COMMISSIONING AND OPERATIONAL EXPERIENCE GAINED WITH THE LINAC4 RFQ AT CERN

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Abstract

The installation of Linac4 has started in 2013 with the 3 MeV Front End, aiming at delivering a fully commissioned 160 MeV H^- beam by 2016. During summer 2013, a first prototype version of the H^- ion source and the Low Energy Beam Transport lines have been installed in the Linac4 tunnel followed shortly by the Radiofrequency Quadrupole accelerator (RFQ), operating at the RF frequency of 352.2 MHz, which accelerates the ion beam to the energy of 3 MeV. The RFQ, which had already been commissioned at the 3 MeV Test Stand, was this time driven by a fully digital LLRF system. This paper reports the result of the bead-pull field check performed after the installation in the tunnel, the experience gained during recommissioning and the results of field characterization as a function of the water temperature in the RFQ cooling channels, showing how the accelerating field can be adjusted by simply tuning the different cavity modules.

INTRODUCTION

After the successful commissioning and operation at the 3 MeV Test Stand between February and June 2013 [1], the Linac4 RFQ was moved to its final position in the Linac4 tunnel (Figure 1) where bead-pull measurements were repeated before the start of operation.

This time the RFQ was driven by a completely new and fully digital LLRF system and integrated in the control environment of the Linac4.

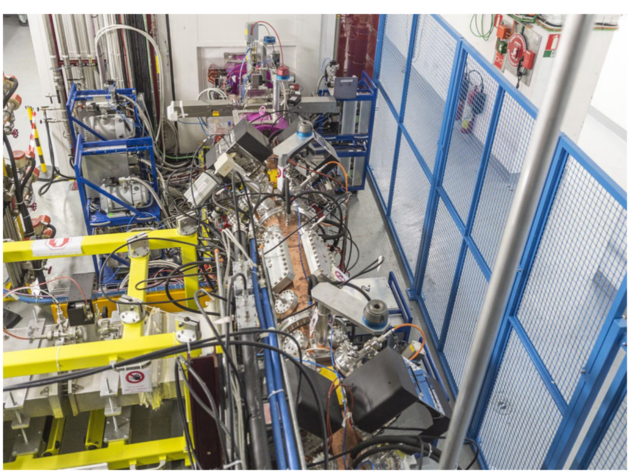

Figure 1: The Linac4 RFQ in the Linac4 tunnel.

The tunnel set up included a prototype ion source, a Low Energy Beam Transport line (LEBT), the RFQ and a Medium Energy Beam Transport followed by a temporary diagnostics bench. The source produced about 20 mA of H^- beam at 45 keV, with an emittance exceeding the RFQ acceptance. A transmission of 75% through the RFQ is expected with this source.

The RFQ operational parameters and the measured characteristics of the beam during the commissioning phase in the Linac4 tunnel are summarized in Table 1.

Table 1: RFQ and Beam Parameters at 3 MeV

Parameter	Value	Unit
Operating frequency	352.2	MHz
Total dissipated RF Power (with beam)	430	kW
Beam current	13	mA
Beam pulse length	400	μsec
Beam energy (input)	45	keV
Beam energy (output)	3	MeV
Beam transmission with present source emittance	75	%

Due to the large emittance of the beam from the source prototype, which exceeds the RFQ design acceptance, the measured transmission is poor; however it is coherent with the results from the simulations.

The installation of the ion source in its final version should bring the transmission of the RFQ to the design value of 95%.

RFQ RECOMMISSIONING AND BEAM TESTS

After the successful commissioning of the 3 MeV Front End at the dedicated Test Stand, the RFQ was moved to its final position in the Linac4 tunnel at the end of June 2013 (Figure 2).

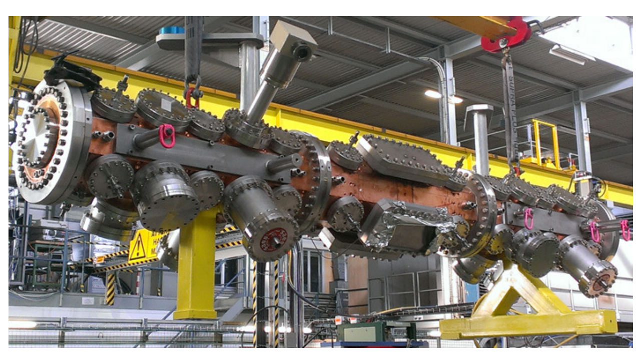

Figure 2: The Linac4 RFQ being moved from the 3 MeV Test Stand to the Linac4 tunnel.

The transfer was done with the RFQ completely assembled; only the vacuum ion pumps and the waveguide matching section were removed.

RF Field Check

In order to assess that the delicate transfer did not compromise the correct tuning of the RFQ, a new bead-pull measurement was performed on site in September 2013.

Figure 3 shows a comparison between relative errors of voltage components as they were measured at the Test Stand after tuning (step14, light colours) and as they have been seen in the Linac4 tunnel (B400, bright colours).

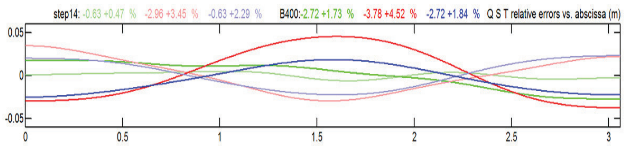

Figure 3: Relative errors for the Q (green), S (red) and T (blue) reconstructed voltage components. Q is the quadrupole, while S and T are associated with the two polarizations of dipole modes.

The plot shows that a significant change has occurred, with a field tilt that brings the main quadrupole component slightly beyond the specified value of 1% and an enhanced contribution of the dipole components; the small shift of the S component error towards the RFQ output and that of the T component towards the RFQ input are maybe suggesting a variation of the boundary conditions at the two RFQ ends, which could be corrected by a new tuning step.

A visible variation of the field profile has also been observed at the level of the RF power coupler, in the fourth quadrant, which nonetheless has not affected the vacuum tightness of the RFQ and has produced a negligible change in the coupling factor.

RF Commissioning and Beam Tests

The installation of the 3 MeV Front End with its diagnostic line was completed in September 2013.

The RF recommissioning in the Linac4 tunnel was performed with the completely new and fully digital LLRF, where feedback voltage and frequency control were progressively implemented to stabilize the field level in the RFQ cavity; the process went quite fast, the time being mainly needed for the commissioning of the new LLRF system [2].

In ten days the nominal accelerating field was established in the RFQ cavity and on the 14th November the first beam was accelerated to 3 MeV.

The beam transmission as a function of the RF power level in the RFQ cavity was measured again (Figure 4), confirming the calibration already performed at the 3 MeV Test Stand.

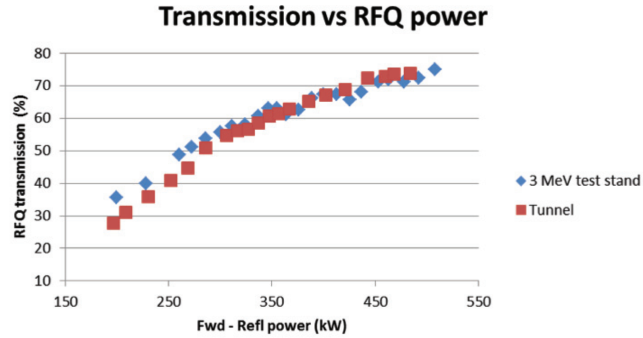

Figure 4: Comparison of beam transmission measurements performed at the 3 MeV Test Stand and in the Linac4 tunnel.

The beam characteristics were measured, confirming the reproducibility of the beam dynamics in the RFQ and transport line after its reinstallation in the Linac4 tunnel [3].

Figure 5 shows very similar horizontal and vertical emittance profiles measured during the first phase of the RFQ commissioning and in the Linac4 tunnel.

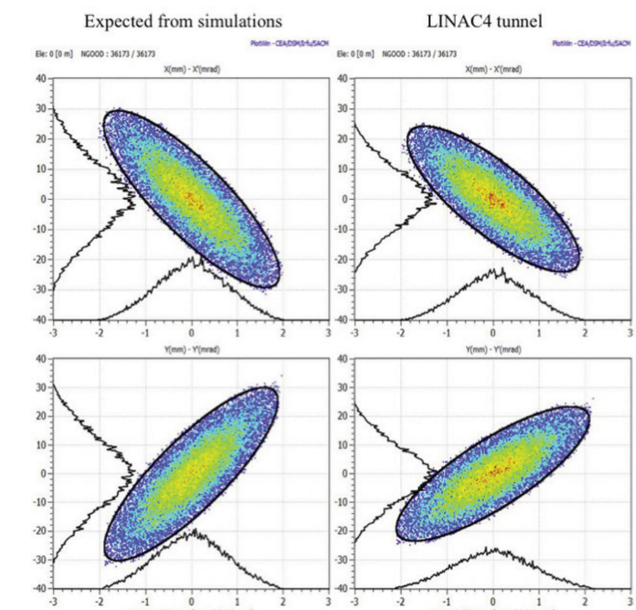

Figure 5: Comparison of the expected beam transverse emittance phase space with measurements in the Linac4 tunnel.

RF FIELD STABILITY STUDIES

The Linac4 RFQ is equipped with 16 RF pick-ups equally distributed in the four quadrants along the cavity length. By means of a digital acquisition system, voltage signals proportional to the field level along each RFQ quadrant are continuously recorded during operation. Calibration is performed by assuming that the field behaviour at low power level is equivalent to what measured during the bead-pull.

Voltage spectral coefficients are derived and RFQ eigen-functions are then used to continuously reconstruct the RF voltage along the RFQ.

ISBN 978-3-95450-142-7

This acquisition system and processing algorithm have allowed studying the field behaviour in the RFQ cavity dynamically at different power levels and with different temperature conditions of the RFQ cooling circuit.

RF Power Sweep

An RF power sweep has been performed from 2.5 kW to 400 kW and the voltage components reconstructed at each value and for each of the four RF pick-up positions. The results of the measurement are summarized in Figure 6 and show that the RFQ is stable at all power levels

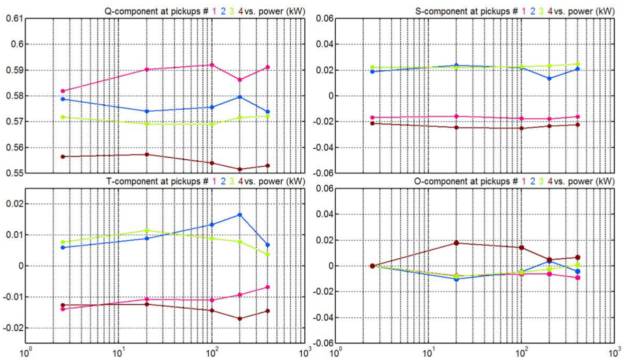

Figure 6: Normalized Q, S, T and O voltage components at the four pick-up locations vs. forward RF power.

Temperature variation studies

The Linac4 RFQ is temperature-stabilized by independent cooling circuits in the three modules; in particular, in each module, independent circuits supply the RFQ body and the vanes, which are fed in parallel. The RFQ tuning has been performed with a uniform temperature of 26 °C in all circuits.

During the study the body temperature was kept constant at 26 °C and the vane temperatures in the three modules scanned following four different patterns, as specified in Table 2.

Table 2: Vane temperature distributions in the RFQ (°C)

Pattern	T_{vane1}	T_{vane2}	T_{vane3}
O	26	26	26
A	25.5	26	26.5
B	26.5	26	25.5
C	26.5	26	26.5
D	25.5	26	25.5

Table 2 shows the different patterns adopted for the vane temperature studies, while the power in the cavity was swept from 40 kW to 400 kW.

In Figure 7, the Q and S components show very small variations for the different temperature configurations and power levels; note that a 23.5/26/28.5°C distribution is expected to compensate the general tilt of the Q component.

On the other hand, the T component reveals a significant sensitivity to temperature changes suggesting sensitivity to dipole-like perturbations. This conclusion is further supported by the observation of results obtained by changing the body temperature while the vane temperature is left constant in the three modules at different values.

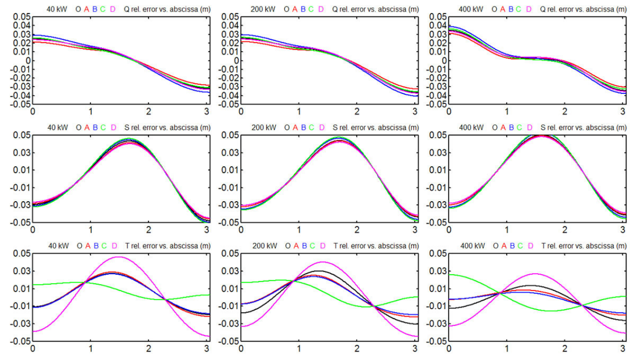

Figure 7: Relative error of Q, S, T components of the reconstructed voltage.

CONCLUSION

The commissioning of the Linac4 RFQ has been successfully performed in the Linac4 tunnel, confirming the good results already obtained at the 3 MeV Test Stand.

The field stability studies have shown a non- negligible presence of dipolar components in the accelerating field, which did not affect the beam dynamics. It has been shown that the general tilt of the quadrupole component of the accelerating field could be corrected by adjusting the vane temperatures of the three modules to appropriate values. If needed, a fine tuning of the RFQ could be envisaged on the spot, with reduced impact on the commissioning schedule.

REFERENCES

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[3] A. M. Lombardi, “Commissioning of the low-energy part of Linac4”, Linac14, Geneva, Switzerland.