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1-D scanning water phantom for 2-D IC array and LDIC

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ABSTRACT

Purpose Two-dimensional arrays of ion chambers have become useful for acceptance testing, commissioning, and patient-specific QA. Due to the finite range of light ion beams, it is often desirable to make measurements at multiple depths for a single portal. Exchanging slabs of solid phantoms is an inefficient use of physicist and treatment room time. A water phantom capable of scanning a large array through different depths is desirable.
Methods A new phantom was designed and built to scan both a PTW XDR 2-D array and a large diameter parallel plate ionization chamber (LDIC) through water.
Results The inside water volume is 375 mm x 370 mm x 430 mm and supports a horizontal beam direction. The depth of the detector can be commanded remotely with a resolution of 0.01 mm, a reproducibility of ± 0.2 mm, and an accuracy of ± 0.15 mm. The phantom surface-to-isocenter distance can be remotely adjusted through a range of 200 mm. Due to the depth of the chambers in the XDR detector, the thickness of the front phantom window, thickness of the front wall of the water proof detector container, and the closest approach of the container to the front wall, the minimum measurement depth is 27 mm.
Summary A new phantom has been built that provides efficient changes of depth and surface distance allowing matching of plan and measurement scatter conditions. Although designed for use with light ion beams, it may be useful for other radiation beams as well.

INTRODUCTION

Circa 2000, 2-D arrays of ICs entered the market allowing quick data acquisition at many locations for commissioning and patient-specific quality assurance. For x ray beam measurements, these arrays were typically sandwiched inside a multi-slab plastic phantom. This was deemed sufficient because the dose distributions varied slowly with depth however, for ion beam measurements, both the lateral and depth dose distributions can vary significantly with depth. To measure different depths, plastic phantom blocks had to be exchanged requiring multiple entries and exits from the treatment room. In addition, the only method of changing the surface-to-isocenter distance to match a specific patient portal plan was to enter the treatment room and manually adjust the patient positioner position onto which the phantom was placed. Such positioning is imperative for matching the scatter, leakage, scan spot spacing, and scan spot size conditions of individual patient portal plans. The need to enter the room and make the positioning adjustment has resulted in most facilities ignoring the set-up distance dependence and measuring all patient plans with an identical surface-to-isocenter distance, typically having a value of zero. Another application for a 1-D scanning water phantom is for measuring the integrated depth dose distribution of single narrow spots. Many studies have shown that to accommodate the wide lateral tails of the dose distribution produced by beamline and phantom scatter and, to a lesser concern, neutron production and scatter, the measurements should be made with a very large diameter chamber. Such ICs are too heavy for typical 1-D or 3-D scanning water phantoms and thus a special 1-D scanning water phantom is required.

The goal of this project was to design and build a 1-D scanning water phantom in which one could insert either a 2-D ionization chamber array or a large diameter parallel plate ionization chamber (LDIC). Both the depth and the surface-to-isocenter distance should be adjustable remotely from outside the treatment room. Naturally the readout of the detectors should also be possible from outside the treatment room.

METHODS AND MATERIALS

The 2-D IC array chosen for this phantom was the PTW XDR series, both the 729 and 1500 versions (PTW, Freiberg, Germany). The outside dimensions of these devices are nearly identical being approximately 420 mm tall x 300 mm wide x 20 mm deep. These devices have no cooling vents with heat from the electronics being removed solely by conduction. The LDIC chosen for this phantom was a specially built circular parallel plate chamber having outside dimensions of 230 mm diameter and 40 mm thickness.

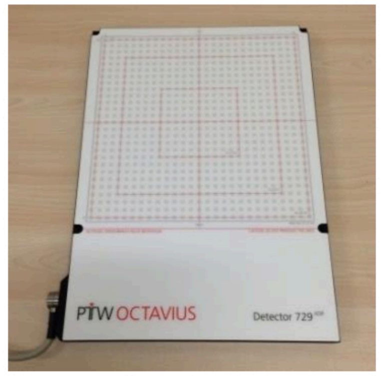

Fig. 1: Top view of PTW XDR Model 729 2-D array.

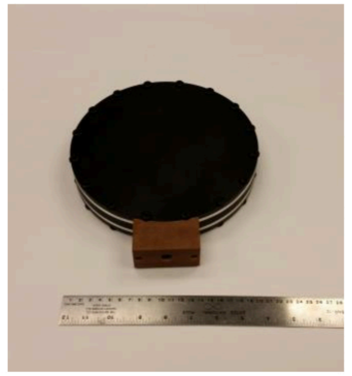

Fig. 2: Front view of LDIC showing mounting block and connector for signal and high voltage.

One constraint is that the set-up condition for the water phantom is to use a horizontal radiation beam that enters from the side of the water phantom. Another constraint is that the floor beneath the patient (isocenter) in many ion beam facilities is either non-existent, in the case of some large rotating gantry beamlines, or not flat such as in the case of a moving floor with overlapping panels. For this reason, the best arrangement is to place the phantom on a table top attached to the patient positioner. This placement, however, limits the maximum weight of the phantom and its accessories. At the same time, the water phantom dimensions should be large enough to allow water to pass around a waterproof box that houses the 2-D IC array or LDIC as it is scanned in depth. The water volume should also be large enough to provide sufficient scatter to the outermost chambers of the array.

The range uniformity of the front window and detector housing was measured with EDR2 film and a low-energy carbon ion beam. The mechanical depth accuracy was measured using a TOPCON DS-101AC theodolite and water equivalent thicknesses were measured using low, medium, and high-energy proton and carbon ion beams.

RESULTS

Figure 3 shows the built 1-D phantom set-up for measurements in a treatment room housing a horizontal ion beamline. The phantom is placed on a flat tabletop that is mounted to a robotic patient positioner. At the right of the picture is a transport cart that also houses a water reservoir and a pump for transferring water to and from the phantom. When used in the treatment rooms, the phantom is slid from the top of the transport cart to the flat patient positioner table top. This procedure may be performed by one person alone. Although the ion beam room patient positioner is a 6 degree-of-freedom device, a 3-point leveling plate is included under the phantom for convenience of proper alignment. A valve and deflector plate are located near the bottom of the water phantom to pass water into and out of the bottom of the phantom without producing copious amounts of bubbles. An internal pressure sensor is calibrated to give the height of the water inside the phantom and the system can be programmed to fill the phantom to a desired level; however, the pressure sensor is housed in the transport cart so the relative height of the phantom compared to the cart can affect the measured height.

Although the water phantom houses a large mass of room temperature water, the water proof detector housing is made of clear polymethylmethacrylate which is a thermal insulator restricting the removal of heat. The cart therefore also houses an air pump that blows air into the bottom of the water proof detector housing; the air flowing upwards out of the housing provides ventilation cooling to the detector in addition to conduction cooling.

Fig. 3: Water phantom on flat tabletop of robotic positioner. Ion beam emanates from the radiation head on the left of the picture. Below the table top are two movable floor panels for a stand-alone beam applicator and stand-alone chair. On the right is the phantom transport cart and water reservoir.

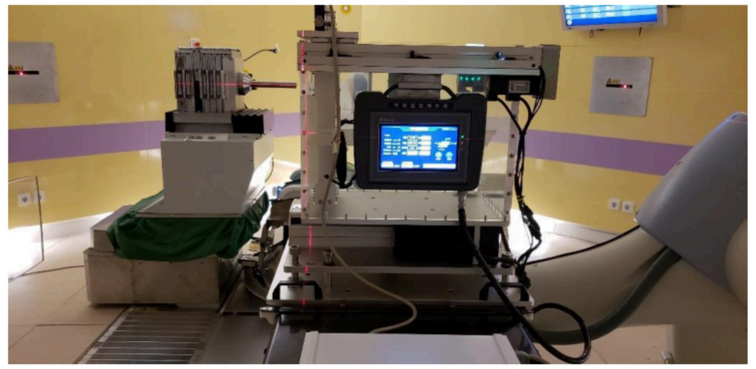

Fig. 4: Side view of water phantom with hand control.

A thin window with dimensions of 257 mm wide by 259 mm high is placed over a hole in the side of the thick tank wall through which the beam enters. The thin window physical thickness at the center was 2.7 mm. The range uniformity test showed the thickness of the window was uniform to within 0.2 mm. The physical thickness of the front plate of the water-proof IC housing was 3.5 mm. The front surface of the water-proof housing for the 2-D IC array and LDIC was shown to be parallel to the front surface of the water tank to within 0.2 mm over the full field of 200 mm x 200 mm. Figure 5 shows the checkerboard pattern used to measure range uniformity. The depth difference between the light and dark squares is 0.2 mm.

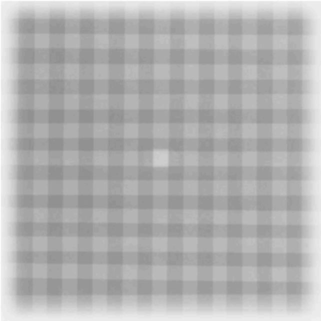

Fig. 5: Range uniformity of the front window and detector housing.

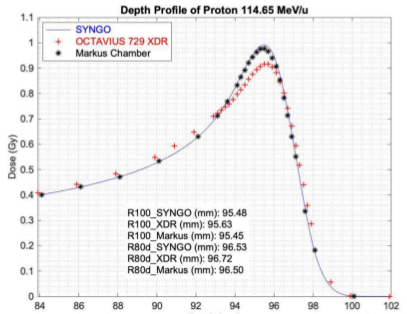

Fig. 6: Depth dose measurements shifted to match TPS calculation.

The motion controller allows the requested measurement depth to be entered by the user to within 0.01 mm. The current array position is displayed both locally at the phantom on a detachable hand pendant and on a laptop computer at a remote command location up to 35 m away using an Ethernet connection (see figure 4). The motion of the water-proof housing with the 2-D array or LDIC installed can be requested by the user to move at any speed between 50 mm / s and 1 mm / s. There is sufficient space around the 2-D IC array holder that, at fast speeds, water is allowed to smoothly flow around the holder without splashing water above the phantom or into the detector holding box. At the fastest speed, however, if the detector is moved to the extreme front of the phantom a small amount of water will be squeezed out of the top. It is therefore recommended that moving large distances to the shallowest depth be made at speeds below 30 mm / s. A jog mode is also provided in which the depth may be changed by 0.1 mm per command. The motion controller is provided with a position readout on the opposite side of the water proof holder from the positioning motor to verify that the detectors have actually reached the commanded position. The reproducibility of the detector depth was shown to be ± 0.11 mm while the accuracy was ± 0.15 mm. Figure 6 shows data from the window and detector holder water equivalent thickness measurements. The range step around the peak was 0.2 mm using the jog mode. The Markus chamber installed into the phantom gave a water equivalent depth 18.1 mm less than a calculation by a TPS (Syngo). Since the water equivalent depth of the 729 XDR detector is 8.95 mm, the minimum measurement depth with the XDR is thus 27.05 mm.

A 1-D motor and slide is located underneath the phantom to provide variable surface-to-isocenter distances that can be adjusted either locally or remotely without entering the treatment room. The adjustment allows ± 100 mm positioning from the nominal set-up. If the phantom is initially placed on the patient positioner table top at a defined position, moving to the extreme positions can cause up to a 1.56 mm vertical shift of the detector relative to the beam axis. A movable counterweight could reduce induction of tabletop roll but would add extra weight.

CONCLUSIONS

A new water phantom was designed and built to scan large detectors and detector arrays to different depths. It provides efficient, accurate, and remote changes of depth and surface distance allowing matching of scatter conditions between treatment plans and measurements.

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Patent pending.