DESIGN OF THE 90 DEGREE DIPOLE MAGNET FOR GANTRY 2

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The new COMET proton cyclotron at PSI will be dedicated to tumor therapy. To allow fast spot scanning in all three dimensions of the tumor, a fast energy variation of the beam by a degrader is foreseen. The beam transport system has to be adjusted to the beam energy in a reasonably fast time. A design study was therefore initiated to evaluate the eddy current effects in the 90 degree Gantry 2 dipole. Some preliminary results are presented here.

INTRODUCTION

The new proton cyclotron COMET is under construction and will enable the expansion and improvement of tumor therapy at PSI in the future. The COMET proton cyclotron is planned to be a prototype for tumor therapy at pure medical therapy centres. The energy of the cyclotron is 250 MeV and will be adjusted to the desired range of 70 to 250 MeV by a degrader [1]. The existing Gantry 1 at PSI will be served by the new cyclotron and a new Gantry 2 is planned (Fig. 1) to improve the therapy capabilities and the spot scanning technique [2] at PSI. One option of the new Gantry facility capabilities is the fast energy variation of the beam. This enables a short therapy duration and allows a repeated rescanning of the tumor volume. The magnets of the beam transport system must therefore allow a fast variation of the magnet field. The highest field value of 1.5 to 1.8 Tesla will occur in the 90 degree dipole magnet of Gantry 2 and we therefore expect that this magnet will need the longest time to reach a stable magnetic field after an adjustment of the beam energy.

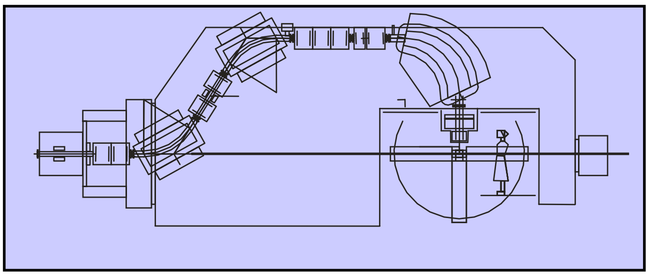

Fig. 1: Schematic Gantry 2 setup.

THE 90 DEGREE DIPOLE MAGNET OF GANTRY 2

The 90 degree Gantry dipole magnet has to allow a very fast horizontal and vertical scanning (with respect to the dipole plane) of the beam. Therefore, two scanning magnets are placed in front of the 90 degree dipole magnet to realise a 100 mm vertical and 200 mm horizontal scanning region. The corresponding required magnet parameters are: an air gap of 120 mm, a good field region of 240 mm width at the exit and 150 mm at the entrance of the magnet.

The energy variation of the beam in the range between 70 and 250 MeV will be realized in steps of 1 to 2 % of the maximum energy. The current in the magnet coils has to vary in the same manner and to minimise eddy current effects; the yoke has to be made using laminated steel. Nevertheless, a magnet made of laminated material is not free of eddy currents. The eddy currents occur in the lamination plates excited by magnetic field components perpendicular to the plates. Such perpendicular field components exist at each end of a normal dipole magnet of window frame or H-type magnet. The eddy currents lead to a distortion of the static field. Displacement and deflecting error of the beam trajectory are the immediate consequences. The finite conductivity of the yoke material leads to a decay of the eddy currents and the field distortions vanish after a specific time.

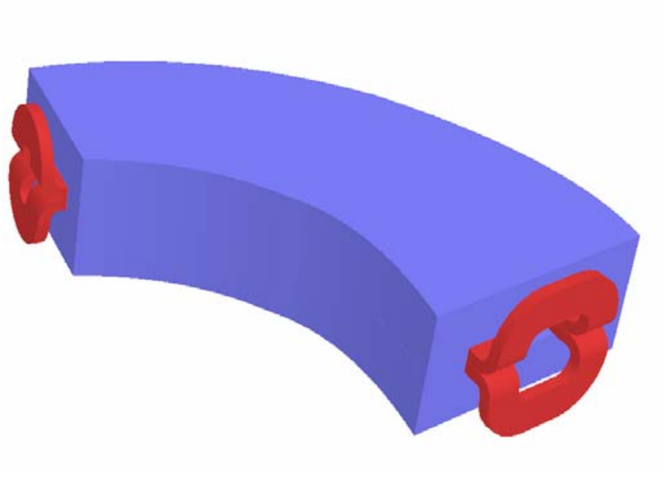

Fig. 2: Design model of the 90 degree magnet; a window frame type magnet for static field calculations.

SIMULATION OF THE EDDY CURRENT EFFECTS

The program package OPERA [3] with the solver code ELEKTRA is able to simulate the effect of the eddy currents with non-linear iron properties and non-isotropic conductivity due to the lamination. ELEKTRA analyses time dependent electromagnetic field problems. The calculations need much more resources (time and memory) on a computer than static field calculations. Therefore, simplified straight models of the dipole are simulated. The time variation is realised by a linear current ramp from I = 0 at t = 0 s up to I = Imax at t = 0.5 s. The current is then kept constant until the eddy currents decay. This strong 100 % current step was chosen to get a strong eddy current effect to overcome numerical noise. Realistic current steps lead to effects that are too small to calculate with the present software.

The non-isotropic conductivity is set to 3600 Siemens/mm in the lamination plates and zero Siemens/mm perpendicular to the lamination. Fig. 3 shows the eddy current density in an octant of a window frame type straight magnet model at t = 0.5 s and 0.9 s. The eddy currents originate in the end regions of the magnet and propagate towards the centre.

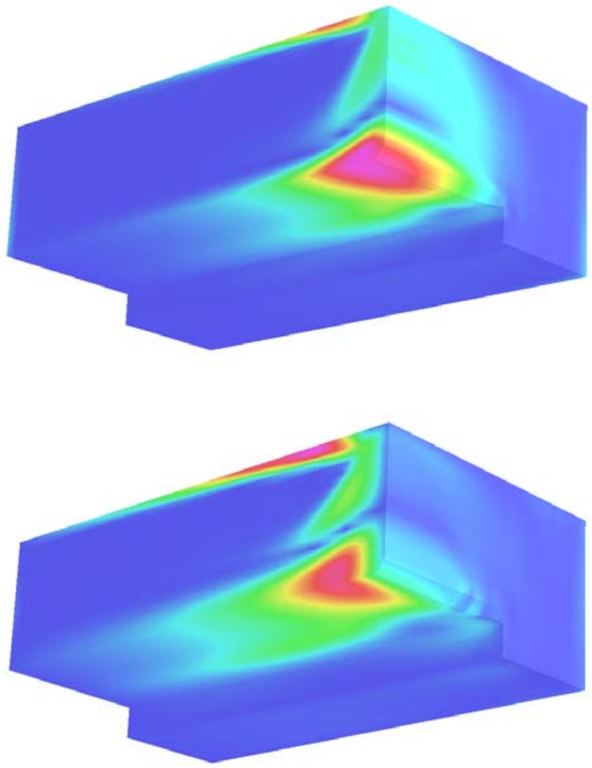

Fig. 3: Contour plots of the surface eddy current density at t = 0.5 s and 0.9 s of an octant of a window frame dipole magnet with a total length of 2000 mm and 1.8 Tesla field strength.

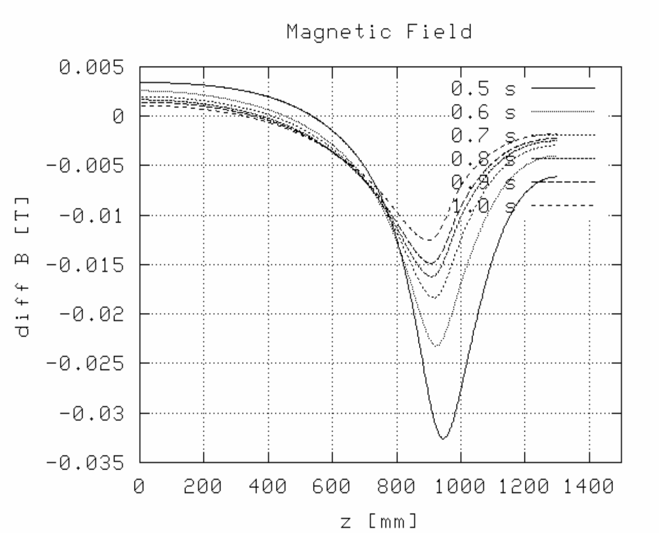

Fig. 4: Magnetic field on the longitudinal axis at t = 0.5 s, 0.6 s, 0.7 s, 0.8 s, 0.9 s and 1.0 s compared with the static field.

A plot of the vertical magnetic field on the longitudinal magnet axis at several times is compared to the static field in Fig. 4. The corresponding values of the longitudinal integrated field Int(By dz) are shown in Fig 5. One can see the decay of the field distortions excited by the eddy currents.

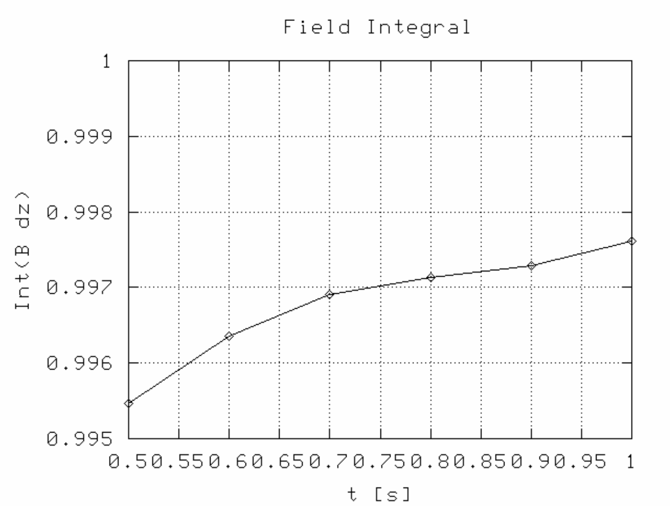

Fig. 5: Longitudinal integrated magnetic field compared to the field integral of the static field.

CONCLUSION

The simulations show a realistic behaviour of the eddy current effects in a ramped laminated dipole magnet. The huge amount of computer resources required forces the use of simplified straight dipole models with a high 100 % current ramp. The simulation of a realistic current ramp (1 – 2 % step) was not successful. Calculations with several types of magnets will give us valuable information required before the design of the Gantry 2 dipole magnet can be completed. The results will also give us more insight into eddy current effects for the whole beam line. Preliminary calculations show a better eddy current behaviour with lower distortions for H-type magnets but further simulations are necessary to verify this first impression.

REFERENCES

[1] H. Reist et al., *A Fast Degrader To Set The Energies For The Application Of The Depth Dose In Proton Therapy*, *PSI Scientific and Technical Report 2001, VI.*

[2] E. Pedroni et al., *The 200 MeV proton therapy project at the Paul Scherrer Institute: Conceptual design and practical realization*, Medical Physics, Vol. 22, No. 1, 37, January 1995.

[3] Vector Fields, Oxford, *OPERA Computer Code, http://www.vectorfields.com.*