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PERFORMANCE OF THE CERN HIGH-INTENSITY RFQ

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Abstract

The CERN RFQ2, designed to become the injector of the CERN Linac 2, has delivered its nominal proton current of 200 mA at 750 keV from the start of the beam tests. However, prior to its installation at Linac 2, extensive measurements on a test stand have to be carried out to assess the quality of the beam and the overall reliability of the accelerator.

Unfortunately, the measurements have been perturbed owing to accidental oil pollution of the RFQ2. The removal of the cracked oil from the vane tips, the reconditioning of the RFQ2, and the reduced measurement programme are reported.

Introduction

The RFQ2, after its very successful start[1] has been operating reliably on a test stand. The nominal proton beam of 200 mA at 750 keV could be easily obtained. By raising the vane voltage by about 10% and by increasing the input current, output intensities of 240 mA were registered. For the sake of completeness, the RFQ2 parameters are presented in Table I.

TABLE I: Main RFQ2 design parameters

RF frequency	f_0	202.56 MHz
Input energy	W_{in}	90 keV
Output energy	W_{out}	750 keV
Output current	I_{out}	200 mA
Trapping efficiency	η	$\sim$ 90%
Vane voltage	V_0	178 kV
Final synchronous phase	ϕ_s	-35°
Modulation factor	m_{max}	1.62
Mean aperture radius	r_0	7.87 mm
Cavity length	L_{RFQ}	178.5 cm
Vane length	l_v	175.2 cm
Cavity diameter	D	35.4 cm

When the system on the test stand was put into operation after a shutdown, breakdowns started to occur in the RFQ2 already at very low RF levels, and it was impossible to reach the nominal vane voltage. Inspecting various elements of the vacuum system, it was realized that a missing interlock of the vacuum valve between the turbomolecular pump and the RFQ2 could have caused, by accident, an oil pollution of the latter. We then tried to recondition the cavity by slowly increasing the RF level, thus progressively eliminating the oil from the vane tips. This allowed us to reach finally, after several days and at the price of many breakdowns, the nominal operating level. However, the RFQ2 was not very stable and, after a few days of interruption of the tests, the situation degraded again. It was then decided to open the RFQ2 and, once the end covers were removed, the typical damage to the vane tips (presence of cracked oil), caused by the breakdowns, together with the marks of excessive heating on the vanes above the turbomolecular pump, could be seen. The RFQ2 was then dismantled from its test stand and brought to the workshop for cleaning. At the same time, all elements of the beam line were cleaned, either *in situ* or elsewhere. When the experimental set-up was reinstalled, careful reconditioning of the RFQ2 permitted us again to reach and go above the nominal RF level. Similar output beam intensities and emittances to those before the accident were obtained.

The experience gained with the cleaning of the RFQ2 had to be paid for by a delay in beam measurements: only a part of our measurement programme has been carried out so far.

Cleaning of the RFQ2

To clean such a complicated structure as the RFQ2, containing a lot of weldings and brazings, is far from obvious. The oil deposited on various surfaces could have been removed, but the cracked oil on the vane tips was the real problem. It rendered any normal operation impossible, in particular in view of the high fields which are required for the RFQ2 (2.5 × Kilpatrick limit). To remove the cracked oil, chemical or mechanical cleaning has to be employed. Chemical cleaning requires subsequent rinsing with distilled water, which is incompatible with the tank being made of mild steel. Therefore, mechanical cleaning making use of inorganic abrasive paper with aluminium-oxyde grains deposited on a substrate was used. The danger is that, after the cleaning, the grains remain encrusted in the cleaned surface. Several papers were tried out and it was found that grains of at least 5 μm were necessary to remove the cracked oil. Before starting the cleaning, a sample of the vane material (Cu–Cr alloy) was gently cleaned with such a paper, rinsed with alcohol, and then analysed under a microscope: no encrusted grains were seen on the sample.

A strip of the abrasive paper was fixed on two Plexiglas rods, which permitted progressive cleaning of the vane tips, see Fig. 1. The progress of the cleaning was continually checked by an endoscope. A few hours were necessary to clean a vane. After all the vane tips were cleaned, the RFQ2 was placed in vertical position and rinsed with alcohol and freon, and then left to dry.

RF measurements and reconditioning

Once the experimental set-up had been put together again, the usual series of tests were performed. In particular, the RF field in the RFQ2 was carefully checked. The measurement showed a degradation in the field symmetry of the quadrants, which was ±1% previously and now raised to ±4%, owing to a decrease of the field in the quadrant where the turbo pump, responsible for the contamination, was mounted. The probable explanation for this asymmetry is the excessive heating in that quadrant due to the many breakdowns occurring exactly in front of the pump hole (where most of the oil was concentrated) and which could have caused mechanical shocks to the vanes. This asymmetry will eventually be corrected by installing a new fixed tuner. However, the asymmetry

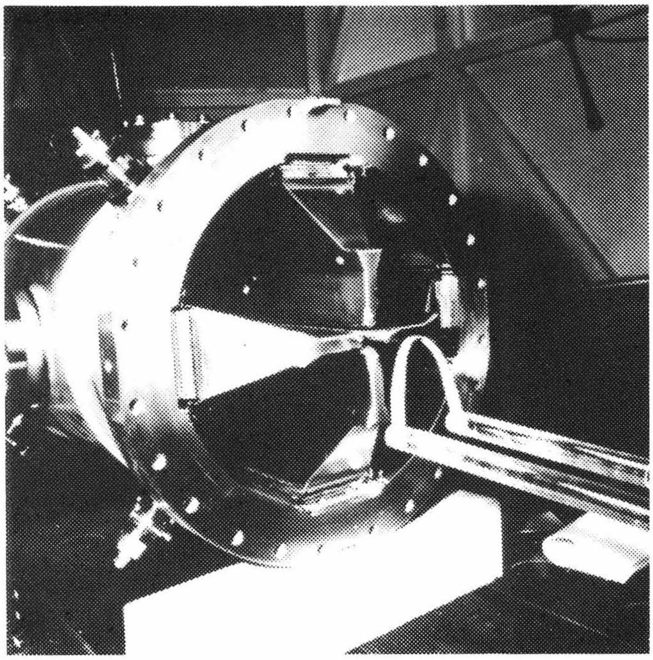

Figure 1: Mechanical cleaning of the vane tips

was present during the beam measurements reported in this paper.

Pumping has been applied for about a week before switching on the RF power. Careful and slow RF conditioning, which lasted also about a week (initially the RFQ2 was conditioned in about a day) brought us, finally, to the situation we had before the accident, with the nominal RF level kept stable. Note that the vanes of the RFQ2 had a gold deposit of about 1 μm, as a protection against oxidation during tuning and adjustment of the cavity, which was removed from the vane tips during the mechanical cleaning; nevertheless, no difference in voltage holding could be detected.

Beam measurements

Our experimental set-up is shown schematically in Fig. 2. When starting to do beam measurements, several tests, already performed before the accident, were repeated.

The duoplasmatron ion source was adjusted to yield a proton beam of about 220 mA. The matching solenoid

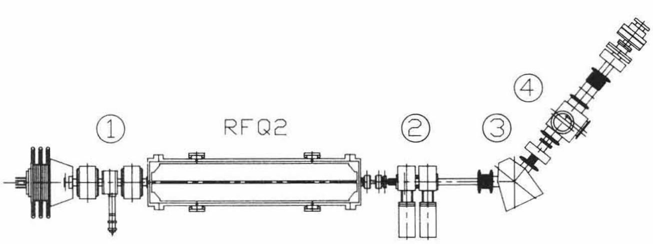

Figure 2: Experimental set-up of the RFQ2: (1) solenoid lenses, (2) emittance measurement device, (3) bending magnet and (4) detector grids (SEM grids)

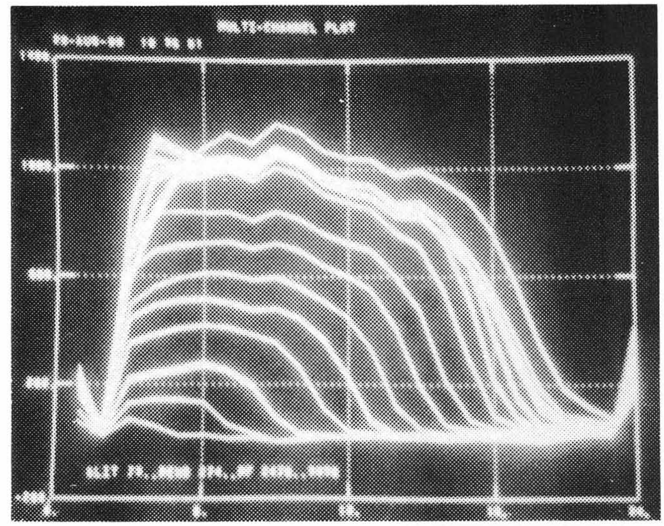

Figure 3: Energy spreads of the RFQ2 beam for different vane voltages. (Horiz. scale: 39 keV/div.)

lenses were given the same values as before. With these settings, the following results have been obtained:

Output beam intensity: for the nominal vane voltage, intensities of about 190 mA were measured. The nominal 200 mA beam could be obtained with a 5% higher vane voltage. Increasing the vane voltage even more, and readjusting the ion source, resulted in an output beam of 215 mA. So far, we have not tried to go to a higher intensity.

Energy spread: about ±70 keV was measured, for an output beam of 200 mA and a 5% higher vane voltage (note that the space charge increases the energy spread by a factor of about 3 between the RFQ2 and the measurement device). In Fig. 3 one sees the energy spreads for different vane voltages, ranging from 70 to 105% of the nominal value.There are practically no particles in the right energy range for voltages below 70%. The areas under the various curves are proportional to the accelerated beam.

Output beam emittances: the measured output emittances are shown in Figs. 4 and 5. The normalized r.m.s. value, $\varepsilon_{rms,n}$, is about 0.6π mm·mrad. For comparison, we also show emittances measured before the accident, see Figs. 6 and 7. Their $\varepsilon_{rms,n}$ value is about 0.5π mm·mrad. The corresponding input emittance values are $\varepsilon_{rms,n} \approx 0.4\pi$ mm·mrad.

It seems that the impaired field symmetry slightly reduces the output beam and increases the output emittances.

Discussion and conclusion

The oil pollution of the RFQ2 prevented us from following up our previously established measurement plan. Intensity limits, bunch measurements, and the detailed analysis of emittance and energy spread still remain to be done. However, prior to this, we intend to re-establish the field symmetry in the quadrants, if possible at the previous value of ±1%.

The experience showing that cracked oil can be mechanically removed, without damaging the vane tips and without impairing the voltage holding, can be considered as a positive result.

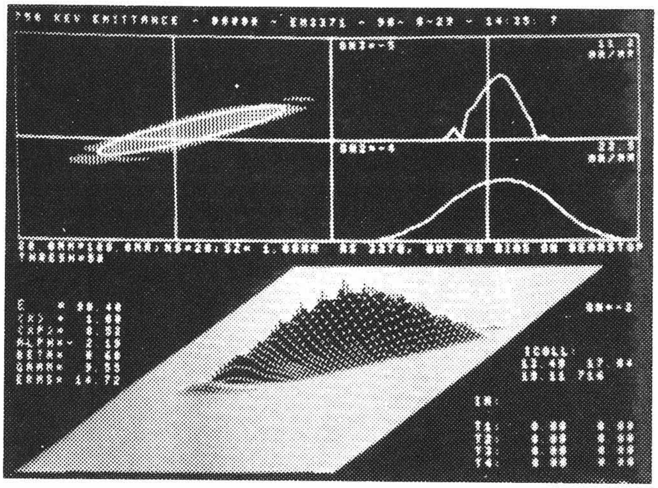

Figure 4: Horizontal output beam emittance

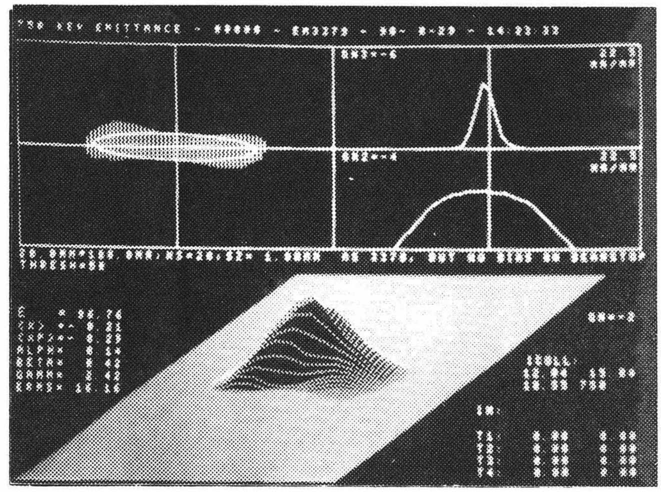

Figure 5: Vertical output beam emittance

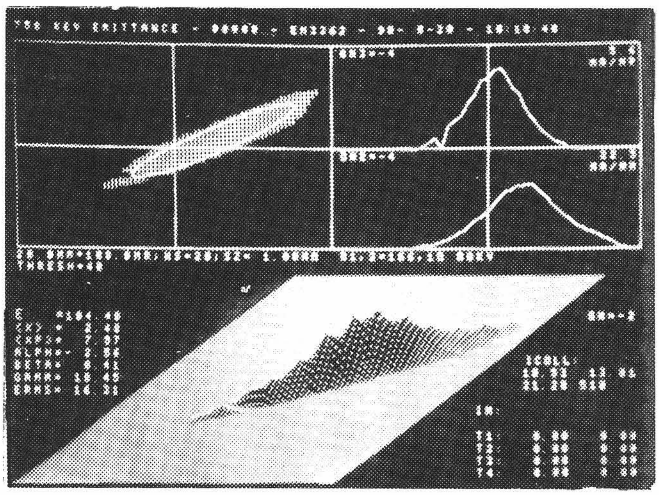

Figure 6: Horizontal output beam emittance, before accident

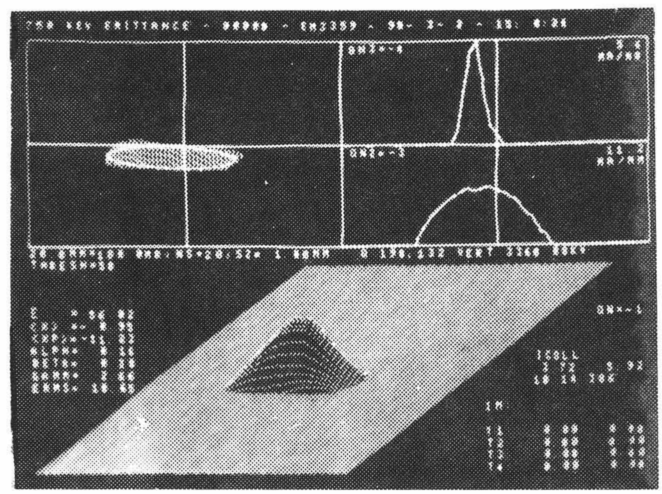

Figure 7: Vertical output beam emittance, before accident

Acknowledgements

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Reference

1. J.L. Vallet, M. Vretenar and M. Weiss, Field adjustment, tuning, and beam analysis of the high intensity CERN RFQ, Proc. European Particle Accelerator Conf., EPAC90, Nice (France), 12–16 June 1990, to be published.