Clinical MR-Linac System

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Purpose

Real-time MR-guidance of radiation therapy, using hard X-rays generated by a Linear Accelerator (Linac), could enable better tumor treatment with reduced damage of healthy surrounding tissues; these advantages could revolutionize cancer treatment. In this abstract we present the development status of a clinical MR-Linac system, based on lessons learned from a first demonstrator, built up at Utrecht University [1], [2]. The new system has been scaled to 70 cm patient bore size and is engineered to meet quality and safety requirements for clinical evaluation.

MR-Linac scanner

The MR scanner is similar in size, field of view and imaging capabilities to the Philips Ingenia 1.5T system, but optimized for simultaneous Linac operation. The 8 MeV Linac and the beam shaping system, together with all hardware to power and operate it, are located on a rotating ring, concentric with the magnet axis. The radiation beam passes through the central section of the cryostat; in order to achieve predictable patient dose over a large radiation field size, this central magnet zone is free of coils or other lumped structures and contains almost no helium. The two helium tanks of the bath cooled magnet are interconnected by a tube, which also carries the superconducting interconnections between the magnet sections. Magnet forces are transmitted through thin stainless steel walls. The active shielding is optimized to achieve an extended low-field ring to minimize interference with the radiation system and a small magnetic dipole moment to avoid disturbing adjacent radiation treatment systems (fig. 2). The gradient coil is an optimized wide-bore version of the gapped design reported before, providing a 200 mm wide conductor free radiation window. The conductor configuration is such that the net magnetic translation and rotation forces on each half are minimized, so that a thin GRP tube is sufficient to keep the coil halves in position. The central part of the RF transmit/receive body coil uses thin printed circuit board rungs without any discrete components on a thin GRP tube, to minimize interference with the radiation passing through. Optional posterior/anterior receive arrays are also made radiation transparent. The magnet is an integral part of the RF shielding of the treatment room. All Linac-related equipment is located outside of the RF-shielded volume. The Linac assembly is constructed from weakly or non-magnetic materials wherever possible. Magnetic components are located in the low-field region of the magnet. In order to ensure that the Linac sees the same field for all angular positions, strongly ferromagnetic materials have to be excluded from a small floor volume adjacent to the Linac pit.

Figure 1 integrated system

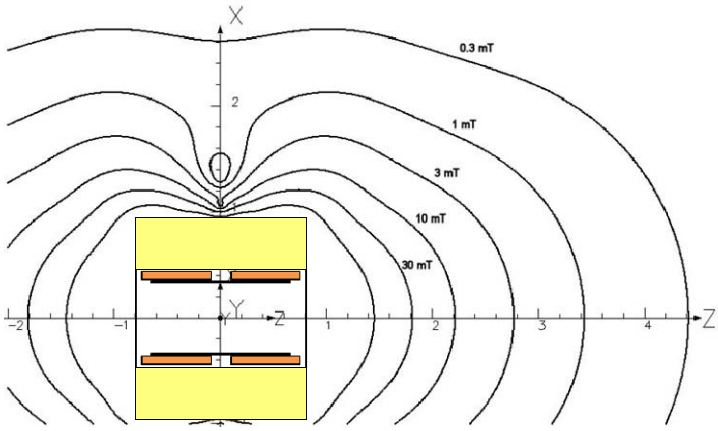

Figure 2 stray field of main magnet

Results

The first prototypes of the scanner have been in test for over a year now and work reliably. Ingenia sequences can be run with nearly identical image quality. The image quality does not deteriorate when the radiation beam is on. The spatial distortion is below 2 mm in the entire field of view. The 4.2 K/1.5 W refrigerator maintains zero boil-off, except when the radiation system is continuously on at maximum dose rate and with more than 400 cm^2 field size for more than an hour. The X-ray attenuation by the entire MR system is approximately equal to that what would be caused by a 90 mm thick layer of aluminium. The remaining effect of the magnetic material on the Linac ring is a predominantly linear transverse gradient with amplitude of less than 1 microtesla over the field of view of the MR system. With some additional static compensation on the rotating structure, good quality images without distortion or artifacts can be made independent of whether the ring is static or rotating.

Figure 3 example image

Conclusions

The concept of integrating an MR scanner with a Linac radiation treatment system investigated with the Utrecht demonstrator has been successfully reproduced in an industrialized version. The MR image quality is excellent and independent of the presence or activity of the Linac radiation system.

References: [1] J.Overweg et al., ISMRM 2009, [2] Raaymakers et al., Phys. Med. Biol. 2009;54:N229–N237