ISBN: 978-3-95450-219-6 ISSN: 2226-0366 doi: 10.18429/JACoW-LINAC2024-TUPB021

CURRENT STATUS OF BEAM COMMISSIONING AT THE FRANKFURT NEUTRON SOURCE

H. Hähnel[1,2*], A. Ateş[1], L. Bauer[1], B. Dedić[1], K. Kümpel[1],
C. Wagner[1], H. Podlech[1,2], U. Ratzinger[1,2], C. Zhang[1,2,3]
[1]Institute of Applied Physics, Goethe University, Frankfurt, Germany
[2]Helmholtz Forschungsakademie Hessen für FAIR (HFHF), Frankfurt, Germany
[3]GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany

Abstract

The Frankfurt Neutron Source FRANZ will be a compact accelerator driven neutron source utilizing the $^7\mathrm{Li}(p,n)^7\mathrm{Be}$ reaction with a 2 MeV proton beam. Followoing successful beam commissioning of the 700 keV proton RFQ, further beam experiments including emittance measurements are currently ongoing. Preparations for conditioning and commissioning of the IH-DTL are running in parallel to the current beam measurement campaign. We report on the current status of commissioning towards a 2 MeV proton beam.

INTRODUCTION

The Frankfurt Neutron Source (FRANZ) is a compact accelerator driven facility originally initiated in the early 2000s [1–6]. It is designed to provide a 2 MeV proton beam for neutron production via the $^7\mathrm{Li}(p,n)^7\mathrm{Be}$ reaction [7]. The produced neutrons with a thermal spectrum around 30 keV can be used for a number of experiments in the fields of applied physics and experimental astrophysics [8].

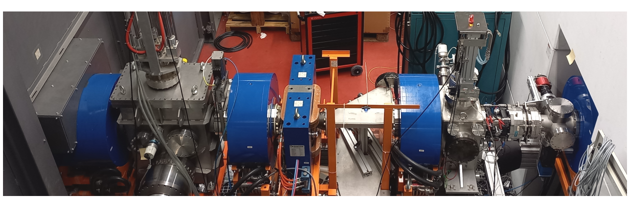

Figure 1: Photograph of the current FRANZ LEBT beamline (Aug. 2022).

Significant progress on the driver linac was made recently. The commissioning of the new CHORDIS ion source [9, 10] in late 2020 was a first milestone. Since the CHORDIS ion source only provides a 35 keV proton beam, an electrostatic post-accelerator was developed and commissioned at IAP to reach the desired beam energy of 60 keV [11]. After stable operation was confirmed, the Low Energy Beam Transport line (LEBT), see Fig. 1, was commissioned and the beam was transported up to the point of injection into the RFQ-Accelerator. The 60 keV beam is now in routine operation at the FRANZ. This presents an important milestone for the initial beam commissioning of the FRANZ facility. Meanwhile, emittance measurements to further improve an efficient injection into the RFQ haven been performed.

* haehnel@iap.uni-frankfurt.de

RFQ RETROFIT

A change of the RFQ injection energy to 60 keV, necessitated a redesign of the RFQ electrodes. The new beam dynamics design is base on the so-called SEGLER method and the resulting electrode geometries were developed in 2022 [12, 13]. Production of the new electrodes was ordered in summer 2022. The RFQ retrofit and low level rf tuning was finished in summer of 2023. Following that, rf conditioning and finally beam comissioning were performed.

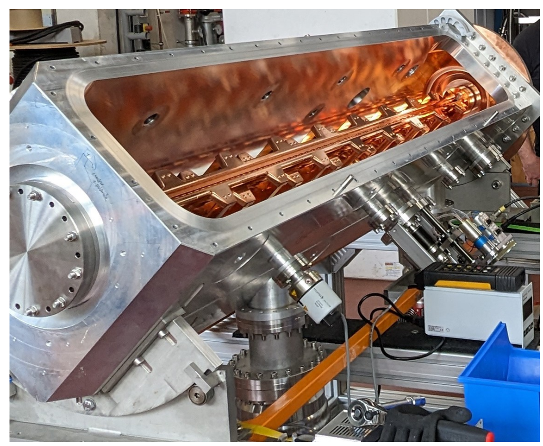

Figure 2: FRANZ RFQ after installation of the new electrodes and successful delivery to IAP Frankfurt with the lid open for final RF tuning.

RF TUNING

After the installation of the new RFQ electrodes at the company Neue Technologien GmbH (NTG) in Gelnhausen (see Fig. 2), the final RF tuning was performed on site in collaboration with IAP. A total of 18 tuning plates had to be installed and adjusted to tune the final frequency of 175 MHz of the RFQ while maintaining a flat voltage distribution over the whole length of the RFQ. For the measurements, the frequency shift introduced by a small dielectric plastic cylinder placed on top of the electrodes is recorded at a position above each tuning plate to deduce the flatness. This process took about two days with numerous iterations, until the results were satisfactory. The final field flatness was within ±3 % which is a typical acceptable value for a four rod RFQ (see Fig. 3 (left)).

ISBN: 978-3-95450-219-6 ISSN: 2226-0366 doi: 10.18429/JACoW-LINAC2024-TUPB021

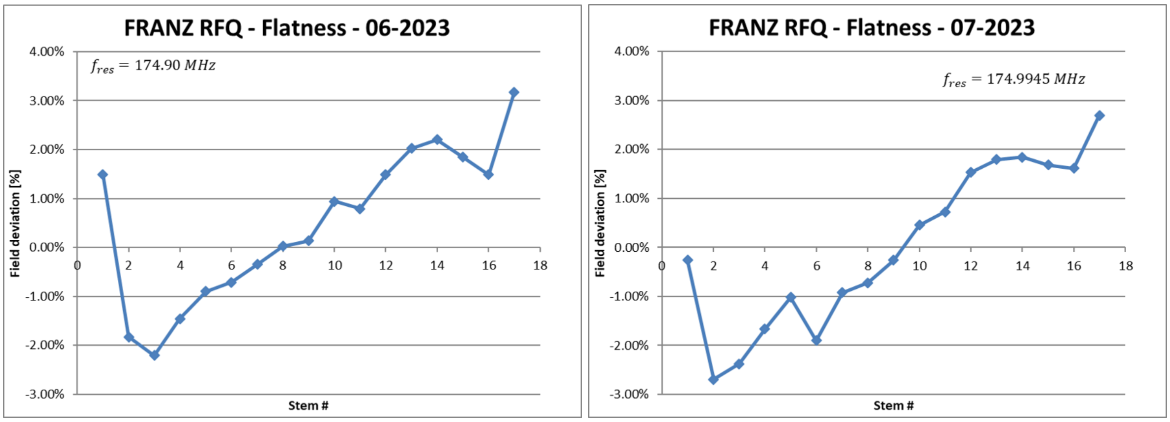

Figure 3: RFQ Flatness measurements (left): without tuner at company NTG. (right): After installation of dynamic tuner at IAP.

After delivery of the RFQ to Frankfurt, the final tuning steps were performed after mounting the dynamic tuner to the cavity. With the tuner installed and the last tuning plate adjusted, the final flatness stayed almost identical to the previous setup without tuner (see Fig. 3 (right)).

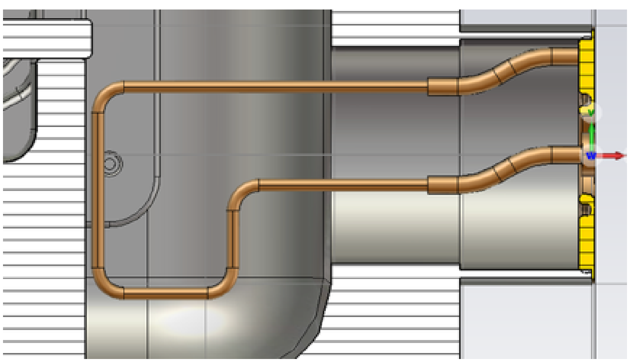

Figure 4: View of the CST model used to determine the loop size and position.

For RF coupling at high power CW operation in the order of 150 kW in the future, a well known coupler using the GSI design was chosen [14]. Consequently, the coupling loop had to be redesigned to match the new coupler. CST simulations were performed to determine the ideal coupling loop shape and position (see Fig. 4). The final loop distance from the RFQ stems is the most critical parameter for loop matching. In simulation, a loop distance of 2 mm to the stem would provide a strong overcoupling up to $\beta \approx 5$. By rotation of the loop, the coupling factor can be reduced (theoretically to 0). Final dimensioning of the loop was done by low level rf measurements to ensure the necessary coupling range between $\beta = 1$ to $\beta \approx 1.5$ for beam operation with the CHORDIS ion source.

Once the final loop geometry was fixed, the loop was brazed to the coupler. Since the first coupler failed vacuum tests after brazing and the fault was localized not at the braze connections, a second coupler was successfully prepared. For RF conditioning and first low current beam tests, the coupler was monted at an angle to achieve critical coupling $\beta = 1$.

From low level RF Q-factor measurements, it was expected to require 68 kW of power for the design electrode voltage of 60 kV. Therefore, the goal for conditioning of the RFQ was set to reach at least 80 kW.

RFQ RF CONDITIONING

For LLRF control, in-house custom digital hardware was used. The control system for FRANZ called MNDACSv2 [1] was used for RF conditioning of the FRANZ RFQ as well. For more details on the software and hardware see [15].

The RFQ was moved into the FRANZ radiation shielding bunker once all low level tuning steps were done. A total of 140 water connections, 61 water temperature sensors and 3 temperature sensors on the cavity frame and near the coupler were attached. The RFQ is connected to the experimental hall central cooling system.

For the first conditioning stage, a 500 W CW broadband amplifier was used. Once the power limit of this amplifier was reached, the cavity was connected to the Thomson tube amplifier on the Bunker roof, capable of up to 250 kW CW at 175 MHz. The same LLRF hardware was used for low power and high power rf conditioning [15]. Low power conditioning with the small broadband amplifier was done within about 5 days, reaching up to 400 W CW. Multipacting barriers were observed at powers of 3 W and 26 W. Otherwise, conditioning up to 400 W was uneventful.

Therefore, the RFQ was soon connected to the RF power line of the main RF amplifier. From then on, high power conditioning required about nine days to reach a forward power of 80 kW. This conditioning period is shown in Fig. 5. Following initial conditioning, the RFQ was further conditioned to 90 kW at a lower duty cycle. While the general performance of the RFQ can be sustained even for longer periods of downtime if vacuum is preserved, each time any part of the beam line was vented, an initial reconditioning of the RFQ spanning usually 3–4 hours was needed.

[1] Mesh Networked Data Acquisition and Control System

ISBN: 978-3-95450-219-6 ISSN: 2226-0366 doi: 10.18429/JACoW-LINAC2024-TUPB021

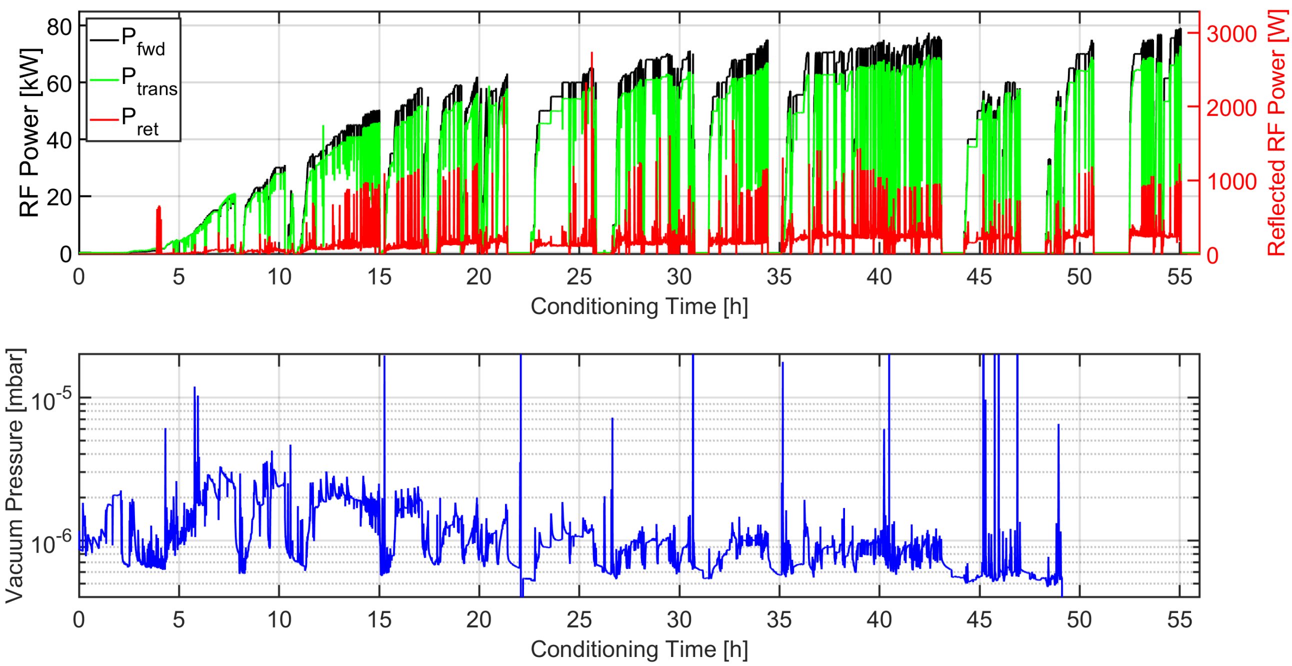

Figure 5: Conditioning power and vacuum pressure plot for the high power CW conditioning resulting in a final power of P_f = 80 kW. The pressure gauge failed around hour 49.

RFQ BEAM COMMISSIONING

After the successful RF conditioning of the RFQ at 100 % duty cycle, the RFQ was operated at a duty cycle of up to 2 % (1 ms, 10 Hz) to match the CHORDIS duty cycle of 0.5 % to 1 % (0.5–1 ms, 10 Hz). Using well known LEBT optical settings from previous beam dynamics and emittance measurement campaigns, first injection of a proton beam was immediatly succesful and on the first day up to 11 mA macropulse current protons were measured (see Fig. 6).

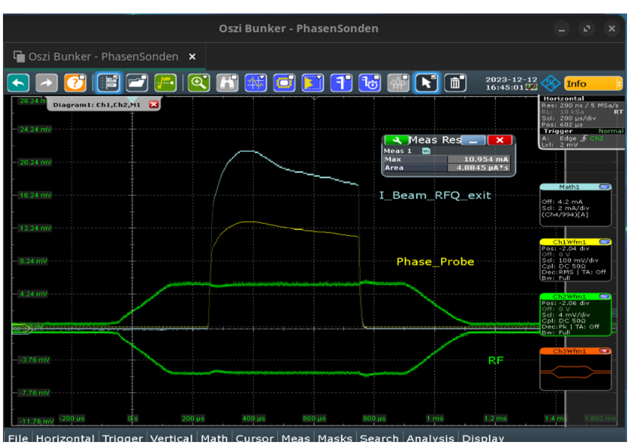

Figure 6: Oscilloscope screenshot of one of the first accelerated 700 keV proton pulses at the FRANZ RFQ. (blue) Faraday cup signal behind RFQ, (yellow) phase probe signal behind RFQ, (green) RF pulse.

After this successful first beam operation, energy measurements behind the RFQ were performed with phase probe signals. The resulting final RFQ energy varied between 699.9 keV and 701.54 keV for P_f = 58 kW to P_f = 90 kW respectively and is very close to the design value of 700 keV.

Transmission Measurements

Transmission measurements were carried out utilizing an aperture just behind the first solenoid in the LEBT. This is necessary to remove the mayority of H_2^+ and H_3^+ from the beam before the current in front of the RFQ is measured. The latest measurement with a matched beam (no losses at RFQ injection aperture cone [16]) show a proton current of 7.66 mA in front and 7.1 mA behind the RFQ. This results in a transmission of 92.7 %.

CONCLUSION

After successful CW high power conditioning up to 80 kW, the RFQ has been operated routinely for several weeks. Beam commissioning at the Frankfurt Neutron Source up to 700 keV was succesfully performed and a transmission of 92.7 % was measured for the RFQ. Emittance measurements of the RFQ beam with a slit grid emittance measurement device are currently ongoing. After that, the RFQ and IH-DTL will be joined together and conditioned for 2 MeV beam commissioning.

REFERENCES

[1] S. Alzubaidi *et al.*, “The Frankfurt neutron source FRANZ”, *Eur. Phys. J. Plus*, vol. 131, p. 124, 2016. doi:10.1140/epjp/i2016-16124-5

[2] C. Wiesner *et al.*, “FRANZ and small-scale accelerator-driven neutron sources”, in *Proc. IPAC’15*, Richmond, VA, USA, May 2015, pp. 1276–1280. doi:10.18429/JACoW-IPAC2015-TUXB1

ISBN: 978-3-95450-219-6 ISSN: 2226-0366 doi: 10.18429/JACoW-LINAC2024-TUPB021

[3] C. Wiesner *et al.*, "Chopping high-intensity ion beams at FRANZ", in *Proc. LINAC'14*, Geneva, Switzerland, Aug. 2014, paper WEIOB01, pp. 765–769.

[4] U. Ratzinger *et al.*, "The driver linac of the neutron source FRANZ", in *Proc. IPAC'11*, San Sebastian, Spain, Sep. 2011, paper WEPS040, pp. 2577–2579.

[5] U. Ratzinger *et al.*, "The Frankfurt neutron source FRANZ", in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper MOPEC059, pp. 597–599.

[6] R. Tiede *et al.*, "A coupled RFQ-IH-DTL cavity for FRANZ: A challenge for RF technology and beam dynamics", in *Proc. HB'16*, Malmö, Sweden, Jul. 2016, pp. 404–408. doi:10.18429/JACoW-HB2016-WEAM1Y01

[7] C. Lederer *et al.*, "Definition of a standard neutron field with the $^7\mathrm{Li}(p,n)^7\mathrm{Be}$ reaction", *Phys. Rev. C*, vol. 85, p. 055809, 2012. doi:10.1071/AS08061

[8] R. Reifarth *et al.*, "Opportunities for nuclear astrophysics at FRANZ", *Publications of the Astronomical Society of Australia*, vol. 26, pp. 255–258, 2009. doi:10.1071/AS08061

[9] R. Keller *et al.*, "CORDIS - An improved high-current ion source for gases", in *Vacuum*, vol. 34, no. 1, pp. 31–35, 1984. doi:10.1016/0042-207X(84)90102-7

[10] R. Keller *et al.*, "Recent results with a high-current, heavy-ion source system", in *Vacuum*, vol. 36, no. 11-12, pp. 833–835, 1986. doi:10.1016/0042-207X(86)90121-1

[11] M. Breidt, "Entwurf und Simulation eines elektrostatischen Nachbeschleunigers für 35keV Protonen", BSc thesis, Institute of Applied Physics, Goethe University, Frankfurt, Germany, 2020.

[12] C. Zhang, "Beam physics and techniques towards efficient linear accelerators with space charge challenges", Habilitationsschrift, Institute of Applied Physics, Goethe University, Frankfurt, 2022.

[13] C. Zhang, *Radio-frequency quadrupole accelerators: from protons to uranium ions*, Springer Nature, New York, New York, 2023. doi:10.1007/978-3-031-40967-7

[14] F. Maimone, R. Brodhage, M. Kaiser, W. Vinzenz, and M. Vossberg, "325 MHz high power RF coupler for the CH-cavities of the FAIR p-LINAC", in *Proc. IPAC'15*, Richmond, VA, USA, May 2015, pp. 3712–3714. doi:10.18429/JACoW-IPAC2015-THPF014

[15] H. Hähnel, A. Ates, B. Dedic, and U. Ratzinger, "Pure copper and stainless steel additive manufacturing of an IH-type linac structure", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 4931–4934. doi:10.18429/JACoW-IPAC2023-THPM020

[16] H. Hähnel *et al.*, "Commissioning status of the Frankfurt Neutron Source FRANZ LEBT and RFQ", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 2530–2533. doi:10.18429/JACoW-IPAC2023-TUPM128