BEAM INJECTION SYSTEM FOR THE PRAGUE MEDICAL SYNCHROTRON

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Abstract

The PRAgue MEdical Synchrotron is a kernel of an oncological hospital, which is planned to be built in Czech Republic. The synchrotron requires a single turn injection system. This paper presents a general layout, requirements, main circuits of the pulse generators, a design and some calculations of the kicker and septum magnets.

1 INTRODUCTION

A medical synchrotron for hadron therapy should be compact and simple in operation [1]. To meet these requirements, a single turn horizontal injection of the proton beam from a linear accelerator into a synchrotron has been chosen. In this case one can get the normalized transverse emittance of the trapped proton beam of 1π·mm·mrad. To use a commercial proton linear accelerator as an injector, the kinetic energy of the injected beam should be equal to 7 MeV. The source current should be about 50 mA to get the required transverse emittance of the trapped beam.

The first element of the injection beamline is a quadrupole triplet mounted as close to the end of the injector as possible. This triplet should focus the beam and get the beam waists in both planes in the vicinity of the centre of a debuncher (DB). After the debuncher it is necessary to put another triplet (QT) to recollect the beam. The dispersion match is obtained from a horizontal bend. The bending magnet (BM) should have a gradient to produce a vertical waist near its centre. The bending magnet is flanked by quads (QA) focusing the beam in the horizontal plane to make also a horizontal waist in the magnet. The slop of the dispersion function has to be matched by the quad (QS) following the bending magnet. The injection system includes also the septum (SM) and kicker magnets (KM). The general layout of the injection beamline from the debuncher till the fast kicker is shown in Fig.1. A detailed information about the ring characteristics and main beam parameters of the injection system are presented in the reports [2].

The ring circumference of the synchrotron is equal to 41 m. Revolution period of the 7MeV beam is equal to 1.1 μsec. Pulse duration of the trapped proton beam is about 0.8 μsec.

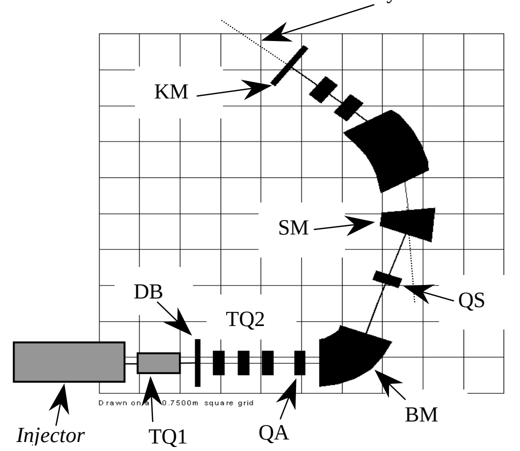

Figure1: General layout of the injection beamline.

The kicker and septum magnets are placed at a distance of more than 3 m. It allows to diminish requirements for the kicker parameters. There is a set of known problems, to be solved while creating the kicker and septum. One of these problems is a ceramic vacuum chamber for them. It is simpler to house the kicker and septum into separate vacuum tanks to avoid these technological problems. The thermal loading in the conductors of the excited winding is not significant for the repetition rate of 1 Hz and the vacuum of 10^{-7} torr. Parameters of the kicker and septum magnets are of the key importance for the injection system.

2 KICKER MAGNET

The kicker is of the lumped type. It consists of ferrite C-cores. The main parameters of the kicker system are given in Table1. The schematic drawing of the kicker magnet is shown in Fig.2.

The kicker is excited by a single turn winding, which consists of straight copper plates connected at the kicker end. One of the plates approaches close to the kicker aperture to improve the magnetic field uniformity and minimise the fill time.

Table1. Basic specification of the injection kicker magnet

Injection kinetic energy MeV	7
Magnet length (mm)	200
Deflection angle (mrad)	20,06
Peak magnetic field (T)	0,0384
Good field region (mm × mm)	60(H) × 40(V)
Physical aperture (mm)	135(H) x 60(V)
Conductor cross section (mm × mm)	60(H) x 5(V)
PFN length (ns)	800
Fall time (ns)	250
Repetition rate (Hz)	1
Peak current (A)	1833
Self-inductance (μH)	0,565
PFN voltage (kV)	33,2
Flat-top reproducibility (%)	±0,5
Flat-top ripple (%)	±0,5

The magnetic field uniformity inside the aperture in the good field region should meet the requirement to accuracy of ± 0.5 %, for the beam emittance would not increase significantly.

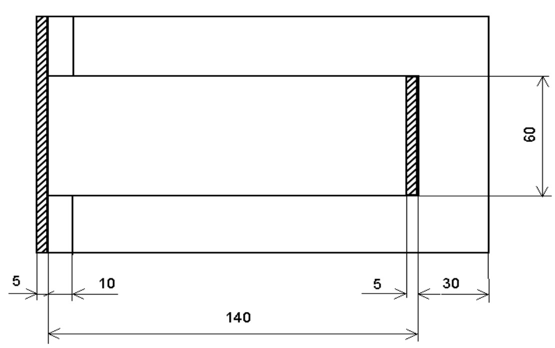

Figure 2: Schematic drawing of the kicker magnet.

The magnetic field distribution in the kicker aperture is shown in Fig.3.

A pulse generator will be located under the magnet to exclude transmission cables in the kicker system and to simplify the kicker design. Due to this very reason the lumped type of the kicker has been chosen. The quasi-rectangular current pulse with the flat-top duration of 0.8 μsec for the kicker will be delivered by means of a pulse forming network (PFN). PFN is the 9 Ω delay line with the lumped elements. It consists of 10 cells. The simplified circuit of the kicker system is shown in Fig.4.

The kicker requires a short rise time of 125 nsec and the fall time of less than 250 nsec. The PFN voltage about 35 kV is required to achieve the mentioned rise/fall time in the available space.

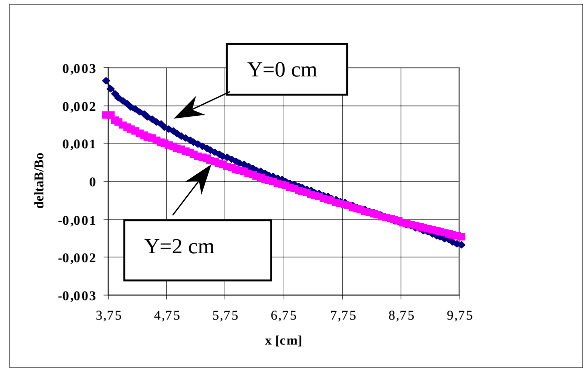

Figure 3: Relative magnetic field distribution in the kicker aperture for different y-values.

Therefore it is necessary to use a thyratron for the high voltage switching. The thyratron anode is connected to the lead of HV capacitance plate of the forming line through a matching resistor. Its cathode is grounded to reduce the fill time.

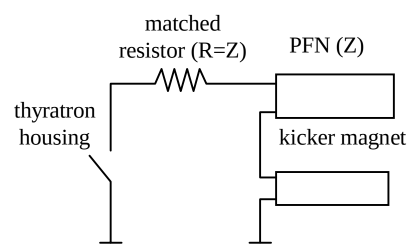

Figure 4: Principal circuit of the kicker system.

The kicker is housed in a vacuum tank. One of the leads of the kicker exciting winding is connected to the 'ground' capacitance plate of the forming line. The other one is grounded. In this case the voltage applied to its ends will be small. Additional efforts will be undertaken to decrease the parasitic inductance of the discharging circuit. The LC elements of the forming line, the thyratron, the matching resistor and etc. will be located in one cabinet. The cabinet will be connected to the kicker vacuum tank through the high-voltage connector. The NN-ferrites will be used for the kicker yoke to reduce the integral remanent field. As calculations have shown, the integrated remanent field does not exceed 1 G·m, that corresponds to the requirements mentioned above. It is achieved due to good magnetic properties of these ferrites and dimensions of the kicker aperture.

3 SEPTUM MAGNET

The septum magnet is located before the kicker to reduce the angle of incidence of the injected beam up to 20 mrad. The septum magnet produces the magnetic field of about 0.35 T in the region traversed by the injected beam. Its influence on the adjacent aperture of the circulating beam of the synchrotron must be very small. The change period of the magnetic field in the septum must be more than the revolution period of the beam in the synchrotron. The magnetic cycle in the septum is 80 μsec, that is much more than the revolution period. Moreover, the dissipated magnetic field should not shift the closed orbit by more than 1mm.

The cross section of the septum magnet is shown in Fig.5. The C-core will be made from laminated transformer steel to minimise the eddy current. The lamination of the steel will be done perpendicular to the axis of the injecting beam. The septum has a copper screen 4.5 mm thick in order to reduce the influence of the magnetic field on the circulating beam.

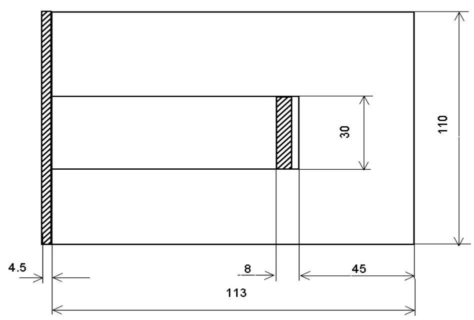

Figure 5: Schematic drawing of the septum magnet.

The core of the septum magnet is curved along the axis of the beam direction for better excitation efficiency. The excitation winding is one turn made from the copper conductors with a rectangular cross section. The excitation of the magnetic field pulse is produced by discharge of a capacitor bank through its winding. The main parameters of the septum magnet are listed in Table2.

Table 2: Basic specification of the injection septum magnet.

Deflection angle (mrad)	476
Magnetic length (mm)	517
Bending radius (mm)	1097
Peak magnetic field (T)	0,3485
Physical aperture (mm∗2)	60(H)x30(V)
Minimum thickness of the septum (mm)	4,5
Nominal distance between the injected beam and the ideal orbit at the exit of the magnet (mm)	68,6
Pulse length (μs)	80 (half-sine wave)
Repetition rate (Hz)	1
Peak current (A)	8344
Self-inductance (μH)	1,3
Minimum peak voltage (V)	430
Maximum capacitance (μF)	494
Flat-top reproducibility (%)	±0,1
Flat-top ripple (%)	±0,5

The current cycle in the septum magnet is a half-sine with the time of 80 μsec for the current should not change more than by ± 0.5 % during the injection period. The discharge of the current is accomplished by means of an ignitron. The magnetic field uniformity in the region 30(H)×25(V) mm inside the septum must be within the limits of ± 0.5%. The calculated magnetic field uniformity is shown in Fig.6.

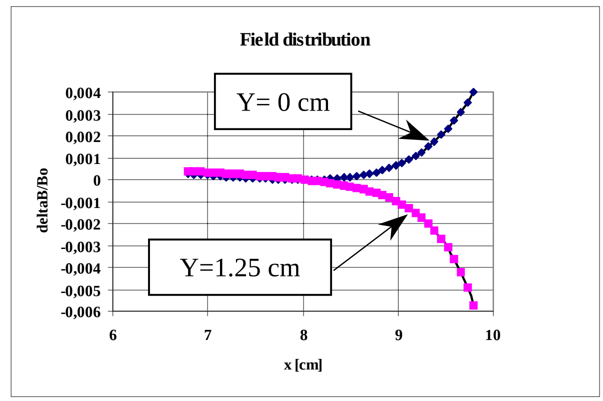

Figure 6: Relative magnetic field distribution for different y-values.

The maximum peak power dissipation in the conductors of the winding, the losses in the laminated steel core caused by the eddy current, and the losses to hystereses are not considered in this report. However, rough estimations have shown that the losses are low in spite of the large required value of the current in the conductors and can not be an obstacle for the septum design.

CONCLUSION

The elements of the injection beamline of the dedicated proton synchrotron for cancer therapy have been discussed. The main parameters of this line have been determined. Magnetic field calculations for the kicker and the septum magnets have been performed. The obtained field distributions meet the necessary requirements. The second stage of this work requires to create the kicker, septum magnets and the pulse generator prototypes to associate the experimental results with the required parameters.

REFERENCES

[1]A.Molodozhentsev, G.Sidorov, V.Makoveev, I.Ivanov, K.Prokesh, J.Sedlak, M.Kuzmiak, The focusing structure of the Prague proton synchrotron for hadron therapy, in: Proceedings of the PAC97 Conference, Vancouver, BC, Canada, May 1997.

[2] A.Yu.Molodozhentsev et al., Design of dedicated proton synchrotron for Prague Radiation Oncology Centre, is presented in this Conference.