PHASE 1 COMMISSIONING STATUS OF THE 40 MEV PROTON/DEUTERON ACCELERATOR SARAF

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Abstract

Since January 2007 all accelerator equipment of the Phase 1 for the 40 MeV Proton/Deuteron Accelerator is at the SARAF site and installed for commissioning. The target for Phase 1 is to get the ECR ion source and RFQ into operation and to perform all relevant tests with the cryogenic module housing 6 superconducting half wave resonators, to show that the design values of the system can be reached. Based on those results the Phase 2 shall start, to reach the final energy of 40 MeV with up to 2 mA of protons and deuterons. The ECR ion source is in routine operation since June 2006, the RFQ already have been operated with protons and currently is under characterization. After the characterization is finalized it is anticipated to move the cryogenic module in the beam line and to perform further beam characterization. The entire beam characterization is closely followed by beam dynamics simulations. Recent results of the commissioning will be presented and comparisons made between measurements and beam dynamics calculations.

ACCELERATOR STATUS

The 40MeV s. c. linac for protons and deuterons designed and currently built by ACCEL Instruments GmbH [1] is described in [2, 3]. It consists of an ECR ion source, a n. c. RFQ and six modules housing 44 s. c. half wave resonators. In the Phase 1 of the project the source, the RFQ and a superconducting prototype module (PSM) with six superconducting resonators have been built, delivered and installed (figure 1).

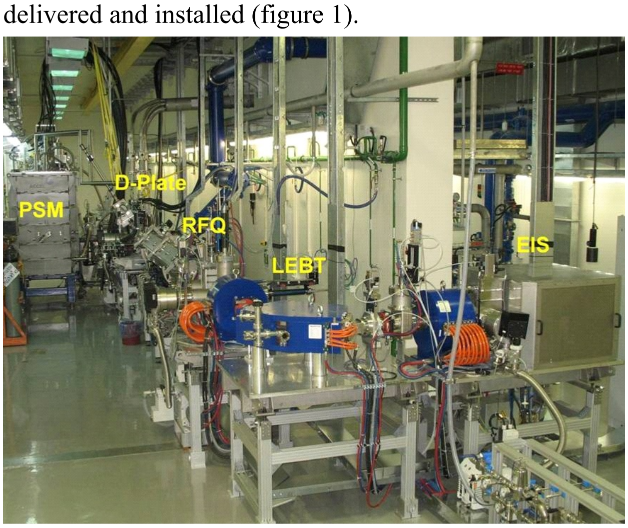

Figure 1: SARAF accelerator Phase 1 installed in the tunnel. From right to left: ECR Ion Source, Low Energy Beam Transport (LEBT), RFQ, Diagnostic-Plate and Prototype Superconducting Module (beside beam line)

Currently the accelerator up to the RFQ including the Medium Energy Beam Transport (MEBT) and the Diagnostic Plate (D-Plate) is under proton beam commissioning. The PSM installed beside accelerator beam line in the accelerator tunnel is connected to the liquid helium supply and was tested up to full power levels.

ACCELERATOR COMMISSIONING

The proton beam for the accelerator commissioning is provided by the ECR ion source and the LEBT which were commissioned before [4]. In the diagnostic mode the beam current is pulsed with a low duty cycle [5].

Commissioning Results of RFQ Accelerator

For commissioning of the RFQ accelerator several beam properties were measured at various RFQ forward powers to determine the optimum RFQ field level. All measurements were performed with the beam diagnostics built in the MEBT directly attached to the RFQ and in the D-Plate which are described in [5].

The transmission through the RFQ was measured by current measurements in front of the RFQ with a Faraday-Cup in the LEBT and behind the RFQ with a current transformer and a Faraday-Cup in the D-Plate. In addition the sum signal of Beam Position Monitors in the MEBT were recorded which are depended on beam current and bunch length. Figure 2 shows that the optimum transmission of ~70% is at a forward power of 62 kW.

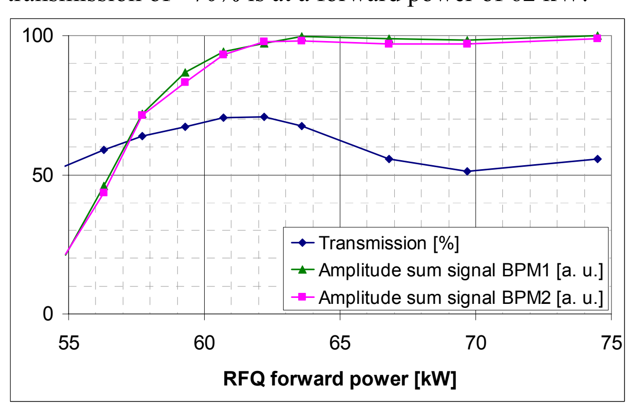

Figure 2: Transmission through the RFQ and amplitude of MEBT-BPM sum signals versus RFQ power

The energy of the proton beam accelerated by the RFQ was determined by Time-of-Flight method (ToF) with two sets of phase probe monitors. The first set of phase probes is the sum signals of the two BPM in the MEBT. The second set is two phase probes in the D-Plate. The energy of the proton beam measured with both monitors is 1.5 MeV as designed. The maximum energy is reached at a forward power of 61 kW (figure 3).

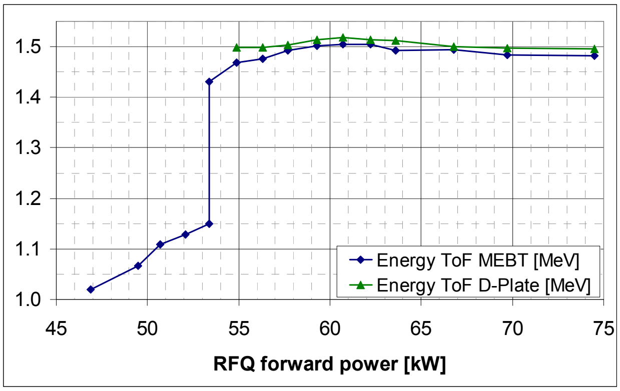

Figure 3: Energy measurements by ToF method versus RFQ power

The bunch length measurements with two fast Faraday-cups (FFC) in the D-Plate at an input beam current of 3 mA show clearly the optimum power level for the minimum longitudinal rms emittance of 30 π deg keV at 62 kW (figure 4).

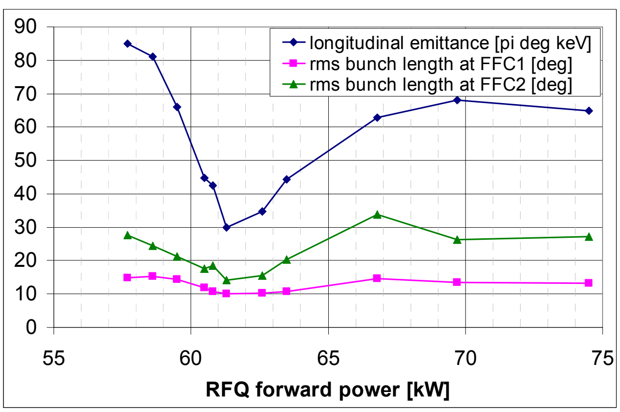

Figure 4: Bunch length measurements behind the RFQ versus RFQ power for determination of longitudinal emittance

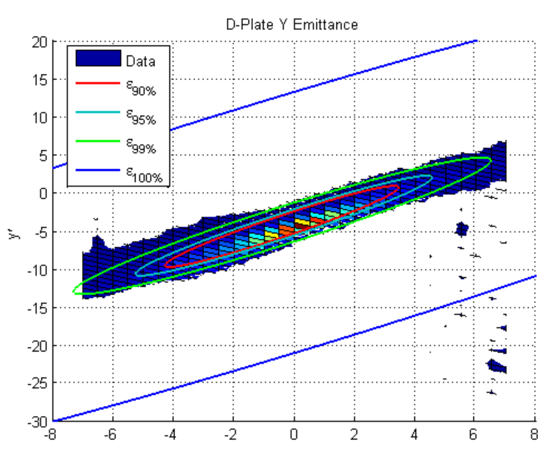

Figure 5: Transversal emittance measurements in the D-Plate by slit and wire method

First transversal emittance measurements with slit and wire method indicate that the RFQ preserves the good emittance of the ion source. Figure 5 shows the vertical emittance measurement for a 0.5 mA beam in the D-Plate which is $\varepsilon_{Y,rms,norm}$=0.172 π mm mrad of 100% of measured particles (LEBT: 0.168 π mm mrad).

Comparison to Beam Dynamic Simulation

The measured beam properties behind the RFQ show good agreement with the beam dynamic simulations (figure 6 and 7) which were performed during the design phase (except the transmission, which is with 70% lower than the calculated value of 95% at 5 mA). The measured beam energy is 1.5 MeV as designed, the measured longitudinal rms emittance is 30 π deg keV at 3 mA as designed and the transversal emittance growth is nearly zero as simulated.

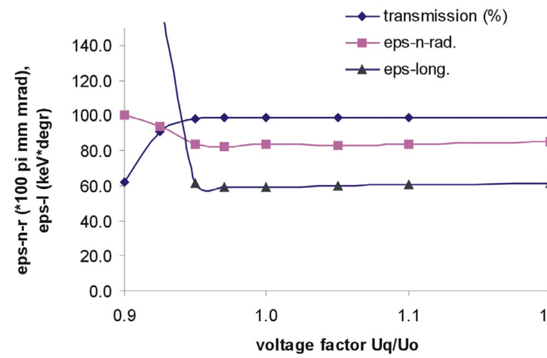

Figure 6: Simulation of beam dynamics versus RFQ field level

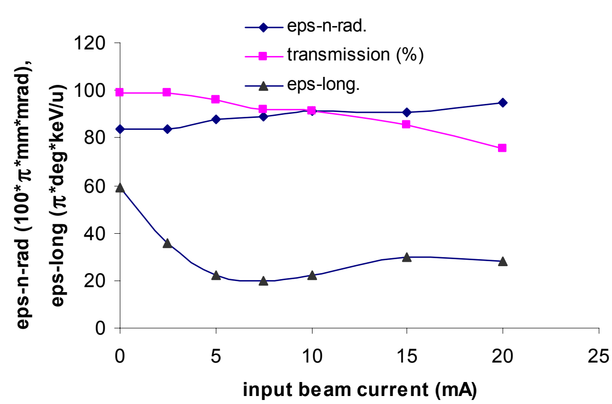

Figure 7: Simulation of beam dynamics versus input beam current

More detailed comparisons of the measured beam properties with recent beam dynamic simulations are presented in [6].

Commissioning Results of PSM

After installation of the PSM and connection to the cryogenic plant the first cool down was done in beginning 2007. The first period of cryogenic operation was dedicated to optimize the pressure stability and operational reliability of the plant itself. The RF conditioning of the cavities started in September 2007. For the first tests the cavities were operated in closed loop operation with a voltage controlled oscillator. The test results are summarized in table 1. The field gradients are scaled to peak surface fields with a calibration factor E_{peak}/E_{acc} of 2.9.

The Q value of the cavities at high fields (E_{peak}>20 MV/m) is mainly determined by field emission. During the test two RF couplers showed excessive heating. The reason was found in a poor thermal contact of the coupler's thermal binding to the radiation shield. This problem could be fixed directly on site.

Table 1: Cavity RF test results of the PSM

Cavity	max field [MV/m]	limit	Q at 20 MV/m	Q at 25 MV/m	losses at 20 MV/m [W]	losses at 25 MV/m [W]
HWR1	30		8,0E+08	7,0E+08	3,5	6,3
HWR2	28	coupler temp.	2,0E+08	1,4E+08	14,1	31,4
HWR3	32		4,0E+08	2,0E+08	7,0	22,0
HWR4	29		4,0E+08	2,0E+08	7,0	22,0
HWR5	31		7,0E+08	4,0E+08	4,0	11,0
HWR6	29	coupler temp.	7,0E+08	3,0E+08	4,0	14,7
				Σ	39,7	107,3

The cavities tuning system consists of a combined system of a stepper motor and a piezo actuator. During the first operation the maximum fields were limited at about 16 MV/m peak surface. At these field levels the tuner lost lock due to strong frequency fluctuations of the cavity. Further investigations showed that the limitation was caused by pondomerotive oscillations. This phenomenon is mainly observed for cavities operated in pulsed mode. In our case the oscillation was generated in cw mode by the interaction of Lorentz force and helium pressure detuning. The problem could be solved by compensating the piezo's tuning response for its hysteresis effect.

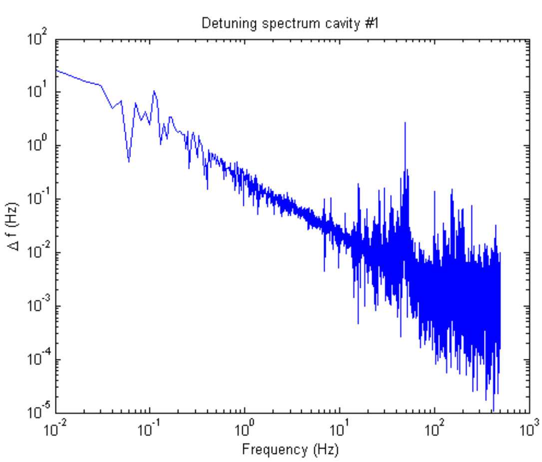

Figure 8: Typical microphonics detuning spectrum*

Measurements of the cavities´ microphonic spectra (figure 8 and figure 9) showed few resonances below 100 Hz. None of these had a problematic influence on the cavities´ frequency stabilization.

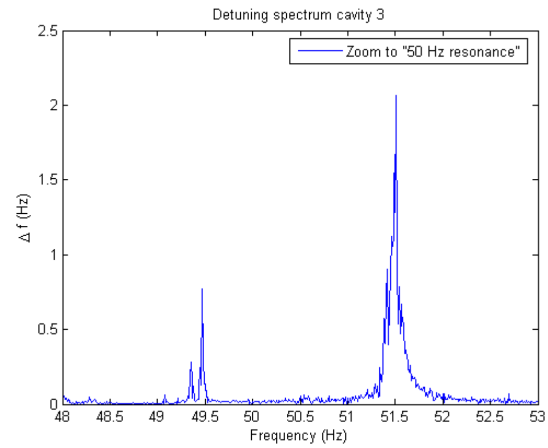

Figure 9: Zoom of detuning spectrum to 50 Hz

OUTLOOK

After the beam characterization of the normal conducting accelerator the PSM will be installed behind the RFQ. Beam commissioning of the entire injector including PSM is scheduled for late summer 2008.

REFERENCES

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* Measurements performed by A. Neumann, BESSY