructed pressure distribution is in close agreement with the original distribution output from the simulated water phantom. This verifies that the reconstruction method works, and that ion-acoustic imaging can be used to a provide dose deposition profile feedback when an ion beam is targeted towards a water tank. Analysis of the reconstructed images led to an initial optimisation of the detector size and position.

Conclusion

Ion-acoustic imaging has been proven to be an accurate method of obtaining the energy distribution of ions propagating through water. As a next step, the simulation must be verified experimentally, by constructing a real water phantom and testing it with a 200 MeV proton beam. At a later stage, the experiment can be performed with real tissue. In addition, the imaging system proposed here is aimed to be used by LhARA and potentially develop an on-the-fly, non-invasive dose deposition profile feedback system.

References

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