FIRST EXPERIMENTS AT THE CW-OPERATED RFQ FOR INTENSE PROTON BEAMS

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Abstract

This contribution describes the first experiments with the CW-operated RFQ [1], which is designed to accelerate protons from 120keV to 700keV for the FRANZ-Project [2]. The commissioning is done using the RF and ion beam scrubbing technique. In the first phase, the acceptance of the RFQ is scanned and the performance of the RFQ without space-charge effects is evaluated with a 2mA proton beam. The second phase will increase the beam current up to 50mA and a third phase with a machine upgrade for a beam current of up to 200mA is planned. The configuration of a high-current RFQ [3] transporting beam current increasing from 2mA with no space-charge forces to a beam with high space-charge effects gives a unique insight in the beam optics of the space-charge effects. The measurements are done with a slit-grid emittance scanner for the transversal phase-space, a Faraday Cup for the transmitted current and a momentum spectrometer to measure the energy spread. The results set the basis for later experiments on variations of the beam current and the future coupling of the RFQ with an IH-structure [4].

INTRODUCTION

The CW-operated RFQ, which is the main component of this paper and seen in Fig. 1, is part of the accelerator driven neutron source at the Stern-Gerlach-Zentrum (SGZ) at Goethe-University Frankfurt [2]. It is located downstream the LEBT[1]-section, which matches protons with an energy of 120 keV into the RFQ. The device is operated in CW-mode at 175 MHz to be able to deliver a continuous beam or short pulses from the Chopper [5] with $\tau = 100$ ns at a repetition rate of 250 kHz. The connected RF-amplifier can deliver up to 250 kW for a maximum beam current of about 200 mA and for the possibility of coupling and supplying a downstream IH-structure [4] inductively with RF-power from the same amplifier. Yet, the present rods are designed to accelerate up to 50 mA protons. The required high power requires a sophisticated thermal design and cooling technique [3, 6].

INSTALLATION

The RFQ is installed and tuned, the 122 water-cooling channels are connected and a pre-conditioning up to 300 W is done [7]. Following this, the RFQ is integrated and aligned into the beam line. To ensure the proper vacuum conditions, two turbomolecular pumps with a throughput of 1400 L/s are connected. In addition the RF connection, coupling and controlling [8] of the amplifier is ensured.

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[1] Low Energy Beam Transport

Figure 1: A glimpse at the RFQ with its matching section.

EXPERIMENTAL SETUP

To verify the performance of the RFQ, an experimental setup with various diagnostic possibilities is available. In front of the RFQ an insulated cone is mounted at the end of the LEBT-Section to prevent the RFQ from transversal mismatched beam. The loss current at this cone can be measured. Downstream the RFQ, a diagnostic train – schematically drawn in Fig. 2 – is installed. As first device, a slit-grid emittance meter measures the transversal phase space. Subsequent, a Faraday Cup (FDC) detects the transmitted current. As the FDC has a 1 mm aperture, a fraction of the beam can pass to a momentum spectrometer to survey the longitudinal phase space. Additionally, a mass spectrometer is mounted at the emittance meter and analyses the composition of the residual gas. At a distance of approximately 10 m, a Low Energy Photon Spectrometer (LEPS) is used to detect the x-ray photons coming from the RFQ.

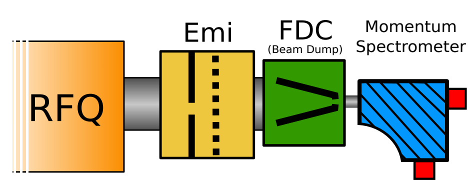

Figure 2: Scheme of the diagnostic train.

COUPLING

The amplifier measures forward and reflected power (S_{11}-measurement), in addition, a pickup measures the RF power transmission through the RFQ (S_{21}-measurement). In Fig. 4 on the left the results for pickup and forward power are shown. In the optimal case, the pickup to forward power graph gives a straight line. Some measurements indicate that this is not the case due to conditioning effects. The longer the machine runs, the measurements become more stable, which indicates positive conditioning effects.

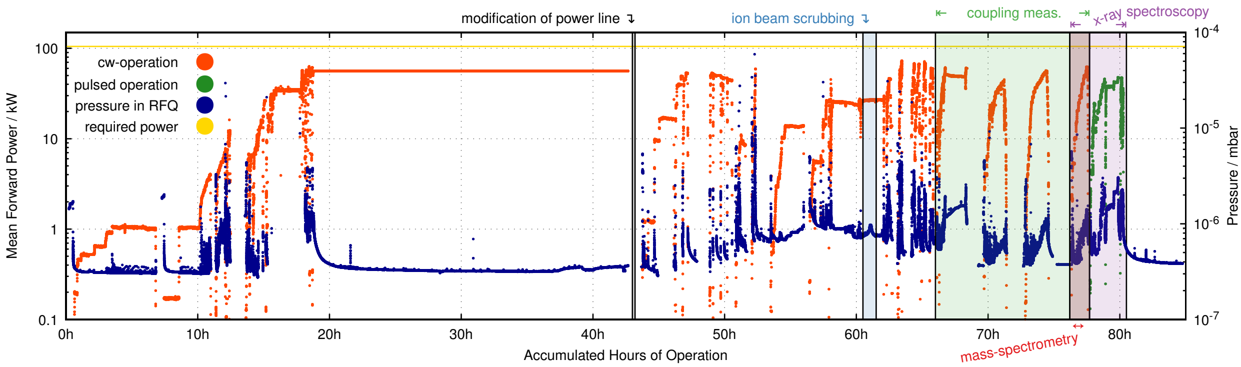

Figure 3: Accumulated operation hours of the RFQ since April 2016. The power for pulsed mode is the mean power at a duty cycle of 40%. After 43h hours of operation, the RF power line had to be modificated. The periods of different measurements have coloured backgrounds.

In the same figure on the right, the reflection against the forward power is given. While increasing the power transmitted into the RFQ, declines of the reflected power are observable. This indicates the effect of the dynamic tuner, retuning the cavity at higher energies. Thermal effects like increased electrical resistance make this necessary. As the coupling is optimised for high power, the overall graph does not incline linear but reaches a saturation.

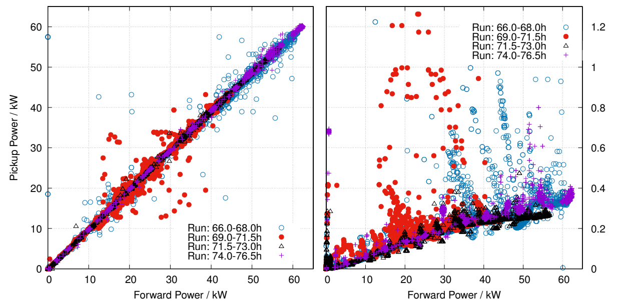

Figure 4: Pickup- (left graph) and reflected power (right graph) as function of the forward power.

RF-CONDITIONING

The RF-conditioning has begun and approximately 80 hours of operation were recorded since the installation of the RFQ in the beam line. The required power for CW-operation is a forward power of 105 kW. After 43 hours of operation, a modification of the RF power line connection was necessary to improve the coupling. In Fig. 3 the accumulated operation hours with the respective forward power and vacuum pressure are plotted. A strong correlation between the forward power coupled into the cavity and the pressure is visible. This indicates degassing inside the cavity caused by the RF. While the experiment was carried out, the cooling performance was kept constant and therefore the structure warmed up, causing desorption at the surfaces. To understand these effects, a mass spectrometer is mounted at the setup and an analysis of the composition of the residual gas is made (see section "Mass Spectrometry"). With increasing power the electrical field is increased and secondary particles, accelerated by the field, play a role. This effect of high-voltage is also seen at the conditioning of the ion-source extraction system [9].

X-RAY SPECTROSCOPY

The voltage between the rods is measured experimentally with a LEPS (Low Energy Photon Spectrometer). In this measurement, a planar HPGe (High Purity Germanium) detector with a thin beryllium window was used for x-ray spectroscopy. The resulting energy spectra are plotted in Fig. 5. The spectra are time normalised, therefore it is seen that the pulsed runs have a lower intensity at the same maximum photon energy. The resulting electrode voltage is given in the key above the graph. For a power of 70 kW and above, no suitable cut-off edge was measured and therefore no electrode voltage is evaluated. The required voltage for normal operation is 75 kV of which 60 kV confidently were reached.

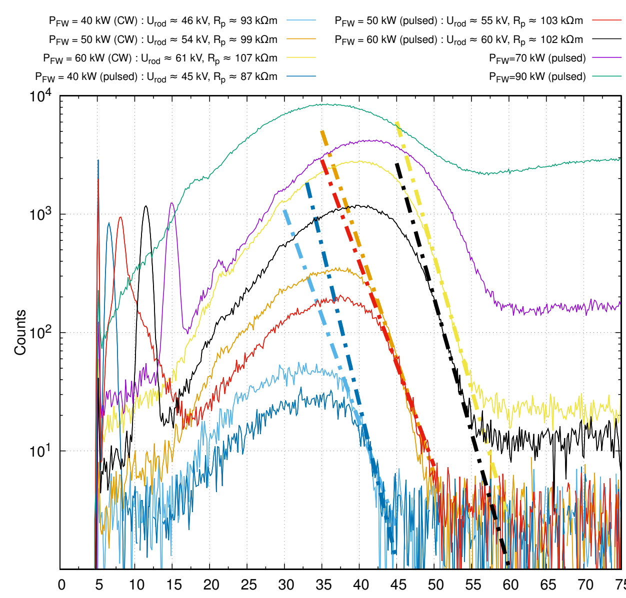

Figure 5: Spectra of x-ray spectroscopy for three RF power levels at CW-operation and six RF power levels in pulsed mode, resulting rod voltages and R_p-values.

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MASS SPECTROMETRY

To analyse the composition of the residual gas, a commercial mass spectrometer[2] was used. For the evaluation here, one 1 h run with CW-operation was recorded. Figure 6 shows the spectrogram integrated over the approximately 1 hour measurement time. Three sources of particles were identified and a closer look at their development over time is given in Fig. 7.

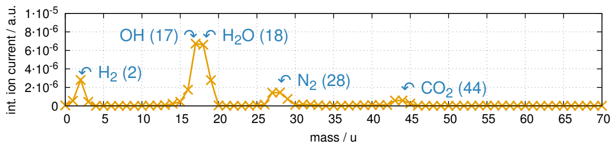

Figure 6: Integrated ion current as function of the mass accumulated for one run. The accumulated experimental time is identical to the time in Fig. 7.

The first and main fraction of residual gas are degassings from leakage within the cooling circuit. This is identified as H_2O and OH. The amount of these gases is comparatively independent of the forward power. The second fraction of particles results from surface desorption. Argon and CO_2 are desorbed at increasing voltage of the rods. A degassing peak is visible at each step of power increase starting at 20 kW until the end of the measurement. From 35 kW onwards, the level of both gases stays almost one order of magnitude higher than before indicating conditioning effects at these power levels. At the end of the measurement, the levels decrease to the initial magnitude. A third and relatively small fraction comes from sputtering effects. The rods and stems of the RFQ are made of copper and therefore, electrons accelerated at the rod-voltage of several tens of kV hit the surfaces and sputter copper atoms.

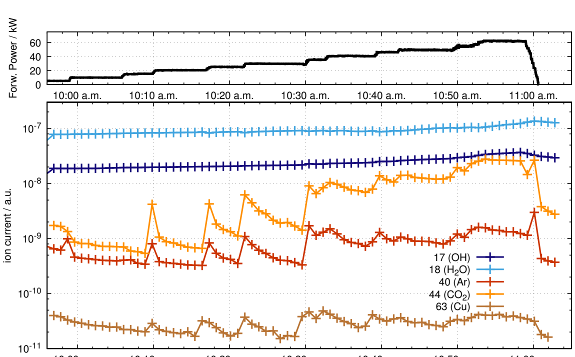

Figure 7: Detailed results of the mass spectrogram shown in Fig. 6.

ION BEAM SCRUBBING

To enhance the conditioning, the ion beam scrubbing (IBS) technique was evaluated with this RFQ. For this purpose, a He^+-beam was adjusted for a transport through the RFQ. Helium gives some advantages over hydrogen for this experiments: as it has only one (practical reachable) charge state, one can establish a controlled environment and exclude multiple peaks due to different molecular forms of hydrogen (H_2^+, H_3^+). Though a He^+-beam can be matched transversally into the RFQ acceptance, the longitudinal acceptance is unreachable, as the beam energy is limited to 120 keV. This means the ions have only half the required speed to be accelerated. The RFQ here is used in the transport mode, where ions are guided unaccelerated through the device. As an RFQ is not an ideal focussing device, losses lead to an ion beam scrubbing effect along the rods. In the experiments, up to 150 µA He^+-beam was transmitted through the RFQ.

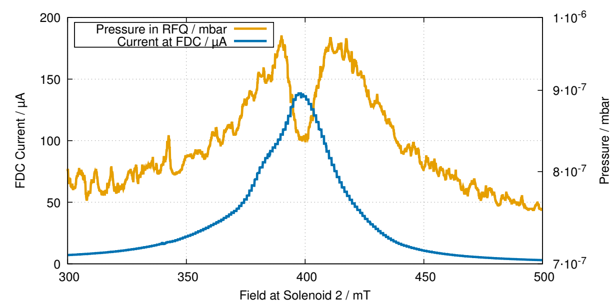

Figure 8: Measured effect of ion beam scrubbing.

To see the effect of IBS, one solenoidal lens in the LEBT is swept in its refractive power. Due to this method, the ion beam is continuously better focussed into the transverse acceptance of the cone, which prevents the RFQ from a strongly mismatched beam. With furthermore increasing refractive power, the beam is overfocussed and mismatched again. One expects that the transmitted beam current is almost zero, increases up to a maximum value and than falls again to almost zero. Figure 8 shows the expected behaviour in blue as a function of the magnetic field in solenoid 2. To indicate the IBS, the vacuum pressure is given in yellow. The pressure rises with increasing beam current, which is injected into the RFQ. For a strong mismatch of the transverse acceptance, the beam is lost at the cone at the injection point and almost no beam is seen in the RFQ. For a better matching, a large part of the beam is lost on the rods, causing to scrub off the contaminations on them. For the case of perfect match, the losses on the rods strongly decrease and most of the beam is transmitted through the machine. The strong drop in pressure for this case is visible, indicating less molecules to be scrubbed off.

OUTLOOK

In the upcoming phase of conditioning, further experiments are planned to verify the performance of the RFQ. The He^+-beam is used for alignment and functional test of the diagnostic train. The subsequent experiments will than focus on accelerating hydrogen and survey the accelerated beam.

[2] Pfeiffer Vacuum "PrismaPlus™"

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