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Modeling the Acoustic Field generated by a Pulsed-Beam for Experimental Proton Range Verification

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Introduction. Proton range verification by ion-acoustic wave sensing is a technique under development for applications in hadron therapy as an alternative to nuclear imaging. It provides an acoustic imaging of the proton energy deposition vs. depth using the acoustic wave Time of Flight (TOF). State-of-the-art (based on simulations and experimental results) points out as this detection technique achieves better spatial resolution (< 1 mm) of the proton range comparing with Positron-Emission-Tomography (PET) and prompt gamma ray techniques.
This work presents a complete Geant4/K-Wave model that allows understanding several physical phenomena and evaluating the key parameters that affect the acoustic field generated by the incident proton radiation.
Methods. The proposed system models the energy deposition in a water absorber of a 20 MeV mono-energetic pencil-like beam and with stress and thermal confinement conditions standing. It has been simulated assuming the current time profile of the beam to be a flat pulse with Gaussian rising and falling edges and the spatial energy distribution to be a homogeneous disk with Bragg Peak FWHM region dimensions. The simplified environment is composed of a water phantom with a reflective polyammide layer on one side and the sensing points lie on the disk axis in the direction away from this reflection surface. The parameters that completely describe the current pulse are time width, raising time, total dose and peak dose in unit time.
Results. By running sweep-simulations of the model, it appears that the signal amplitude depends neither on the total deposited dose, nor on the pulse time. This confirms theoretical expectations that only changes in the deposition rate should generate a pressure wave. Rising time has been varied between 50 ns and 1000 ns showing a linear decrease of pressure wave amplitude at 0.5 cm from 17.7 Pa down to 4.9 Pa. Dose in unit time, which is strictly linked to the beam current intensity, affects the signal in the opposite way: the strength increase linearly from 90 mPa up to 948 mPa in the 0.89-82.4 MGray/s range. The evidence that only two beam parameters influence the measure in a controlled environment allows to plan of appropriate detection systems, to design clinical particle accelerators with the right characteristics and to concentrate scientific efforts on the in vivo setting uncertainties.
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