DESIGN AND DEVELOPMENT OF KICKERS AND SEPTA FOR MEDAUSTRON

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Abstract

The MedAustron facility, to be built in Wiener Neustadt (Austria), will provide protons and ions for both cancer therapy and research. Different types of bumpers, septa and kickers will be used in the low energy beam transfer line, the synchrotron and the high energy extraction lines. They are presently being designed in collaboration with CERN. Both 2D and 3D finite element simulations have been carried out to verify and optimize the field strength and homogeneity for each type of magnet and, where applicable, the transient field response. The detailed designs for the injection and dump bumpers, the magnetic septa and the fast chopper dipoles are presented. A novel design for the electrostatic septa is outlined.

INTRODUCTION

The MedAustron facility will be an accelerator complex for protons and ions. It consists of different primary particle sources, a linac to reach the synchrotron injection energy of 7 MeV, a synchrotron and a transfer line, which directs the beam towards the experimental areas or the medical treatment rooms. The synchrotron delivers protons for medical treatment in an energy range from 60 MeV to 250 MeV and carbon ions from 120 MeV/u to 400 MeV/u. For research purposes it will be possible to accelerate protons up to 800 MeV. A number of different septa and kicker systems are needed for the MedAustron project and their design and production are coordinated in collaboration with CERN. All kickers and septa are installed in the synchrotron hall of the MedAustron facility. Fig. 1 shows a schematic overview of the magnet locations of the MedAustron accelerator.

SEPTA

The synchrotron injection and extraction systems are designed with reliability as the driving parameter. To obtain this, the magnetic septa were designed to run at the lowest possible current and power consumption per magnet, to ease the cooling requirements. The extraction channel was designed, using four magnetic septa, to provide space for a relatively large electrostatic injection septum. This septum uses a classical cathode opposite the hollow septum anode support, allowing the orbiting beam to pass inside the anode support. The anode and cathode positions are remotely adjustable, and the mechanical displacement systems for both anode and cathode are located on the inside of the ring, to provide sufficient space for the adjacent extraction channel. Overall, the injection and extraction uses only two types of magnetic septa and two variants of the electrostatic septum.

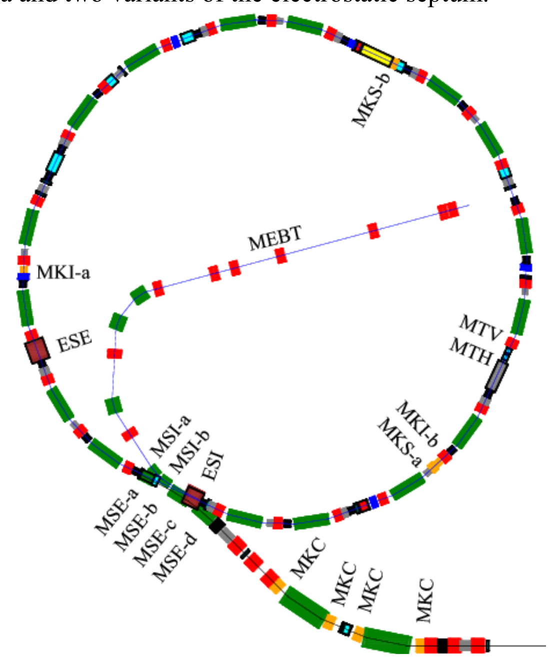

Figure 1: Schematic overview of the magnet locations in the MedAustron accelerator (green: bending magnets, red: quadrupoles, orange/yellow: special magnets).

Electrostatic Septa

The electrostatic septa are located under vacuum, and use titanium cathodes and molybdenum septum foils. The hollow anode supports provides reasonably low coupling impedance to the beam. The High Voltage (HV) feedthroughs of the septa are located on the same side of the vacuum vessel as the remote displacement system for the cathode and anode to gain space for the extraction channel on the other side. The nominal voltage required is less than 70 kV; however the feedthroughs and cathode supports are designed for up to 150 kV, to allow sufficient margin for HV conditioning.

Table 1: Principal Parameters for the Electrostatic Septa

Septa parameter [unit]:	***ESI***	***ESE***
Equivalent electric length [mm]	600	800
Deflection angle [mrad]	60	2.5
Septum thickness [μm]	100	100
Gap width nom (min, max) [mm]	25 (15,35)	15 (10,25)
Septum height [mm]	74	74
V_{nom} (max.) [kV]	69.7 (150)	63.7 (150)
E_{nom} [MV/m]	2.79	4.26
Good field region [mm x mm]	49 × 33	49 × 30
Field quality [%]	± 1	± 0.5

The cathode and anode shape are chosen such as to minimise the electric field amplification on the HV components and to obtain the required field homogeneity in the gap. The principal septum parameters are indicated in Table 1. The injection septum (ESI) provides a relatively large deflection angle, and therefore the septum and cathode are bent at 60 mrad to minimise the required gap width whilst maintaining the required beam acceptance. The extraction septum (ESE) provides a moderate deflection of 2.5 mrad, hence the septum and cathode are straight.

Magnetic Septa

The septa design and layout are driven by the thin extraction septa requirements. To ensure that the extraction provides sufficient beam displacement with respect to the ESI, the first extraction septum (MSE-a) must provide a minimum deflection angle of 50 mrad. To achieve this using a relatively short septum the coil uses 6 turns in a single layer. This septum design is also used for the injection line (MSI), where 2 septa provide 250 mrad each to the beam at 7 MeV/u. The beam displacement and the beam dimensions at injection define the magnet aperture, whilst parameters at extraction define the coil design. The septum parameters are given in Table 2.

Table 2: Principal Parameters for the Magnetic Septa (MSI: values in brackets refer to the extraction design)

Septa parameters [unit]:	***MSI 6 turn (MSE)***	***MSE 8 turn***
Equivalent magnetic length [mm]	590	840
Deflection angle [mrad]	250 (52)	99.4
Septum thickness + screen [mm]	10.3+1.1	20.2+1.1
Gap aperture w × h [mm]	80 × 40	75 × 40
Number of turns	6	8
I_{nom} [kA]	1.73 (3)	3
B_{nom} [T]	0.32 (0.56)	0.75
Good field region [mm x mm]	49 × 33	49 × 30
Field quality [%]	± 1	± 1
Integrated fringe field [ ]	10^{-3}	10^{-3}
Power consumption p. mag. [kW]	9.5 (29)	31

The MSE-a is powered in series with 3 thick extraction septa (MSE-b,c,d). The position of the 2nd extraction septum is set relatively close to the MSE-a. The entrance of the 3rd septum is located downstream of the ESI tank flange. Thus the remaining space determined the maximum septum length for the thick septa.

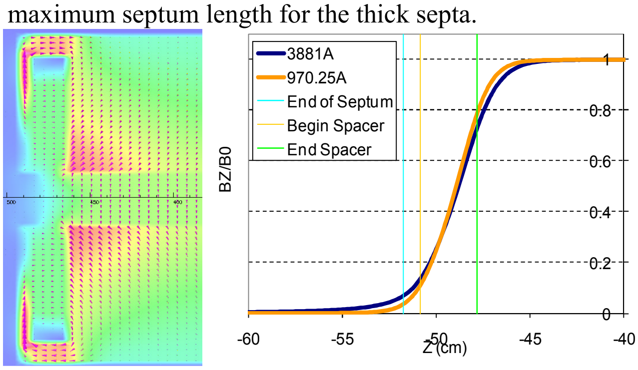

Figure 2: Magnetic flux in the field clamp of MSE-b.

Fig. 2 shows on the left side a cross section in the vertical plane (along the beam axis) of one MSE-b end-plate indicating the flux density and a graph showing the B-field change in this region on the right. In the past the endplates turned out to be a significant contributor to non-linear behaviour of the magnetic length change (for different currents).

FAST PULSED MAGNETS

Medical synchrotrons usually use fast pulsed magnets for injection, extraction, tune measurements and beam chopping/dumping. The MedAustron design [2] comprises two injection bumpers (MKI, Fig. 1), two dump bumpers (MKS-a and MKS-b, Fig. 1) in the synchrotron, and four chopper magnets in the extraction line (MKC, Fig. 1). In addition the synchrontron is equipped with tune kickers (MTV and MTH, Fig. 1). All these magnets are placed outside the machine vacuum, have a metalized ceramic vacuum chamber and use a ferrite yoke. The dimensions of the ferrite yoke are chosen to limit the maximum flux-density, in the central-vertical (Y=0) plane of the NiZn ferrite, to below 210 mT.

Injection Bumpers

A horizontal injection bump is excited by two identical dipoles. These magnets are a window-frame construction (Fig. 3). For economy, and to ensure the same shape of their individual magnetic fields, the two magnets are powered in series and hence form a single electric circuit. Race-track type coils are utilized the surrounding aluminium box acts as an eddy-current shield and hence limits the stray field which must be carried by the ferrite yoke. The maximum rise-time of the current is limited by the 20 mm thick aluminium box, and is thus specified to be ≤ 1 ms.

The injection is made over a nominal 24 turns during which the field in the injection bumpers is decreased linearly from a nominal 27.8 mT (512 A) to 0 T. Provision is required for variation in the injection configuration from 15 to 50 turns. Revolution time at injection energy of 7 MeV/u for both protons and for 12C6+ ions is ~2 μs. Thus the duration of the linearly decreasing magnetic field is between 30 μs and 100 μs (48 μs nominal).

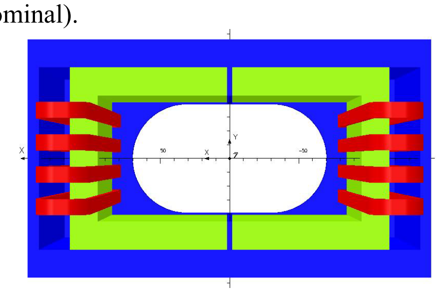

Figure 3: Injection bumper.

Dump Bumpers

The particle beams are injected into the synchrotron ring at low energy then ramped up to the extraction energy, according to the needs of the treatment plan. In the event of a machine malfunction or other operational abnormality the circulating beam must be dumped: this dumping action occurs over many revolutions of the circulating beam and is actuated by two dipoles. For economy, and to ensure the same shape of their individual magnetic fields, the two dump bumpers are powered in series and form a single electric circuit. The two yokes are identical, but the coils are arranged so that one dipole (6 turns) gives half the kick of the other (12 turns): the maximum current is 1350 A. The beam is deflected vertically. Due to the vertical dimension of the vacuum chamber, the magnet is constructed in one piece as an open C-core closed by a 20 mm thick aluminium eddy-current screen. A CAD view of the 12-turn dump bumper is shown in Fig. 4. The dump is made over a nominal 48 µs. The beam dump can be triggered at any instant in the machine cycle hence the power supply must be able to "track" the machine cycle.

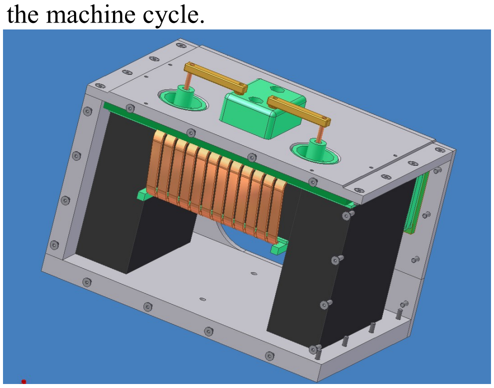

Figure 4: 12-turn dump bumper.

Chopper Dipoles

All treatment rooms will be able to switch the beam on and off routinely during operation by means of the beam chopper. When the chopper is on it makes a closed-orbit bump that bypasses a dump block, mounted inside the vacuum chamber (Fig. 5). When the chopper is off the beam is stopped by the dump block. The four chopper dipoles are in series and fed by a common power supply. Since the four dipoles sit in a common drift space, the bump is "perfectly" closed and the downstream trajectory of the beam is unaffected. Hence the stability and over-shoot of the power supply are not critical issues.

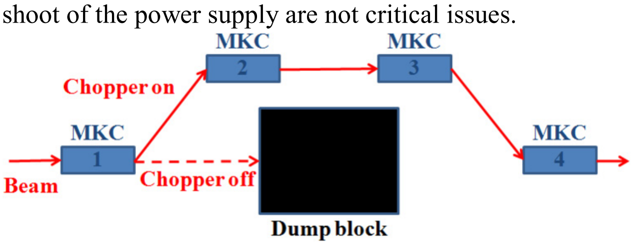

Figure 5: Beam chopper principle.

The chopper dipoles have a window frame construction with two water cooled saddle coils of 6 turns each (Fig. 6). Each magnet will be housed in a box whose sides, top and bottom are 20 mm thick aluminium. End-plates, which form a magnetic mirror, are 12 mm thick 3% silicon steel constructed from 1 mm thick laminations. The chopper dipole requires a current of almost 600 A. The specified current rise and fall time is 250 µs, however the magnet insulation is specified such that it is capable of 90 µs rise and fall time. The current flattop can be from 0 s to DC. The design of the chopper has been optimized to achieve a uniformity of ∫B.dl of not worse than ±0.2% over an area of 45 mm x 45 mm (Fig. 7). The predicted inductance, derived from 3D simulations, is 85 µH per dipole. This permits a rise/fall time of 90 µs with a voltage of 2.3 kV per four series dipole magnets.

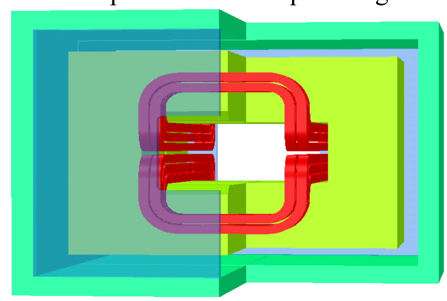

Figure 6: Chopper dipole model for finite element calculations.

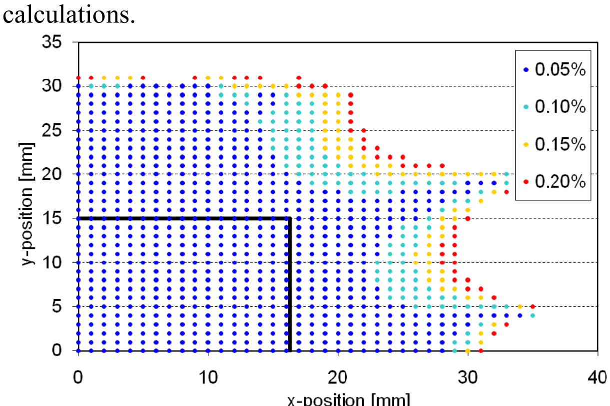

Figure 7: Predicted uniformity of ∫B.dl.

The power supply design is based on that for CNAO [3] and is composed of an HV part, which generates the rising and falling current ramp, and of a low voltage part (tens of volts) which ensures the current flat top.

CONCLUSIONS AND OUTLOOK

The design for the MedAustron bumpers and septa is finalised. The next phase will see the manufacturing of the hardware in industry for all magnetic elements, which is to be completed before the end of summer 2012, in time for the installation phase of the synchrotron.

REFERENCES

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[2] The MedAustron accelerator design report, Wr. Neustadt, unpublished.

[3] E. Dallago et al., "The power supply for the beam chopper magnets of a medical synchrotron", 37th IEEE Power Electronics Specialists Conference. 2006 (PESC06), Jeju, Korea.