E×B CHOPPER SYSTEM FOR HIGH INTENSITY PROTON BEAMS*

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Abstract

An E×B chopper system for proton beams of up to 200 mA and repetition rates of up to 250 kHz is under development at IAP. It will be tested and installed in the low energy section of the Frankfurt Neutron Source FRANZ at a beam energy of 120 keV.

The chopper layout and beam simulation results are presented. Measurements of the high voltage pulse generator based on MOSFET technology as well as beam deflection experiments are shown.

INTRODUCTION

High intensity beams which are increasingly needed for a variety of applications pose new challenges for beam chopping. An E×B chopper minimizes the duty cycle for electric beam deflection and constrains the mobility of secondary particles, therefore reducing the risk of voltage breakdowns. In addition, the beam is dumped outside the transport line in order to avoid uncontrolled power deposition and production of secondary particles.

E×B CHOPPER LAYOUT

The chopper consists of a static magnetic dipole field and a pulsed electric field in a Wien filter-type E×B configuration [1]. The electric field temporarily compensates the magnetic deflection thus creating a proton pulse in forward direction (Fig. 1).

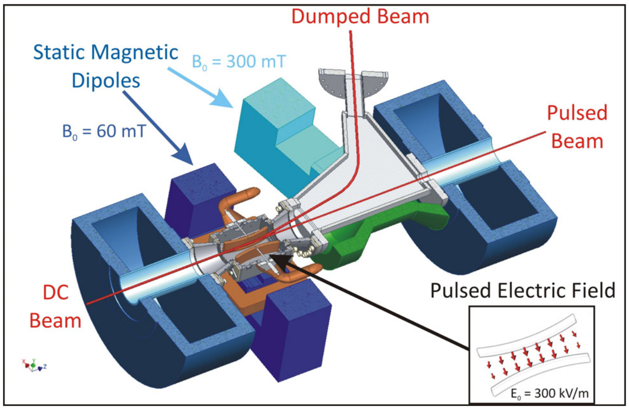

Figure 1: E×B chopper system consisting of a static magnetic dipole field and a pulsed electric field in a Wien filter-type configuration. Beam trajectories shown in red.

Downstream of the deflection section a second dipole will be used as septum magnet to separate the beams, ensuring clean dumping outside the transport line. A magnetic shielding tube is used to reduce the dipole leakage field to the 1 mT level.

The chopper system will be installed between the second and third solenoid in the Low Energy Beam Transport (LEBT) section of the Frankfurt Neutron Source FRANZ [2, 3]. An overview of the main components is given in Fig. 2.

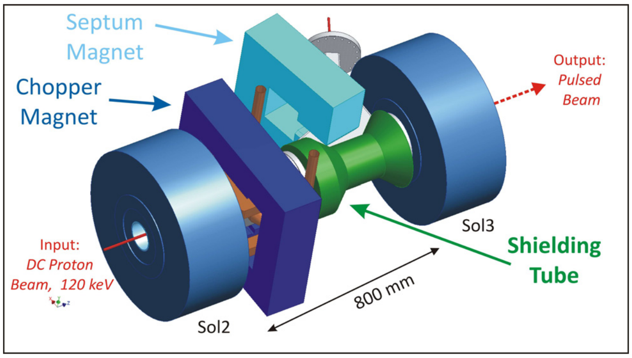

Figure 2: Overview and main components of E×B chopper system.

Careful matching of magnetic and electric deflection forces is required to minimize transverse beam offset and emittance growth [4]. Therefore shims and shorting tubes are used to shape the electric as well as the magnetic field. All fields were computed using CST EMS [5].

Figure 3 shows a sectional view with the optimized pole shoe profile of the chopper magnet, the shorting tubes and the vacuum chamber containing the deflector plates.

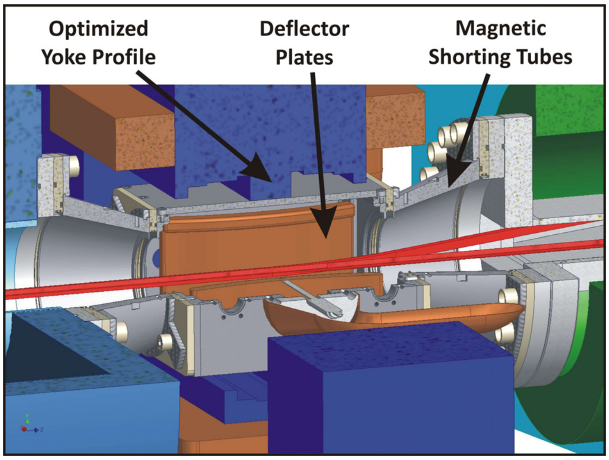

Figure 3: Sectional view of the chopper's magnet yoke and vacuum chamber containing deflector plates.

HIGH VOLTAGE PULSE GENERATOR

The electric chopper field will be driven by a high voltage pulse generator (Fig. 4). The primary circuit uses fast MOSFET technology based on commercially available transmitter equipment. The secondary circuit is

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designed to provide the high voltage with a ferrite transformer core.

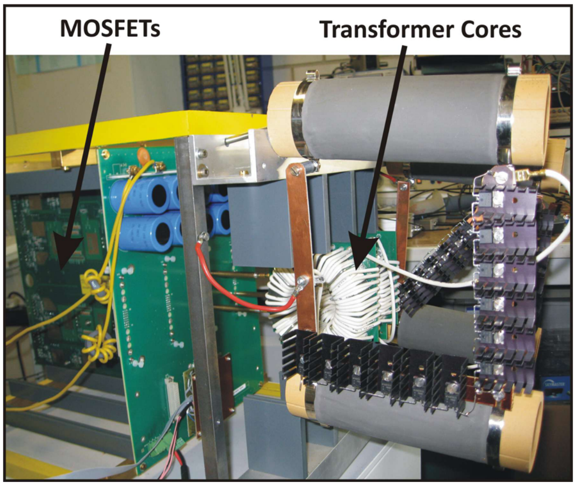


Figure 4: High voltage pulse generator for 12 kV, 250 kHz operation.

Two pulses of more than 5 kV of positive and negative voltage, respectively, are required to charge both deflector plates symmetrically. As shown in Fig. 5 voltage pulses of ±5.8 kV with a repetition rate of 250 kHz were achieved.

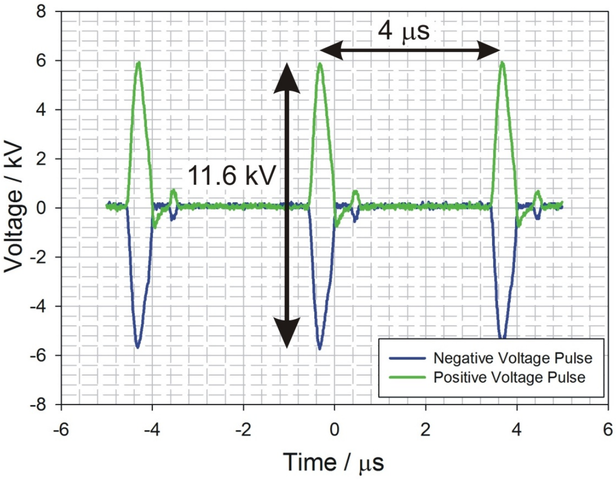


Figure 5: Measured HV pulses for symmetric deflector operation.

Post-pulse oscillations were successfully minimized by reducing parasitic capacitance and by installing blocking diodes as well as low inductive ohmic resistances. In order to ensure stable operation and clean pulses the capacitive load of the pulse generator is limited to 120 pF.

BEAM SIMULATIONS

The transport of the proton beam through the chopper system was simulated using a numerical code developed at IAP. The simulation package uses the Particle-in-Cell-Method for space charge calculation, whereas the external field distribution is loaded from data files calculated by CST EMS. Multiple species can be transported simultaneously in order to study effects by secondary electrons produced at the vacuum chamber walls.

For the optimized field configurations the transverse offset of the reference particle due to deflection force mismatch is reduced to below 1 mm.

The simulated time structure of a 120 keV, 150 mA proton pulse behind a 6 cm aperture is reproduced in Fig. 6. Using the measured voltage pulse as input data, the required beam plateau length of 50 to 100 ns can be achieved. The fall time of the pulse is longer than the rise time which results from the slightly asymmetric shape of the input voltage pulse.

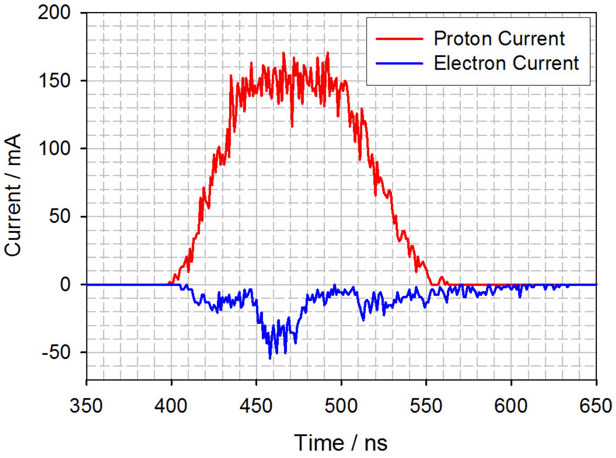


Figure 6: Simulated proton pulse including secondary electrons using measured voltage pulse as input data.

BEAM DEFLECTION EXPERIMENTS

Beam deflection experiments were made at the new Deflector Test Stand at IAP shown in Fig. 7. The beam is deflected by the high voltage applied between two copper deflector plates of 15 cm length and 7.6 cm distance.

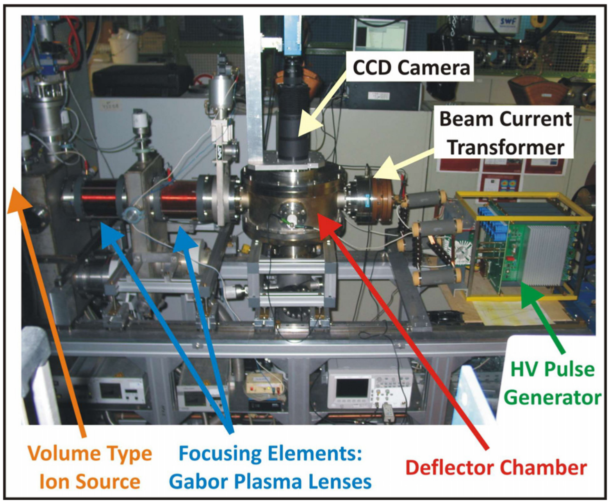


Figure 7: Main elements of the new Deflector Test Stand at IAP.

For the deflection of an ion beam accelerated longitudinally with V_{acc} and deflected transversely by

V_{defl} between two plates of distance d along an effective field length l_{eff} the analytical solution for the deflection angle α gives:

$$\tan\alpha = \frac{1}{2}\frac{l_{eff}}{d}\frac{V_{defl}}{V_{acc}}. \qquad (1)$$

For static deflection measurements the beam induced residual gas fluorescence was detected using a CCD camera installed above the deflector chamber in order to determine the deflection angle. For typical beam currents of $I_b = 1$ mA and residual gas pressure of $p = 1{\cdot}10^{-5}$ mbar (nitrogen) a camera exposure time of 5 s was used.

The measured deflection angle for a 20 keV helium beam is plotted in Fig. 8 in dependence of the applied static deflection voltage. For comparison the analytical solution (Eq. 1) and the numerical calculation using a single particle tracking code in combination with the computed electric field distribution are included.

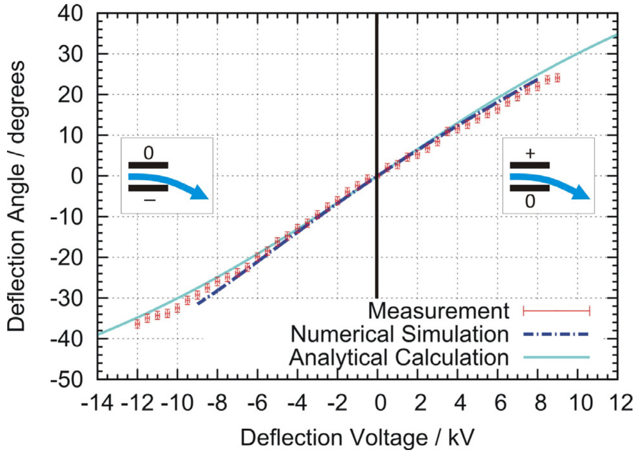
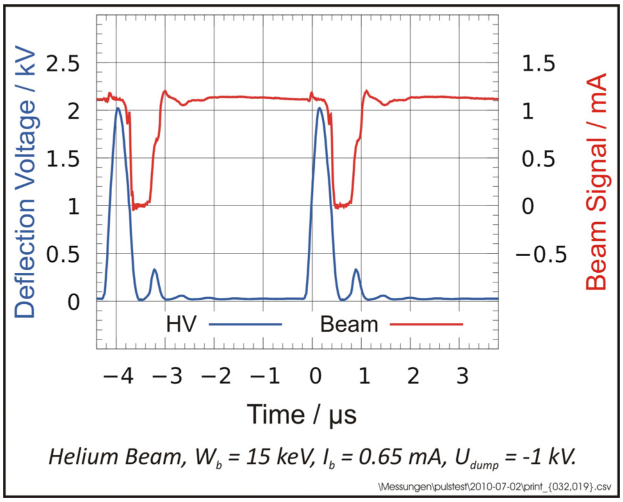


Figure 8: Static deflection of 20 keV helium beam in dependence of applied voltage. In order to eliminate the influence of geometric asymmetries the beam was deflected in the same direction for negative as well as positive deflection voltage.

After observing that the static deflection behaves as expected, pulsed measurements were made. The beam was deflected using the high voltage pulse generator. The deflector plates were charged symmetrically with the positive and negative voltage pulse respectively.

The capacitance of the whole electric deflection system (deflector plates, vacuum chamber, HV feedthrough, transmission cables) was reduced to 10 pF, well below the maximum capacitive load of the high voltage pulse generator in order to guarantee stable operation.

Successful chopping of the helium beam with the required repetition rate of 250 kHz was achieved. The beam signal was recorded using a fast current transformer with nanosecond time resolution behind a 7.2 cm aperture. The measured signal of a 15 keV chopped helium beam is shown in Fig. 9. The left ordinate shows the voltage applied to the positive deflector plate while the right one shows the signal at the beam current transformer cleaned from the RF noise induced by the pulse generator. The measured signal is the superposition of ion and secondary particle current.



Helium Beam, W_b = 15 keV, I_b = 0.65 mA, U_{dump} = -1 kV.

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Figure 9: Measured helium beam pulse with 250 kHz repetition rate and voltage applied to positive deflector plate (negative voltage pulse not shown).

Electron effects can be observed especially when the beam enters and leaves the aperture. The time difference between the voltage pulse and the beam signal is in good agreement with the analytical value corresponding to the time of flight (τ ~ 450 ns) of 15 keV helium ions travelling to the beam current transformer.

CONCLUSION

An E×B chopper system for high intensity applications is under development at IAP. It consists of a static magnetic dipole field and a pulsed electric field in a Wien filter-type configuration. The electric field will be driven by a high voltage pulse generator capable of generating 12 kV at 250 kHz. Beam simulations using the optimized electric and magnetic field configurations show an efficient transport through the chopper section.

A Deflector Test Stand was designed and constructed at IAP. Chopping of a 15 keV helium beam with the required repetition rate of 250 kHz was successful.

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