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PRELIMINARY RESULTS OF A RASTER SCANNING BEAM DELIVERY SYSTEM*

T.R. Renner, W. Chu, B. Ludewigt, J. Halliwell, M. Nyman, R.P. Singh, G.D. Stover, R. Stradtner University of California, Lawrence Berkeley Laboratory, Berkeley, California 94720

Abstract

A beam delivery system using a raster scanning technique has been developed to create large radiation fields with light ion beams for radiation treatment of cancer patients. Radiation fields up to 20 cm by 30 cm have been produced with a beam of Ne ions having a magnetic rigidity of 6.9 T-m.

Description of System

Components

The system consists of a pair of dipole magnets, two power supplies, a set of detectors, and a computer control system. A schematic of the system's layout is shown in Fig. 1



Fig. 1. A general schematic of the raster scanning beam delivery system is shown. The individual components are magnets, power supplies, detectors, computer system, and CAMAC hardware.

One magnet's field cycles slowly compared to the other to sweep the beam across the treatment field as shown in Fig. 1. The magnets, shown in Fig 2, can deflect a beam with a magnetic rigidity of 8.0 T-m, to ± 20 cm in the horizontal and vertical plane at a distance of 6.0 m. The apertures of the two dipole magnets were designed to permit the transport of the beam without obstruction at its largest deflection. Lamination of the magnet's iron core minimizes the induced eddy currents during their operation.¹

The power supplies were designed to drive each magnet to the desired maximum magnetic field in a linear fashion to insure a linear sweep of the beam. A constant scan velocity with a constant beam spill results in a uniform dose distribution.

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A discussion of the power supplies is to be found in a another paper at this conference.²

The vertical scan frequency of the beam can be varied from 0.5 to 1.0 Hz at its maximum deflection and the power supply can run with a DC current offset to allow the beam to dwell at a fixed vertical position. The fast scanning velocity is constant corresponding to a scanning frequency of 30 Hz for a beam of maximum rigidity at its maximum deflection. The scanning frequency increases with decreasing field size and magnetic rigidity. A sweep of a light ion beam across any rectangular area within a 30 cm by 30 cm boundary for the highest magnetic rigidity is possible.



Fig 2. The two dipole magnets are shown in this picture. The fast scan magnet is on the left and the slow scan magnet is on the right. The beam enters from the left and exits to the right.

An ionization chamber and secondary emission monitor measure the beam fluence before the raster magnets. Near the isocenter a multi-segmented ionization chamber measures the ionization of the beam over the entire radiation field.³ A standard thimble reference ionization chamber measures the total dose at the center of the radiation field for calibration purposes.

The computer system, which controls the scanned beam and records and displays the measured results, uses CAMAC hardware and a VAX 780 computer. The control system controls the boundaries of the field to be irradiated, the starting point in the field, the scanning frequencies and the beam intensity on a pulse by pulse basis. The radiation delivered by each beam pulse is measured and displayed at the end of a beam pulse. The dose distribution is monitored to insure patient safety and to evaluate the system's performance. A comparison of the delivered dose to the requested dose is made for the patient's record and treatment planning purposes.

Operational Requirements

The delivered dose must be uniform across the radiation field to within $\pm 2\%$. Consequently, an entire scan has to be completed within one beam spill. Since the Bevatron spill is nominally 1 sec long, the vertical or slow scan must sweep the field in slightly less than 1 second. The horizontal or fast scan must be fast enough to paint lines close enough together to yield a dose distribution without peaks and valleys between them.

Since temporal structure in the beam translates into spatial structure in the radiation field, requirements on beam spill structure are critical. Coarse structure in the beam spill on the order of one hertz can lead to a rounding off of the edges of the radiation field. High frequency structure can lead to localized hot spots in the radiation field. The beam intensity must also be controlled so that the requested dose can be achieved. Since the beam can not be terminated in the middle of a pulse, each pulse must deliver a successively smaller fraction of the total dose until the desired dose is reached within the specified accuracy.

Initial Tests

Parameters

The initial tests have been done with a neon beam at an energy per nucleon of 456 MeV. The beam size was measured at isocenter to be 5.0 cm FWHM and beam intensities between 1.0×10^8 and 2.0×10^9 particles per pulse were used. The field scanned was 20 cm by 30 cm with a scan frequency of 0.8 Hz and 20 Hz for the slow and fast magnets respectively.



Fig. 3. A display of the output of the multi element ionization chamber is shown. The radiation field was shaped by an actual patient collimator. The chamber is segmented into 144 individual collecting elements. The area of each square in the display is proportional to the dose measured by that element. The dose uniformity of the radiation field is $\pm 10\%$.

Measurements of Radiation Field Uniformity

Three separate methods were used to measure the uniformity of the dose distribution transverse to the beam direction. The first is a multisegmented ionization chamber with 144 square elements each having an area of 6.25 cm^2 . The second device, MEDUSA⁴, is a multiwire proportional chamber with 16 planes of 64 wires each from which a dose distribution is reconstructed. The third was x ray film which was manually digitized after exposure to determine its uniformity. The beam was shaped by an actual patient collimator. The dose uniformity measured by the three different detector systems is shown in Fig. 3, 4, and 5. The delivered dose was 2.0 Gy at the center of the field with an error of ± 0.05 Gy and a variation of $\pm 10\%$ across the field.



Fig. 4. Shown is the beam uniformity as measured by a multi-wired proportional chamber called MEDUSA. The highest dose is white and lowest dose is black.



Fig. 5. An X ray film shows the dose uniformity of the beam. The darkest area is the highest dose while the clear film is zero dose.

Summary

A proof of principle test has demonstrated the feasibility of scanning light ion beams for use in the radiation treatment of cancer patients. The radiation fields produced by this method appear to be less sensitivity to beam position and beam shape than the wobbler dynamic beam delivery system⁵, but require more stringent beam spill requirements to insure uniform radiation fields.

Future Developments

A chief advantage of scanning will be the ability to perform 3D conformal radiotherapy by layering the treatment volume and shaping the cross sectional area of each layer with a variable, multileaf collimator. The accompanying reduction of the radiation to normal tissue areas should improve the efficacy of light ions. In addition minimizing the scanned field to a size more nearly that of the treatment volume will assist in reducing unwanted neutron background radiation to the patient.

A fully operational system with a fixed range beam and a fixed range modulator is expected to be used with patients in the fall of 1989. The scanning system will be used in conjunction with patient positioner called ISAH.⁶ In the near future the raster scanning system will be further developed to perform 3D conformal therapy.

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