

FRANZ – ACCELERATOR TEST BENCH AND NEUTRON SOURCE

O. Meusel, L.P. Chau, M. Heilmann, H. Podlech, U. Ratzinger, K. Volk, C. Wiesner
IAP, University Frankfurt/Main, Germany

Abstract

Accelerator based neutron sources are used for different kinds of research programs in nuclear astrophysics, material science and for the development of next generation nuclear power plants. The challenge of existing and planned neutron sources is to provide highly brilliant ion beams with high reliability.

The Frankfurt neutron source FRANZ is not only a neutron source but also a test bench for novel accelerator and diagnostic concepts for intense ion beams. The experiment consists of a compact linear accelerator for the acceleration of an intense proton beam to 2MeV producing neutrons via the ${}^7\text{Li}(p,n)$ reaction. The final beam intensity will be 200mA. Therefore the space charge and space charge compensation effects can be studied with high statistical significance along the accelerator.

The hot filament-driven gas discharge ion source already delivers 240mA beam current with a proton fraction of 92%. The low energy beam transport LEBT section is equipped with four solenoids matching the beam into a chopper system and into a RFQ-IH combination already under construction. Coupling of the RFQ accelerator stage and the IH drift tube cavity offers the possibility to use only one power amplifier as a driver for both of these resonators and reduces investment costs. The compact design of the low- β accelerator stage is optimized for high beam intensities to overcome the expected strong space charge forces in this accelerator test bench.

The presentation will give a brief overview of the FRANZ accelerator and discusses the beam dynamics, comparing numerical and experimental results.

INTRODUCTION

To advance the development of accelerator technology a dedicated test bench was needed. Different work groups are now able to test their devices under realistic conditions with respect to the interplay of each of the accelerator components. The main focus of the planned experiments is to reach the intensity and power limits for conventional RF accelerator technics. The question of these limits is highly relevant for several future accelerator projects and the basis of next generation accelerator concepts.

It is planned to use a proton beam with beam energies of 2MeV with energy variation of about $\pm 0.2\text{MeV}$. These parameters enable various experiments by the use of thermal neutrons produced by the ${}^7\text{Li}(p,n)$ reaction at the end of the accelerator test bench. Therefore an astrophysical research program was launched for the measurement of neutron capture cross sections relevant for nucleosynthesis [1].

Figure 1 shows the scheme of the experimental setup of the FRANZ facility. It consists of a high voltage terminal facilitating ion source operation, a low energy beam transport section including a chopper system, the main accelerator, a bunch compressor and target stations. Two operation modes for the experiments will be available. The compressor mode will deliver a 1ns beam pulse with a repetition rate of 250 kHz and an estimated peak beam current of 9.6A. The activation mode uses a cw beam to produce a continuous neutron flux. Because of the average power density the proton beam in activation mode is limited to a current of about 8 mA for the use of solid targets and up to 30 mA for liquid metal targets.

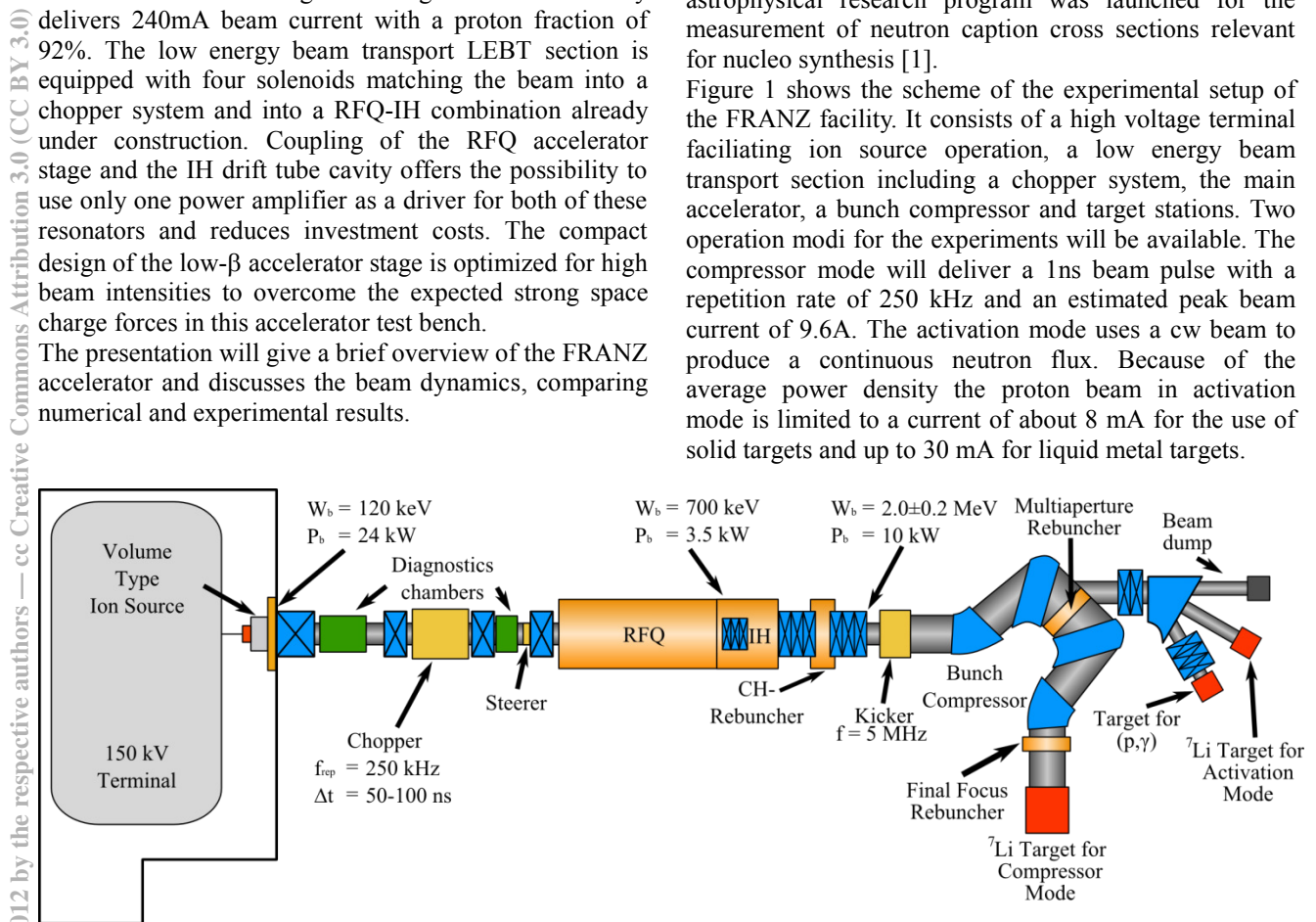


Figure 1: Experimental setup of the FRANZ facility. The accelerator test bench and neutron source consist of a 2MeV proton accelerator equipped with bunch compressor and several target stations.

ION SOURCE

A volume type ion source was chosen for FRANZ to extract the proton beam from a hot filament driven gas discharge plasma [2]. Figure 2 shows the design of the ion source. The life time of the filament is limited to about one month of operation. On the other hand the plasma temperature of a gas discharge at moderate arc power as well as the confining magnetic field is 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 test bench.

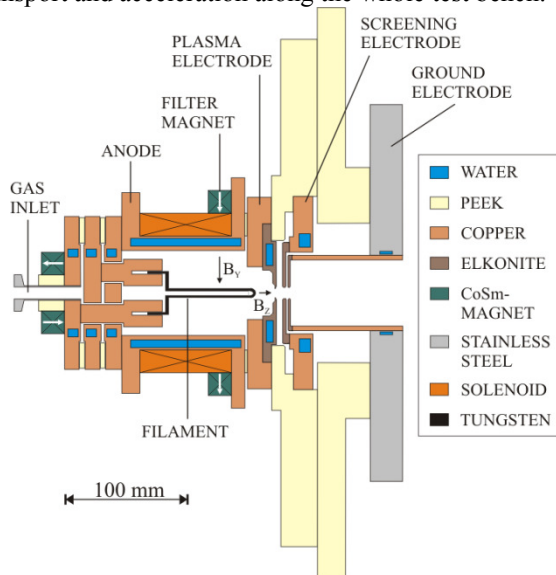


Figure 2: Cross-sectional view of the volume type ion source under construction.

Numerical simulations using of the IGUN code [3] show that for the planned beam intensities a triode extraction system keeps quite well the beam emittance during the extraction phase when compared with other extraction schemes [4]. The simulations for the extraction and beam transport were performed for multi species beam with measured fractions $H^+ = 91\%$, $H_2^+ = 7\%$, $H_3^+ = 2\%$.

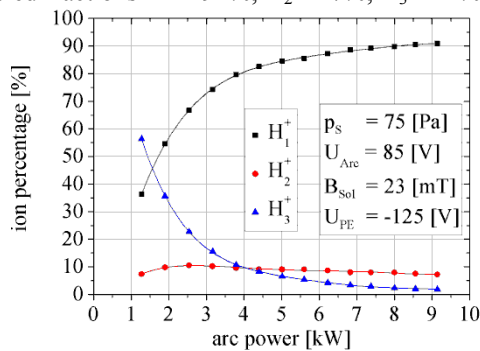


Figure 3: Measured beam composition as a function of the arc power.

The chosen aspect ratio of $S = 0.61$, an emission area of 0.5 cm^2 and an extraction field strength of 6.2 kV/mm result in a simulated beam radius of $r_{beam} = 5.5 \text{ mm}$, $\epsilon_{rms} =$

$0.085 \pi \text{ mm mrad}$ and a divergence angle of $r' = 84.5 \text{ mrad}$. The measured total beam current was 261 mA .

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 pulsed Wien filter combined with a massless septum provide the 100 ns proton beam pulses. Figure 5 shows the arrangement of the chopper system.

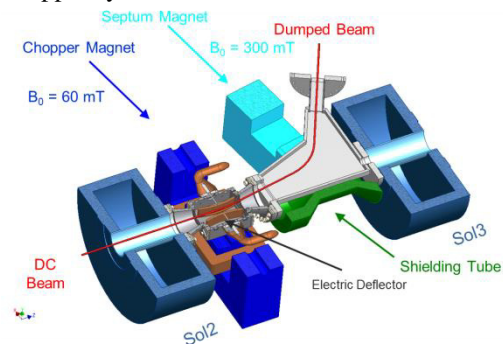


Figure 5: Cross sectional view of the chopper system consisting of a pulsed ExB filter, a septum magnet with magnetic shielding tube and an aperture.

A fast electric kicker compensates the magnetic force of the static chopper magnet with a repetition rate of 250 kHz. The massless septum consisting of a septum magnet and a shielding tube provides the post separation and a pulse with a flat top of at least 50 ns. Numerical simulation of the ExB chopper system 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 these device. For the electric deflector the secondary electrons bear the risk of sparking and sputtering from the electrodes. Therefore the shortening tubes will be used as screening electrodes. Beam transport and chopping leads into an emittance growth by a factor of 4. It seems possible to reduce this value further by optimization of beam transport with respect to the filling degree of the solenoids and a detailed description of space charge compensation. Pulsed beam with proton densities of $n_p = 8.2 \times 10^{14} \text{ m}^{-3}$, generalized perveance of $K = 3.1 \times 10^3$ will be injected in the coupled RFQ-IH accelerator.

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 planned [4]. Figure 6 shows a crosssectional 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. Numerical simulations using the PARMTEQM code show a beam transmission of 95% with acceptable emittance growth at the design current $I = 200 \text{ mA}$ 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 also be compressed longitudinally. Beam transport simulation show the micro bunch phase width is in the range of 60 degree. The average bunch current increases up to 1.2 A and the resulting compression ratio is $\eta = 6$.

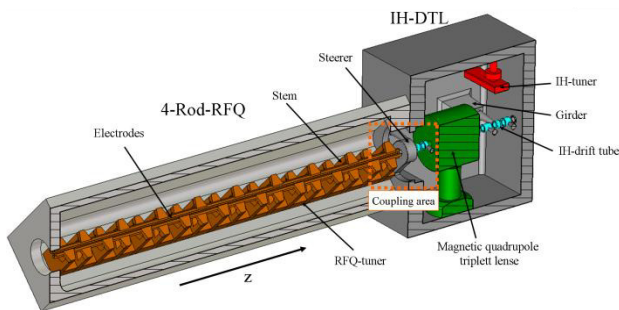


Figure 6: Cross sectional view of the coupled RFQ-IH accelerator.

BUNCH COMPRESSOR

By applying the bunch compressor concept of the Mobley type for high current beams a split magnetic dipole array include edge focusing was chosen. The periodic deflection by the RF kicker at one focus of the bending system guides up to 9 bunches on different paths to the final focus, where the neutron production target is

located. As shown in figure 7 two rebuncher cavities are needed to focus the beam longitudinally.

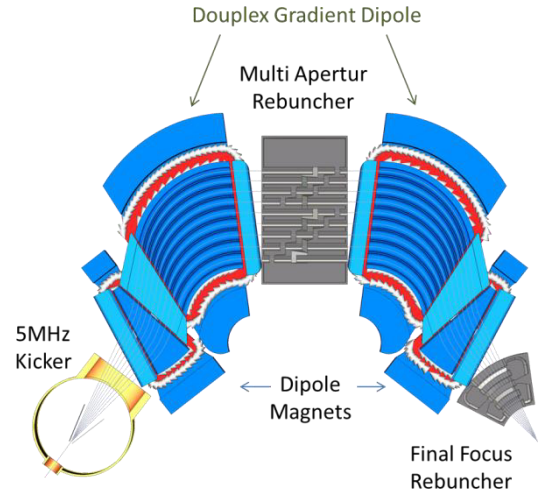


Figure 7: Scheme of the Mobley type bunch compressor.

By choosing adequate parameters all 9 bunches will overlap at the target and produce a 1.1 ns proton pulse with a proton density of $n_p = 8.2 \cdot 10^{14} \text{ m}^{-3}$. 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 $\eta = 48$.

CONCLUSIONS

In a first step the beam current will be limited up to 50mA. 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 ${}^7\text{Li}(p,n)$ target. Right after the first measurement period an intensity upgrade on 150mA and later on 200mA is planned.

REFERENCES

- [1] R. Reifarh et al., "Opportunities for Nuclear Astrophysics at FRANZ", Publications of The Astronomical Society of Australia - PUBL ASTRON SOC AUSTRALIA, vol. 26, no. 3, 2009
- [2] K. Volk and W. Schweizer private communication
- [3] C. Wiesner et al., "A 250 kHz Chopper for Low Energy High Intensity Proton Beams", Proc. of the Eur. Part. Acc. Conf., Genua (2008).
- [4] L. P. Chau et al., "Bunch Compressor for Intense Proton Beams", Publications of The Astronomical Society of Australia - PUBL ASTRON SOC AUSTRALIA, vol. 26, no. 3, 2009