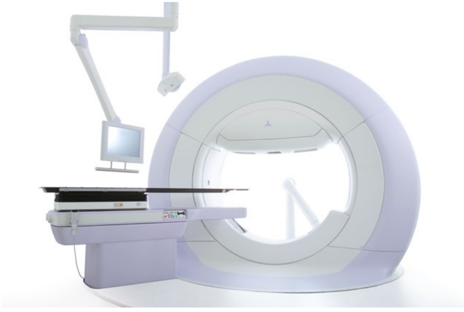
State-of-the-Art Medical Treatment Machine MHI-TM2000



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1. Introduction

The combination of the aging population and the declining birthrate means that the proportion of aged patients with cancer is increasing rapidly. An improved quality of life (QOL) is required so that patients can go about their daily lives, finding fulfillment on their own and feeling content while they are treated. The three main approaches for treating cancer are radiotherapy, surgery, and chemotherapy. Of these, radiotherapy is considered the most patient-friendly therapy, meeting the goals of our aging society. Mitsubishi Heavy Industries, Ltd. (MHI) is actively involved in the development and manufacture of a cancer treatment machine, working jointly with Kyoto University and the Institute Biomedical Research and Innovation laboratory based on MHI's experience and technology in the field of industrial machines.

This paper introduces a state-of-the-art medical treatment machine developed by MHI.

2. Composition and features

The MHI-TM2000 radiotherapy machine developed by MHI is a device to realize image-guided radiotherapy (IGRT) that combines x-ray imaging and treatment.

Its design adopts a unique configuration that incorporates to a maximum extent the knowledge accumulated by MHI, such as the micro-positioning technology required by machine tools, image processing technology developed for printing machines, and system control technology used in steel-making machines, manufacturing, and the development of large accelerators (**Figure 1**) [1].

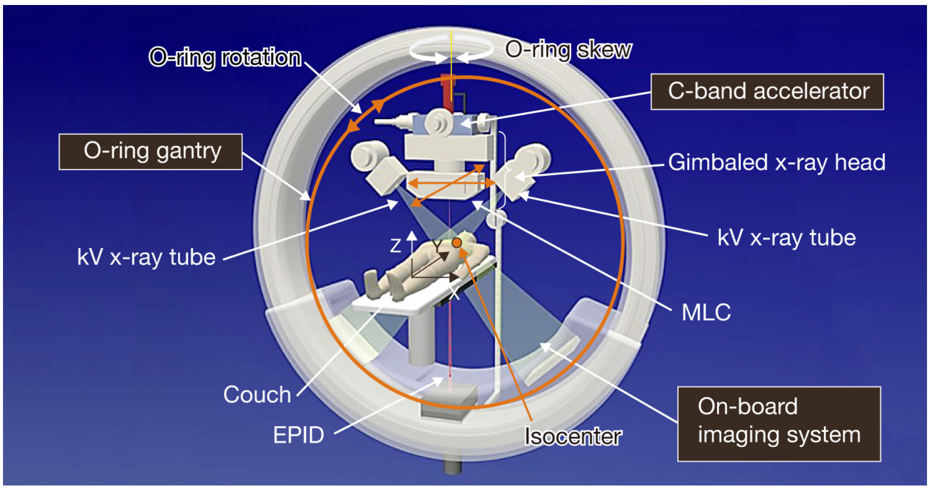

Figure 1 Diagram showing the configuration of the MHI-TM2000

(1) As the structure main body frame, we adopted a ring-shaped gantry with high rigidity. Because distortion deformation can be minimized, we can realize high-precision positioning while simultaneously enabling x-ray irradiation from all radial directions to the diseased part at the center location that is called isocenter of the machine without moving the couch on which the patient is lying.

(2) The device uses a compact C-band standing wave type accelerator that was jointly developed by the Institute of Physical and Chemical Research, the High Energy Accelerator Research Organization (KEK), and MHI. Its acceleration frequency (5.712 GHz) is two times higher than that used in general therapy devices, and microminiaturization and weight saving are achieved while maintaining the stability of the beam, making the device one third the size of typical therapy devices. This is the first C-band type of therapy device. This allowed its installation on gimbals mechanism, as mentioned below. In addition, it is necessary to adjust the acceleration frequency in accordance with the thermal expansion of the accelerator during operation, and output stability is ensured by adopting a new automatic wide-band frequency control[2].

(3) Two pairs of kV x-ray imaging systems are installed. An imaging function is used to confirm the precise irradiation location, and high-quality three-dimensional static images of the patient can be taken from every angle. Furthermore, our machine can obtain cone-beam computed tomography (CT) images quickly and of a quality comparable to conventional slice CT by taking images while rotating one pair of imaging systems. The machine is also equipped with an algorithm to automatically identify the diseased organ from the radioscopy images.

(4) The head used for generating therapeutic x-rays can be swiveled on gimbals mechanism (**Figure 2**). The accelerator is installed on gimbals to realize high-precision positioning by correcting deviation of the irradiation site due to mechanical flexion of the gantry.

(5) The couch on which the patient lies can be moved in 3- (**Figure 3**) or 5-axial directions with high precision, enabling correct positioning of the isocenter. High-precision correction is enabled by using a system that combines an infrared (IR) marker on the body surface and an IR camera.

(6) The therapeutic x-rays are formed into a beam of the desired shape by using a multi-leaf collimator (MLC) with high precision and rapid response that has been newly developed, enabling irradiation with the optimal irradiation pattern. In addition, x-ray images can be taken and recorded using an electronic portal imaging device (EPID).

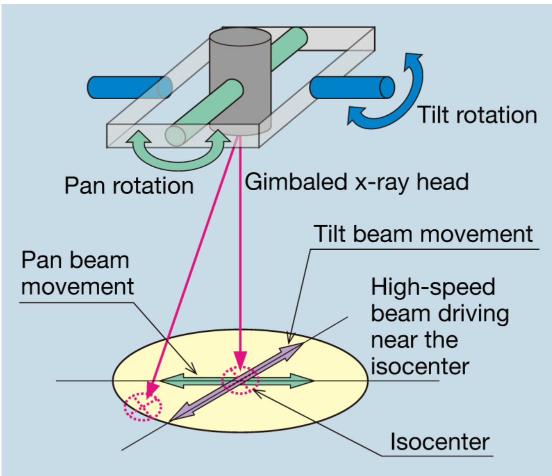

Figure 2 Schematic of the gimbals mechanism
The movement of the gimbals mechanism and their relationship with the change in beam position are shown.

Figure 3 Photograph showing the direction of couch movement in three axes

As mentioned above, irradiation of normal tissues during therapy is avoided, and the exposure dose is reduced because the radiation irradiation therapy can be done with high precision from multiple directions with this machine.

Furthermore, because ample image support functions are provided and the therapy can be done quickly, one machine can be used to treat many patients.

3. Performance of the machine

Figure 4 shows a typical flow chart for irradiation therapy with the MHI-TM2000. We present examples of the main performance features of this machine:

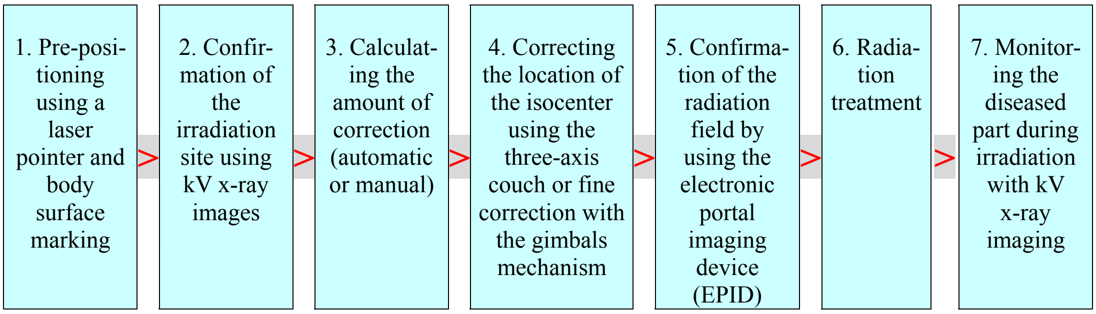

Figure 4 Flowchart showing a typical therapeutic procedure using our machine

(1) Irradiation location precision

As the accelerator head rotates along the ring, some flexion is generated due to its dead weight. This is corrected automatically by fine adjustments of the accelerator head with the gimbals mechanism so that the irradiation is focused on the isocenter. The threshold value of the correction deviation can be set arbitrarily. We have achieved an effective precision of static irradiation positioning of the x-ray of 0.1 mm or less when the isocenter is within the 360° rotation field of the ring type gantry. This is a specification that allows irradiation of diseased organs that require high precision, such as the brain.

(2) Image fusion function

Because a monitor is used to display a composite of the CT image used for therapeutic planning and the x-ray image from the imaging system, any deviation in the location of the isocenter can be calculated quickly. The composite image can be produced manually or automatically. When it is done by manual fusion, the reference image (left side) and imaging system image (right side) are both displayed, and the amount of deviation can be calculated when a part of the image is selected using a mouse (**Figure 5**).

(3) Safety countermeasures

Any medical treatment machine must be assurance of safety. With regard to radiation, the device ensures radiation leakage of 1/1000 or less in the patient plane. Furthermore, as countermeasures against failure, the device has redundant main and auxiliary systems that are independent of each other, so that there is no possible room for failure. Safety is further ensured by using independent interlock controls for the electric power source, dosimeter system, control system, etc.

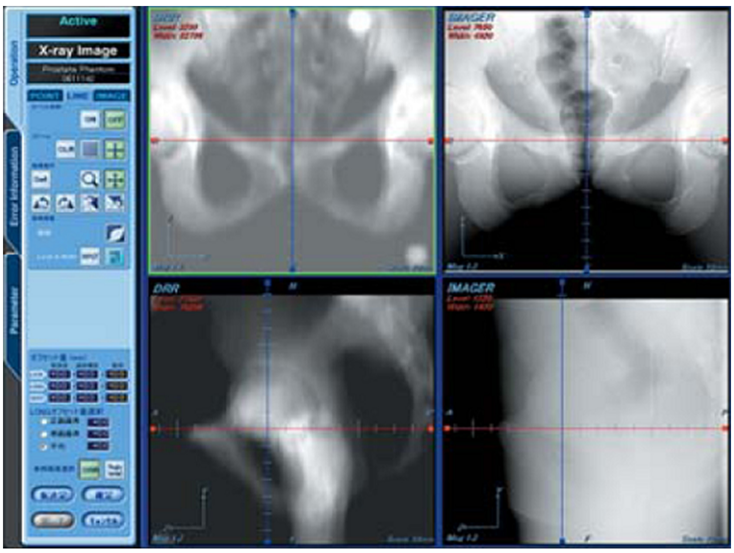

Figure 5 Example of fused x-rays images (manual)
The reference image (left side) and imaging system image (right side) are both displayed.

4. System specifications

Table 1 shows the system specifications. The device uses an x-ray energy of 6 MeV, which does not generate neutrons. This system can be used for treating lesions in the brain, head and neck region, and lungs for radiosurgery procedures, and for treating deep organs, such as the prostate and pancreas by combination with intensity modulated radiation therapy (IMRT). We can provide as option the latest software that increases the efficiency of therapeutic planning and supports high-precision therapy.

Table 1 Major specifications of the system

Item		Specification
Electron acceleration energy	(MeV)	6
Absorbed x-ray dose	(cGy/min)	500
X-ray radiation field (maximum)	(mm)	150×150
Rated therapy distance		1 000
High-frequency electric power source	(MW)	Klystron 4
Head rotation angle	(°)	−185 to +185
Head rotation speed	(°/ s)	7
Ring swing angle	(°)	±60
Gimbals driving range	(°) / [(mm)]	±2.5 / [±44]
External dimensions of the couch	(mm)	450 × 2 200 × 1 100
MLC type		Single focus
Weight	(kg)	Approximately 12 000

5. Conclusion

The MHI-TM2000 has received approval by the U.S. Food and Drug Administration (FDA) and by the Japanese Ministry of Health Labor and Welfare as a new pharmaceutical products and has been marketed since April 2008. It is now being used clinically in the Institute of Biomedical Research and Innovation laboratory located in Kobe, and we are accumulating clinical experience and obtaining reliability data. In the future, we plan to develop a system that can identify a moving diseased organ automatically from radioscopy images, and we anticipate further addition of the said function and developments that meet the needs of patients and physicians.

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References

1. Y. Kamino, et.al, Development of a Four-dimensional Image-guided Radiotherapy System with a Gimbaled X-ray Head, Int. J. Radiat. Oncol., Biol., Phys. 66, (2006) p. 271-p.278
2. Y. Kamino, et.al, Development of a New Concept Automatic Frequency Controller for an Ultra-small C-band Linear Accelerator Guide, Med. Phys. 34,（2007） p.3 243-p.3 249

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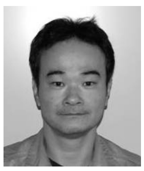

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