A 250 kHz CHOPPER FOR LOW ENERGY HIGH INTENSITY PROTON BEAMS

C. Wiesner[#], L.P. Chau, M. Droba, O. Meusel, U. Ratzinger, IAP, University Frankfurt/Main, Germany

Abstract

A neutron pulse with 1 ns pulse length and a repetition rate of 250 kHz is needed for experiments on nuclear astrophysics using the Frankfurt Neutron source at the Stern-Gerlach-Zentrum. The time structure of the neutron flux is given by the primary proton beam which hits a ^{7}Li target. The creation of the required time structure on a 200 mA proton beam at reasonable emittance growth and at well controlled beam loss conditions is demanding.

A chopper system will be installed in the Low Energy Beam Transport (LEBT) section to transform the incoming 120 keV dc proton beam into a pulsed beam before injecting into the RFQ. Pulse durations of 50 to 100 ns at a repetition rate of 250 kHz are required. The chopper system consists of a fast kicker system for preseparation of the beams and of a static septum magnet to lower the deflection fields of the kicker.

Beam Transport Simulations for the LEBT Section and Particle in Cell (PIC)-Simulations for the kicker system are discussed. Preliminary experiments for operating an electric kicker system are presented.

LOW ENERGY BEAM DYNAMICS

The Frankfurt Neutron Source at the Stern-Gerlach-Zentrum (FRANZ) is designed to produce short neutron pulses of high intensity [1,2]. Intensity and time structure of the neutron pulses depend on the characteristics of the primary proton beam.

A dc injection into the RFQ [3] results in rf power consumption due to beam loading and the problem of beam dumping at a beam power of several hundred kW. Therefore a chopper system with a fast kicker will be installed in the LEBT section [4]. The position of the chopper system is shown in figure 1.

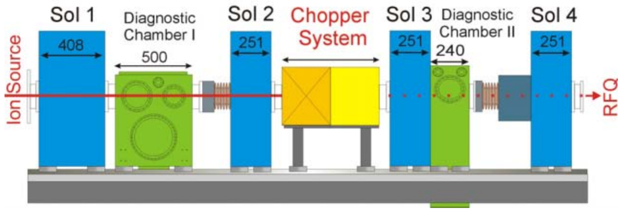

Figure 1: Position of chopper system in the LEBT.

The LEBT section consists of four solenoids already installed at the FRANZ experiment site: two for matching the proton beam into the chopper system and two for injecting it into the RFQ.

Beam Dynamics from Ion Source to Chopper

Transport simulations for a 150 mA proton beam lead to an efficient transport from the ion source to the chopper system assuming a space charge compensation of 85%. A homogenous beam with 6 mm radius and 80 mrad divergence angle was deduced from beam simulations behind the source extraction system. The phase space projections to the x-x'-plane are given in figure 2.

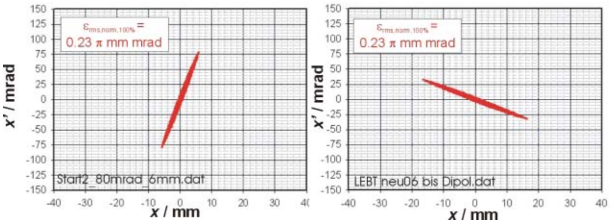

Figure 2: Ion source output (left) and chopper input (right) distributions in x-x'-plane.

Beam Dynamics in the Kicker System

To study the beam dynamics in the time-dependent kicker field a PIC-Code was developed. It is based on codes elaborated at IAP for multi-particle processes in electric and magnetic fields [5]. The multispecies code allows simulating the collective effects of compensation and secondary electrons on the proton beam.

Simulation results with a dc beam of 160 mA injected into a magnetic kicker of 30 cm length oscillating with an amplitude of 100 mT are shown in figure 3. The transmitted proton current is recorded behind a slit located after a drift of 30 cm. Two cases are shown: The first one is calculated without any electrons in the system, whereas the second one considers the production of secondary electrons from the high intensity beam hitting the vacuum chamber walls.

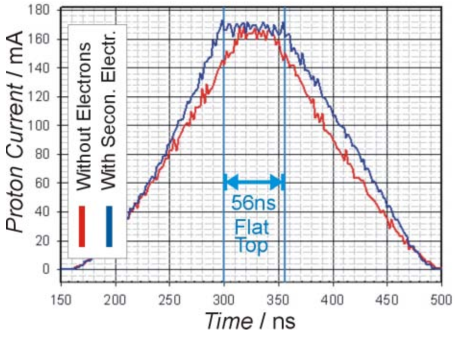

Figure 3: Simulated proton pulse shape behind the chopper system.

[#] wiesner@iap.uni-frankfurt.de

The presence of electrons in the kicker and drift section increases the beam flat top length and reduces the emittance of the flat top beam compared to the mere proton beam.

Preliminary simulations of an electric kicker system demonstrated a high electron flux on the deflector plates. For high currents this bears the risk of sparking and sputtering from the electrodes which must be further investigated to develop appropriate measures.

Beam Dynamics from Chopper to RFQ

The chopper output emittance for the magnetic kicker simulation without the influence of secondary electrons is given in figure 4. An emittance growth of a factor 3 for the flat top beam and nearly 5 for all transmitted particles is perceived.

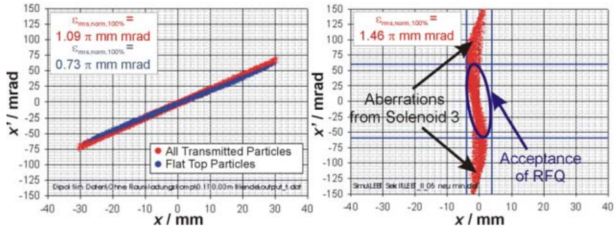

Figure 4: Chopper output (left) and RFQ input (right) distributions in x-x'-plane.

The beam leaves the chopper system with an x-radius of 30 mm originating from the slit radius. The large radius of the divergent beam causes a high filling degree of about 90% in the following solenoid. At this filling degree, the nonlinear field component of the solenoid acts on the proton beam creating aberrations and causing emittance growth.

Even though most particles not matched into the RFQ acceptance belong to the tail of the beam pulse, which is not relevant for subsequent acceleration, further improvements for the injection scenario will lead to an enhanced beam matching into the acceptance of the RFQ.

TECHNICAL REALIZATION OF THE CHOPPER SYSTEM

Chopping High Intensity Beams

Space charge forces of high intensity beams restrict all drift lengths. This makes high deflection fields necessary to achieve transversal separation of the beam. Realization of high deflection fields is challenging for high intensity beams with beam radii in the cm range, which demand big apertures for deflector plates or magnets.

Electric Kicker System

A low energy 120 keV beam requires less field energy for electric deflection than for magnetic deflection. At a high repetition rate of 250 kHz a magnetic kicker system would entail high power consumption. Therefore, an electric kicker system is proposed.

The high beam radius within the kicker system makes a significant transversal distance of the deflector plates necessary. With parallel deflector plates of 20 cm length and a distance of 10 cm between them a voltage of 23 kV is needed to gain transversal separation of the beam after 30 cm drift.

Preliminary experiments to accomplish the voltage pulse for the electric kicker were carried out. The scheme of the test setup is shown in figure 5. After the trigger signal the *Toshiba* IGBT opens, so that the energy stored in the capacitor is discharged through the primary winding. The voltage pulse is transformed using a metglas nanocrystalline tape wound core from *Hitachi Metals*.

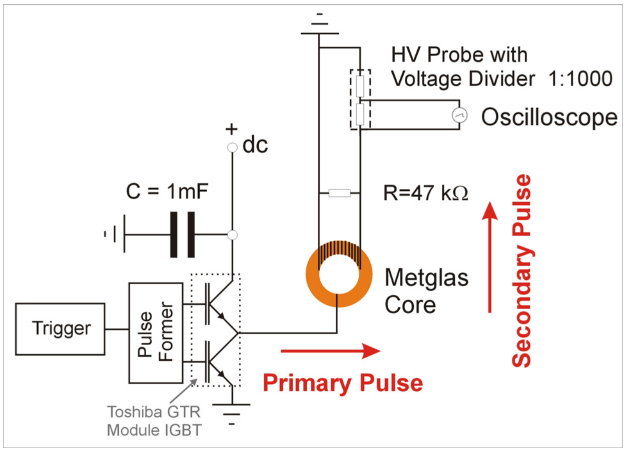

Figure 5: Scheme of test setup.

A measured voltage pulse is shown in figure 6. A secondary pulse of 15 kV with a length of 1.3 µs was achieved. A pulse width of 300 ns is reached at 12.5 kV.

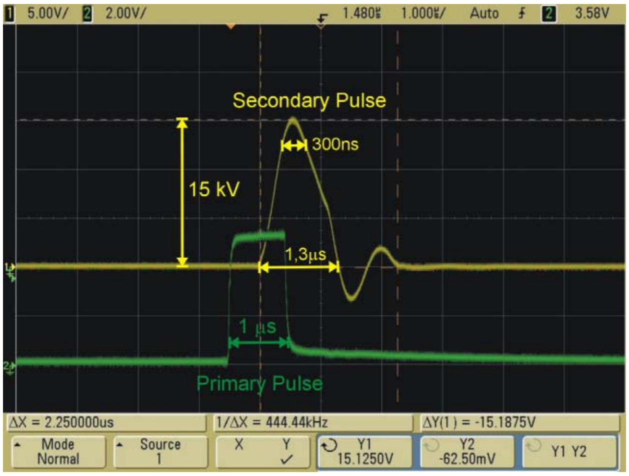

Figure 6: Measured voltage pulse.

CHOPPER SYSTEM LAYOUT

The use of a static septum magnet is proposed to transport the deflected beam into the beam dump, protect the following solenoid and lower the maximum deflection fields for the dynamic kicker (figure 7).

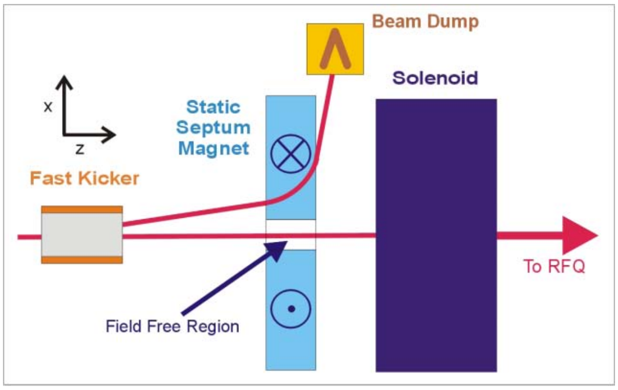

Figure 7: Scheme of chopper layout.

A 3-dimensional view of the main chopper components is given in figure 8.

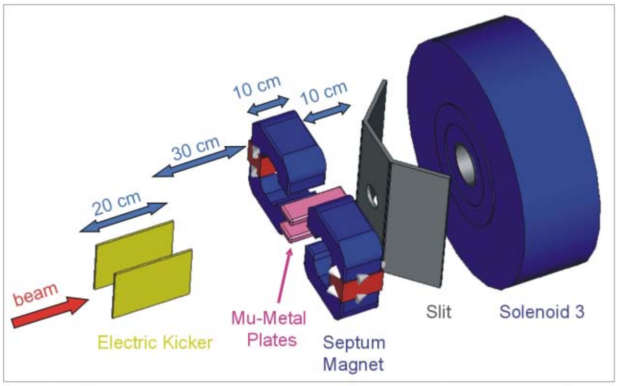

Figure 8: View of chopper components.

Septum Magnet

Due to a beam power of several kW per cm^2 a so-called massless septum magnet without a material septum in the beam path is proposed. The septum magnet includes two C-magnets with opposite B-field direction and Mu-metal plates in between them to improve the low field region for the good beam.

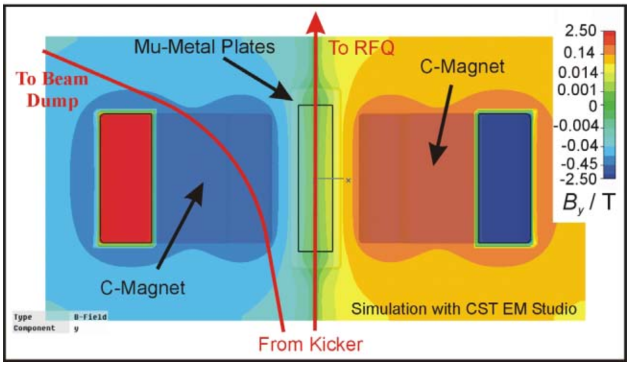

Figure 9: Top view magnetic induction in septum magnet.

Simulations with CST EM STUDIO were carried out. The deflecting component of the magnetic induction in the centre plane is shown in figure 9 in a false-colour plot. The low field region for the beam transmitted to the RFQ is indicated in green colour.

A first simulation result for two C-magnets with a 60 mm gap, 200 windings and a coil current of 200 A is shown in figure 10. The achieved deflection field of 280 mT is sufficient to transport the proton beam into the beam dump.

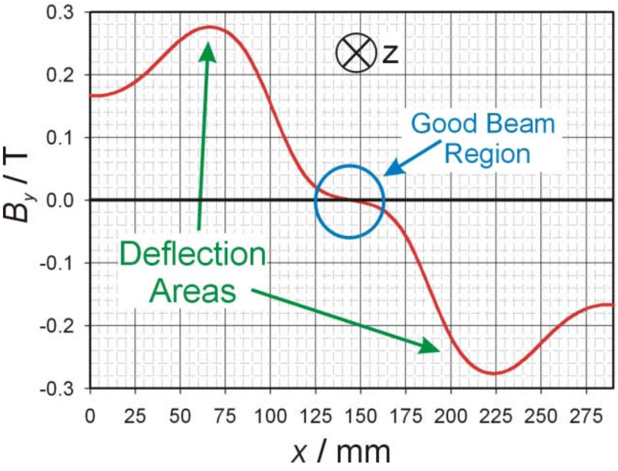

Figure 10: Simulated magnetic induction in centre plane of septum magnet.

CONCLUSION

Due to high power consumption of the magnetic kicker an electric kicker system is proposed. The challenges of space charge compensation, sparking and sputtering have to be tackled in order to assure the reliability of the system.

A PIC simulation code was developed. It can be used to optimize the electric kicker layout and study collective phenomena especially relevant for high intensity beams which pose novel challenges to beam dynamics and technical realization of accelerator components.

Preliminary experiments to achieve the required voltage pulses for the operation of the electric kicker system are encouraging.

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