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A VERSATILE PATIENT POSITIONER FOR RADIATION THERAPY*

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Summary

Mechanical features, control philosophy, and operational characteristics are described for the automatic, computer-controlled patient positioner "ISAH." This device is presently in operation at LBL's 184-Inch Cyclotron. It is capable of positioning a patient or experimental animal to 0.1 mm accuracies in three dimensions. It can simultaneously or selectively translate the patient in three orthogonal axes and rotate him about two perpendicular axes. Translational motions are 61, 40 and 23 cm respectively while rotations are 400 deg. It is used to deliver a therapeutic dose of radiation from the cyclotron (910 MeV Helium ions) to an arbitrarily defined volume within the patient's body and to manipulate the patient during irradiation so as to minimize radiation exposure of the intervening tissue. The patient motions are under on-line control of a PDP-8/I computer which directs the necessary motions and verifies their performance. The computer may also control a variable thickness water column used to vary the depth of the Bragg peak within the patient.

Introduction

This unit is designed to be used with the unsteered horizontal beam from the 184-Inch Synchrocyclotron; specifically, the 910 MeV Helium ion beam. It is called ISAH (an acronym for Irradiation Stereotaxic Apparatus for Humans). If desired other animals may be positioned.

Since it is necessary for any radiotherapy procedure to position the patient with respect to the radiation source, this device is called a "positioner." It is, however, a more versatile device which, during treatment, permits moving the patient at varying speeds in any or all of 5 deg of freedom (3 orthogonal translations and 2 rotations). The arrangement of motions is shown in Fig. 1. Thus it is possible to irradiate any desired volume within the patient with minimum damage to the intervening tissue. This is done by "scanning" the treatment volume across the Helium ion beam while simultaneously rotating the patient about points within that volume. An additional element of control is gained by the use of a variable length water column. By using this as a beam energy degrader, the depth within the patient of the "Bragg Peak" may be controlled. Control may be either manual or automatic as desired.

The precise series of motions comprising a treatment may be computed in advance for each patient by a large general purpose computer. This series is recorded on magnetic tape which serves as the "input command" to ISAH during treatment.

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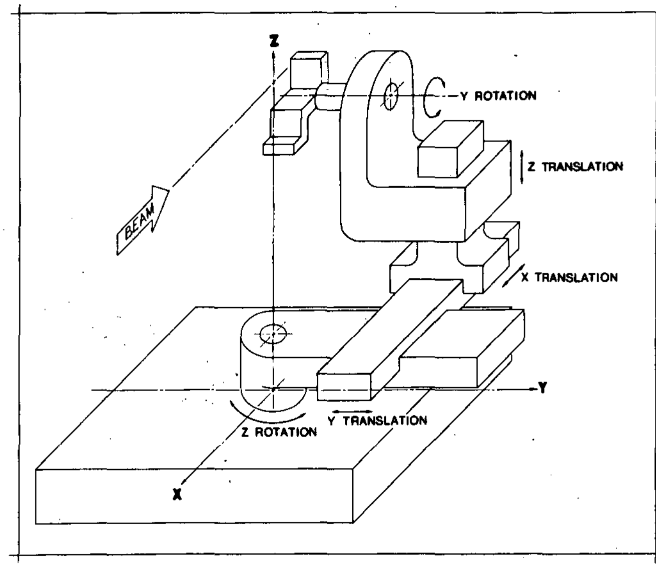

Fig. 1. Arrangement of motions.

General Description

The base of the positioning unit is a 20-in. thick slab of granite whose 10-ft square top has been polished to a flatness of ± 0.0002 in. It is positioned in space by four adjustable supports with most of the weight of the slab being supported by air-inflated rubber bags. The adjustable supports enable the granite surface to be leveled as well as positioning the slab so that the vertical axis of rotation (z axis) intersects the cyclotron's beam. This latter function could have been accomplished by the use of electromagnetic steering magnets, but the limited available space made mechanical positioning of the slab a more attractive alternative.

The ranges and speeds of the various motions provided are:

x translation	23 cm total at 0.1 to 1.0 cm/s
y translation	61 cm total at 0.1 to 1.0 cm/s
z translation	40 cm total at 0.1 to 1.0 cm/s
y rotation	continuously rotatable at ± 0.1 to 10 deg/s
z rotation	400 deg total oscillatory at ± 0.1 to 10 deg/s

Translational motions have a position tolerance of 0.2 mm total and the optically encoded readout discs have a like tolerance. Consequently the maximum positional error is designed to be 0.4 mm total. Rotations have position tolerance of 0.5 deg total and their optical encoders have a tolerance of 0.1 deg total. Thus the maximum rotational error is designed to be less than 0.6 deg total.

These moderate precision requirements and the modest dynamic motions are relatively easily satisfied.

The design philosophy was prompted by the similarity of the positioner to a modern multi-axis, numerically controlled milling machine. The major differences are the substitution of the Helium ion beam for a milling cutter and the "work piece" being a relatively light human patient. Accordingly, the design is similar to the latest techniques used by the machine tool industry for computer controlled metal fabricating machines. We go a step further and not only command the motions to be executed, but also check to see that they have been achieved; we may also permanently record them on magnetic tape as a part of a patient's medical records.

Design Features

Air Bearings

The weight of the positioner plus patient or other load is supported on the granite block by four pressurized air thrust bearings or pads. This feature permits simultaneous rotation about the z axis together with any combination of x and y axis translations. Air bearings have minimal friction and so minimize the power requirements of the various drive motors. These bearings, built by the Fox Company, operate on relatively low pressure, 40 psi, and have a minimum operating clearance of about 0.0002 in. Thus, they do not require a large volume of filtered air. The support system is shown in Fig. 2.

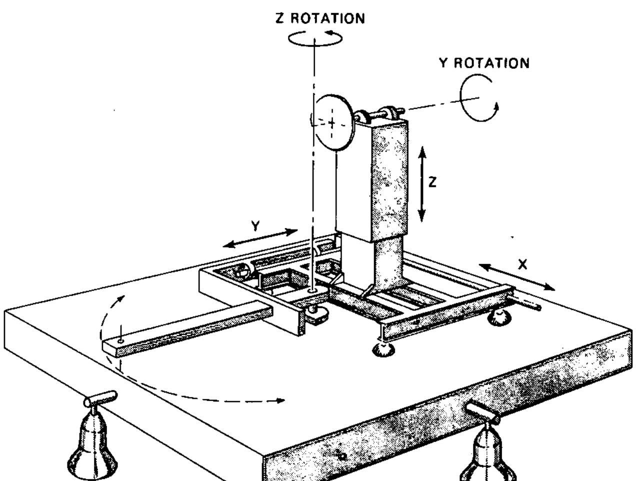

Fig. 2. Support system.

Control Philosophy

The control logic for all motions is identical since all are driven by five-phase digitally-controlled stepping motors. This feature permits economy of design, convenience of maintenance and checkout, and increased reliability.

A master digital clock provides the prime frequency for each motion channel. This frequency is divided for each axis to yield the rate as dictated by the control computer. The secondary frequency is then applied to the motor drive as determined by the scan control. An optical encoder gives the instantaneous position of the motion which is then digitally displayed on the control console and compared by the PDP-8/I computer with the calculated treatment plan. Should the position differ from the plan by more than a predetermined amount, the beam is momentarily interrupted to allow the error to be reduced to within the tolerance. This computer monitored, digital type of "closed loop" operation provides a high degree of accuracy. The system is inherently stable because of the use of the digital stepping motor. A diagram of the control logic is shown in Fig. 3.

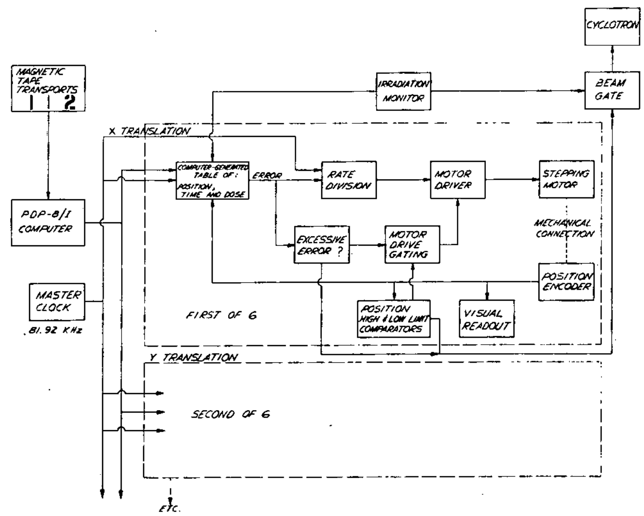

Fig. 3. ISAH motion control.

Optical Bench

Any such complex motion scheme as this must rely heavily on a reliable method of verifying the location of the treatment area with respect to the beam and to the coordinate axes of the patient positioner. A sort of optical bench is provided which can position x-ray cassettes together with suitable cross hairs and targets, colinear with or at angles to, the cyclotron beam and the intersecting z axis of rotation of ISAH. Appropriate film exposures with x-rays and/or the Helium ion beam can verify an immobilized patient's position to within 0.1 mm. This accuracy is sufficient for the most exacting radiotherapy procedures.

Patient Treatment Modes

Two types of patient modules have been built and used with the positioning device. The simpler of the two is a chair-like structure which is side mounted to the faceplate of the y rotation shaft. The y rotation is utilized to tilt the chair to a desired position for therapy. The x, y, and z translations are utilized to position the target volume at the intersection of the beam axis and the z rotation axis. A simple z rotation will irradiate a spherical volume of diameter equal to the beam diameter. A more complicated off-axis rotation (to irradiate an annular region) may be performed by coupling appropriately the x and y translations with the z rotation. Large areas (40 x 40 cm) may be irradiated by appropriately scanning (with y and z translations) the patient across a small diameter beam.

The patient module which at this time has received the most attention and usage is that for radiation hypophysectomy (removal of the pituitary). In this configuration, the patient lies supine upon a couch which is supported from the z translation pedestal. The y rotation shaft is positioned via the x and z translations, so that its rotation axis intersects the beam axis and the z rotation axis. Attached to the faceplate is a small precision x' - z' translation way, to which is mounted a custom-built, vacuum-formed polystyrene head holder. The x' and z' motions are short, manually adjusted translations which are parallel to the x and z axes of ISAH. By moving the patient's head in space via the x', y and z' translations, the pituitary gland may be placed at that point in space where the beam axis intersects the y and the z rotation axes. Thus positioned, the patient is ready for therapy which is administered as the head is rocked ± 35 deg (via y rotation motion) and the patient is swept through a 66-deg arc (via z rotation).

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