INJECTOR DEVELOPMENT FOR HIGH INTENSITY PROTON BEAMS AT STERN-GERLACH-ZENTRUM

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Abstract

The Frankfurter neutron source at the Stern-Gerlach-Zentrum (FRANZ) uses a 2 MeV proton LINAC as a driver for the $^{7}Li(p,n)$ neutron production. A volume type ion source will deliver a 120keV, 200mA proton beam continuously. A LEBT section consisting of four solenoids is under construction to transport the beam and to match it into the acceptance of the RFQ. A chopper system between solenoid 2 and 3 will provide beam pulses with a length of about 50 to 100 ns with a repetition rate of up to 250 kHz. The RFQ and the following IH drift tube LINAC will be coupled together to achieve an efficient beam acceleration. Furthermore only one power amplifier will be needed to provide the RF power for both accelerator stages. The Mobley type bunch compressor will merge 8 micro bunches formed in the accelerator module to one single 1ns bunch with an estimated peak current of up to 9.6 A. A rebuncher will provide the post acceleration to final beam energy adjustable between 1.8 and 2.2 MeV. The whole system is optimized for high beam intensity causing high space charge forces. As a consequence new accelerator concepts and beam diagnostic concepts have to be developed.

INTRODUCTION

FRANZ comprises two experimental areas allow different types of neutron capture measurements. The compressor mode offer time of flight measurements in combination with a 4π BaF_2 detector array. The proton beam will be compressed to a 1ns pulse with a peak current of about 9.6 A and a repetition rate of 250 kHz. On the other hand activation mode uses a continuous neutron flux. Primary cw proton beams with a current up to 8 mA on solid targets and up to 30 mA on liquid metal targets as a later option are feasible.

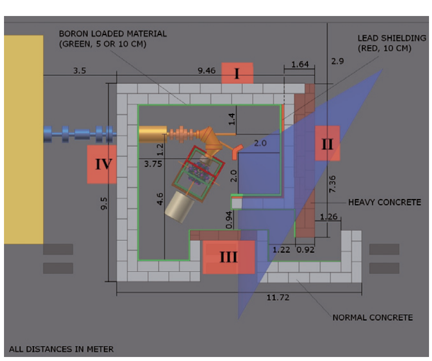

Figure 1: Scheme of the FRANZ facility with targets and detector and iradiation and neutron shielding.

FRANZ is not only a neutron generator but also a test bench for new accelerator and diagnostic concepts for intense ion beams. The envisaged proton beam properties on the target lead into a challenging accelerator design to overcome the space charge forces.

ION SOURCE

A volume type ion source was chosen for FRANZ to extract the proton beam from a hot filament driven gas discharge plasma [1]. Figure 2 shows this source type. The life time of the filament is limited about one month of operation. On the other hand the plasma temperature of a gas discharge at moderate arc power is as well as the confining magnetic field very low compared with other source types e.g. ECR sources. Therefore the beam emittance is small and gives the possibility to investigate causes of emittance growth during beam transport and acceleration along the whole LINAC.

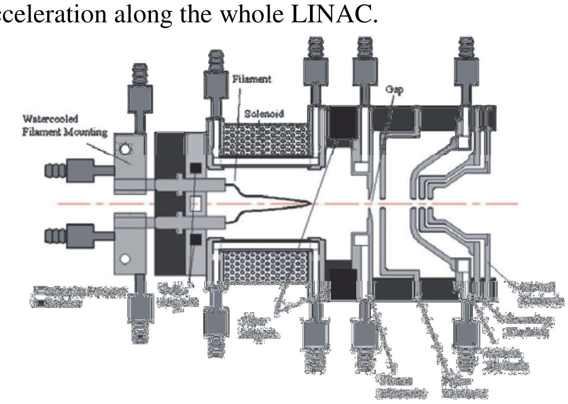

Figure 2: crossectional view of the volume type ion source under construction.

For the planned beam intensities a pentode extraction system keeps quite well the beam emittance during the extraction and pre acceleration phase when compared with other extraction schemes [2]. Figure 3 shows a preliminary numerical simulation of the beam extraction by the use of the IGUN code [3] and under respect of a multi species beam with approximately H^{+} = 80%, H_2^{+} = H_3^{+} 10%.

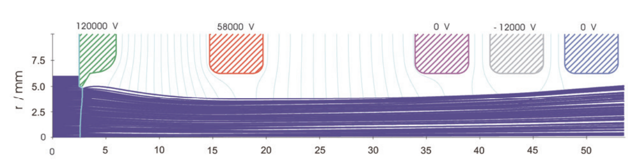

Figure 3: Illustration of a preliminary IGUN calculated beam profile along a pentode extraction system.

The chosen aspect ratio of S = 0.2, an emission area of 0.78 cm^2 and an extraction field strength of 6.2 kV/mm result in a beam radius of r_{beam} = 5 mm, ε_{rms} = 0.06 π mm mrad and a divergence angle of r' = 74.5 mrad.

LEBT SECTION WITH CHOPPER

The LEBT section consists of 4 solenoids for beam focussing and includes partial of space charge compensation due to residual gas ionisation. Figure 4 shows a scheme of the planned LEBT. The first and second solenoid will be used for separation of ion species and to match the proton beam into the chopper system. Downstream of the chopper two solenoids will focus the beam into the acceptance of the RFQ. Two pumping and diagnostic tanks will be used for several non interceptive diagnostics e.g. optical beam profile measurement and beam potential measurements using a residual gas ion energy analyzer.

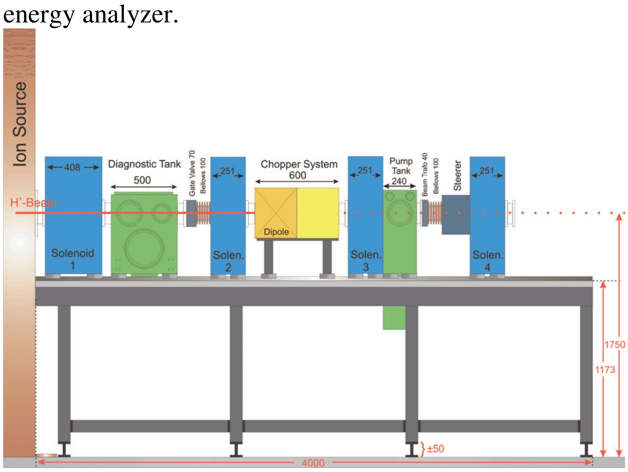

Figure 4: Scheme of the LEBT section with four solenoids and the chopper device.

The chopper system consisting of a kicker and a septum magnet combined with a slit provide the 100 ns proton beam pulses. Figure 5 shows the arrangement of the chopper system.

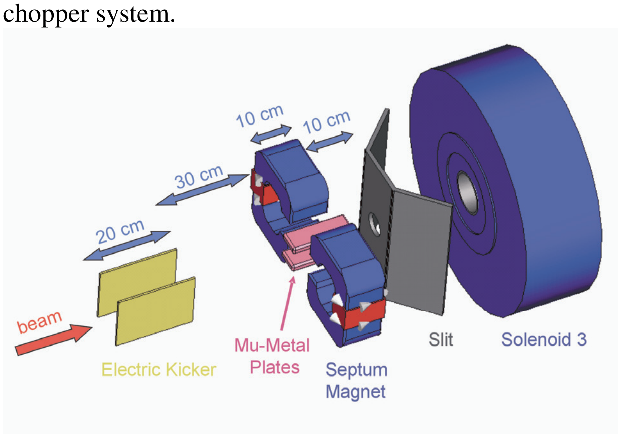

Figure 5: schematic drawing of the chopper system consisting of a fast kicker, a septum magnet and an apertur.

A fast magnetic or electric kicker deflects the beam with a repetition rate of 250 kHz whereas the static septum magnet provides the post separation and a pulse with a flat top of at least 50 ns. Comparison of electric and magnetic kicker systems by the use of numerical simulation shows an influence of secondary electrons. The high production rate of electrons in the chopper system gives the possibility for partial space charge compensation of short beam pulses. Preliminary studies result in approximately 30% of space charge compensation by the use of a magnetic kicker system. For an electric kicker the secondary electrons bear the risk of sparking and sputtering from the electrodes [4]. Beam transport and chopping leads into an emittance growth by a factor of 4. It seems possible to reduce this value by further optimization of beam transport with respect to the filling degree of the solenoids and more detailed description of space charge compensation. Pulsed beam with proton densities of n_p = 8.2·10^{14} m^{-3}, generalized perveance of K = 3.1·10^3 and time structure shown in figure 6 will be injected in the coupled RFQ-IH DTL.

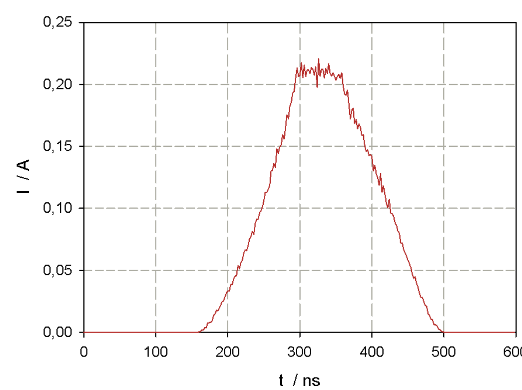

Figure 6: Simulated beam current as a function of time at the entrance of the RFQ, Pulse duration of about 50 ns and repetition rate of 250 kHz.

COUPLED RFQ-IH DTL

In order to minimize installation costs and to use one compact common rf amplifier a coupling of the RFQ and IH-DTL is foreseen [5]. Figure 6 shows a crossectional view of the coupled accelerator stages. Both of the cavities can also be used separately. The RFQ is 1.75 m long and needs an input power of 150 kW [6]. Numerical simulations using the PARMTEQM [7] code show a beam transmission efficiency of 95 % with acceptable emittance growth at the design current I = 200 mA for an electrode voltage of about 75 kV. Output energy of the RFQ will be 0.7 MeV. The IH-DTL will boost the proton beam to its final beam energy of 2 MeV. The power consumption of the IH cavity is in a range of about 45 kW to establish a gap voltage of 300 kV. Due to the fact that a RFQ acts like a buncher the incoming proton beam will be compressed longitudinally. In result of the beam transport simulation the micro bunch phase width is in a range of 60 degree. The average bunch current increases up to 1.2 A and the resulting compression ratio is η = 6. At beam energy of 2 MeV downstream of the accelerator stages the proton density is n_p = 8.2·10^{14} m^{-3} and the space charge forces expressed by the generalized perveance decreases of about $K = 2.7 \cdot 10^4$. Figure 7 shows the micro bunch current as a function of time at the exit of the accelerator stages. The average current of one micro bunch is equal to the peak current.

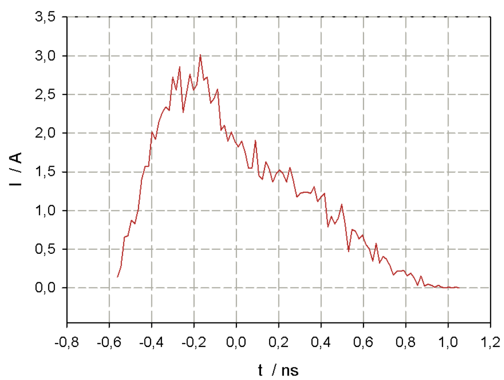

Figure 7: Micro bunch current as a function of time about 1 m behind the LINAC, increase of pulse duration of about 1.2 ns due to the large energy spread and space charge forces.

BUNCH COMPRESSOR

By applying the bunch compressor concept of the Mobley type [8] for high current beams a split magnetic dipole array include edge focusing was chosen [9]. The periodic deflection by the RF kicker at one focus of the bending system guides up to 8 bunches on different paths to the final focus, where the neutron production target is located. As shown in figure 8 two rebuncher cavities are needed to focus the beam longitudinally.

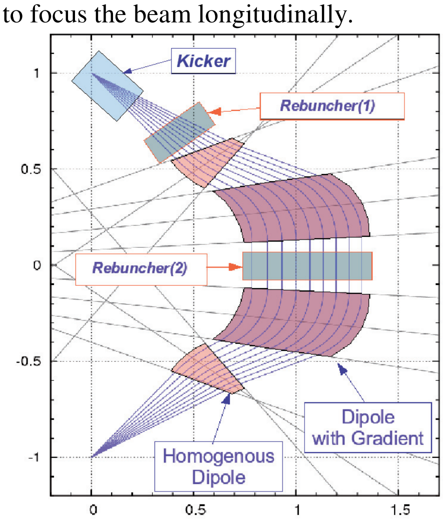

Figure 8: Scheme of the Mobley type bunch compressor.

By choosing adequate parameters all 8 bunches will overlap at the target and produce a 1.1 ns proton pulse with a proton density of $n_p = 8.2 \cdot 10^{14}\ m^{-3}$. Space charge forces become dominant, the generalized perveance is $K = 2.2 \cdot 10^3$. Figure 9 shows the bunch current as a function of time, the peak current is 9.6 A. The compression ratio downstream of the whole proton injector is of $\eta = 48$.

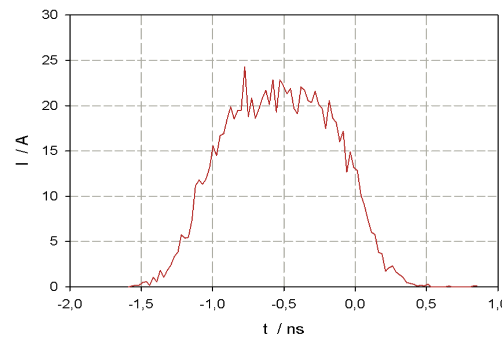

Figure 9: Beam current of the compressed bunch as a function of time at the target, Pulse duration of about 1.1 ns at a repetition rate of 250 kHz.

CONCLUSIONS

The hardware of the planned proton injector is under construction. More detailed multi particle transport simulations show that the activation mode using a 30 mA cw beam will be limited by the rf power consumption, target power deposition and radiation safety. The compression ratio of the compressor mode is 48. The resulting proton density and space charge force leads into increasing beam spot sizes and pulse duration at the $^7Li(p,n)$ target.

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