Building a combined cyclotron and MRI facility: implications for interference

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Introduction

With the introduction of hybrid PET/MRI systems [1,2], it has become more likely that at university medical centers cyclotron and MRI (especially PET/MRI) systems will be located closer to each other than in the past. In our newly planned imaging building they are even considered within close distance. As both systems use magnetic fields, interference may occur. In the literature no data on mutual interference of these two specific systems can be found, and manufacturer guidelines on MR installation do not take cyclotrons into account. Especially, the effect of switching on and off the magnetic field of the cyclotron may have an effect on MRI up to significant distances. For site planning of a new building, a site survey to measure the interference at the planned location of the MR system is not possible. In this study we considered the theoretical interference of cyclotron facilities on MRI systems, and compared in a specific situation the simulated stray field with site measurements. This provides general guidelines for the minimum distances between these two systems.

Theory

Cyclotrons typically contain a large electromagnet with a Helmholtz coil configuration to produce a strong local magnetic field to accelerate charged particles within a loop setup to a target. The magnet is a resistant electromagnet, without active or passive magnetic shielding. Therefore from theoretical considerations, the magnetic stray field of a cyclotron at large distance is expected to be closely approximated by the field of a magnetic dipole. The magnet of a cyclotron is switched on and off several times a day, depending on the production process, creating a dynamic magnetic stray field.

Most clinical MRI systems use superconducting magnets with field strengths in the range of 1.5-3T. Current whole body systems are active magnetic shielded, resulting in a drop of the stray field much steeper than a magnetic dipole field. Static external magnetic fields can be compensated for by shimming the magnet. However, dynamical perturbations of the magnetic field are more critical. For a superconducting system, the interference of dynamic external magnetic fields is determined by the spatial gradient of the magnetic perturbation within the imaging FOV. The magnetic field offset (zero order term) is compensated due to the induction law of Faraday that works perfectly in case of a superconducting coil. For MR imaging, mainly the gradient of the field component parallel to the B_0 field of the MR systems is of interest.

The most critical MR applications are spectroscopy and fMRI. For spectroscopy, a typical line width is about 3 Hz, thus a frequency shift one 0.5 Hz (12 nT) is acceptable. For an image field of view of 30 cm, this results in a maximum allowable gradient of 0.04 µT/m. Manufacturers have specifications for maximum allowed dynamical perturbation. Some of them specify these in terms of dynamic gradients, whereas others specify only the maximum allowable change in magnetic field, typically in the range of 0.4 µT peak to peak for a superconducting whole body system [3].

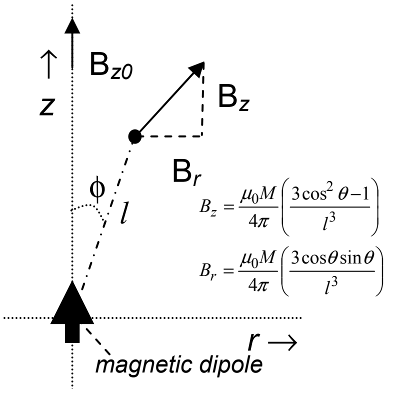

Figure 1: Magnetic dipole field [4].

The magnetic stray field of a cyclotron can be assumed to be a magnetic dipole at distances larger than 5x the size of the Helmholtz coil. We consider a vertical dipole for a typical cyclotron. The stray field can be described as shown in figure 1 [4]. The spatial gradient at any location can be obtained by spatial derivatives of these equations in the 3 dimensions. The main relevant spatial gradient components showed to be $G_r = dB_r/dr$ and $G_z = dB_r/dz$. From the magnetic dipole field, these can be derived to be:

$$G_r = \frac{\mu_0 M}{4\pi}\frac{3z}{l^5}\left(1-5\left(\frac{r}{l}\right)^2\right) \quad and \quad G_z = \frac{\mu_0 M}{4\pi}\frac{3r}{l^5}\left(1-5\left(\frac{z}{l}\right)^2\right)$$

Measurements and Simulations

The magnetic stray field of an 18 MeV cyclotron (Cyclone 18, IBA Group, Louvain-la-Neuve, BE) was measured in situ. This system has a coil-diameter of about 1 m. With 4 fluxgate magnetometers direct measurements were performed from the magnetic field and its spatial gradient in three orientations [5]. Repeated measurements were performed during ramping of the cyclotron magnet, outside office hours to exclude other sources. Above and besides the building, at 5 locations the dynamic magnetic field was determined at distances from 4.5 up 20 m.

Directly above the cyclotron, at 4.5 m (z_0) above the iso-center, the vertical component of magnetic field (B_{z0}) was measured to be 31 µT. From this single measurement point, the strength of the magnetic dipole moment (M) could be estimated. With this value, the whole magnetic dipole field and its spatial gradients can calculated. At the other measurement locations the simulated and measured values of B_r, G_r and G_y were compared, and found to agree within a factor 1.2 for B_r (figure 2) and within a factor of 1.4 for the gradient components.

With the simulated dipole field, minimum distances between an MR system and this type of cyclotron could be assessed. For the criterion of G_r and $G_y < 0.04$ µT/m, the distance (from iso-center to iso-center) has to be larger than 19-21 m (depending on the vertical distance). When we apply the criterion of $B_r < 0.4$ µT, the distance has to be larger than 11-18 m (with a higher value for a larger vertical difference).

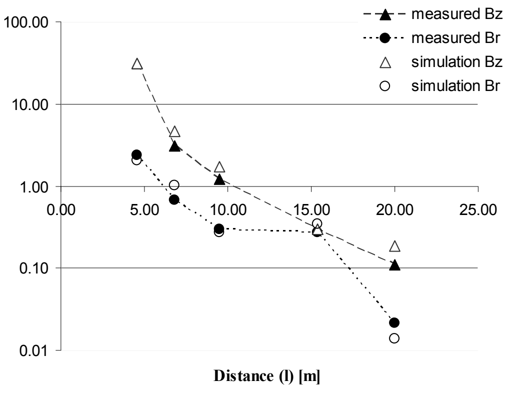

Figure 2: Magnetic field of an 18 MeV cyclotron as a function of distance (l) measured versus simulated values.

Discussion

This study showed that is simulating the magnetic interference of a cyclotron with a dipole field for MRI site planning is realistic. The stray field can be characterized by a single measurement. For a typical cyclotron, and a superconducting whole body MRI system a minimum distance in the range of 11-21 m has to be taken into account. For shorter distances, passive magnetic shielding around the cyclotron could be applied. However, manufacturers of cyclotrons have limited knowledge about magnetic shielding. Another approach is active compensation of the stray field within the MR system. Several companies offer such a system, built into the RF cage [6].

References: *[1] Pichler BJ et al J Nucl Med 2009;51:333. [2] Ratib O et al, Eur J Nucl Med Mol Imaging 2011;38:992. [3] Pre-installation Manual Discovery MR750 3T, GE Healthcare, http://www.gehealthcare.com/siteplanning/. [4] http://www.netdenizen.com/emagnet/index.htm. [5] Report of site survey Amsterdam VUmc, IMEDGO AG, Hägendorf, Switzerland, 2011. [6] Carlson JW et al, US patent No 5245286, 1993.*