PERFORMANCE OF THE CERN RFQ (RFQ1 PROJECT)

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Summary

The 520 keV 80 mA CERN RFQ (RFQ1), intended as injector for Linac 1, has been successfully operating in an experimental set-up since March 1983. It is now being installed on Linac 1.

Some results from the experimental set-up and the performance RFQ-Linac 1 are reported.

Introduction

The first CERN RFQ is now operational on Linac 1, which delivers 50 MeV proton beams for the low energy antiproton ring (LEAR). The project RFQ1 has thus been terminated.

The 520 keV, 80 mA RFQ1 has been considered from the start (1981) as an experimental device[1], which would help to get acquainted with and master a new technique and, at the same time, permit to test various possibilities of this type of accelerator. The help of LANL, in particular at the early stage of this project, has been decisive.

Delivering 80 mA of protons (f = 202.56 MHz, repetition rate = 1 pulse per second, pulse length = 100 µs), the RFQ1 is, to our knowledge, the most intense accelerator of this type in operation as injector. It has from the start and without difficulties performed up to expectations[2].

Belonging to the "first RFQ generation", it has a variable transverse radius of curvature of the vanes and no special means for field symmetrization in the four quadrants.

A particular feature of the CERN RFQ is that it is rigidly connected to the first Alvarez tank. This has been an imperative due to beam matching considerations. Unfortunately, the vacuum tanks of Linac 1 are separated from the RF structures (liners), making the alignment RFQ1 - Linac 1 very delicate. The space constraints between these two accelerators are such as to provide no space for the installation of steering devices.

To achieve a matching in 6-dimensional phase space, three magnetic quadrupoles (spares from Linac 2) and a matching cavity (of "buncher type") are added to make a mechanical unit with the RFQ-cavity. The first few quadrupoles of tank 1 are also used to complete the transverse match. So far, after only a few tests, more than 65 mA have been accepted and accelerated in Linac 1, which is a reasonable result given the general state of the CERN "old Linac".

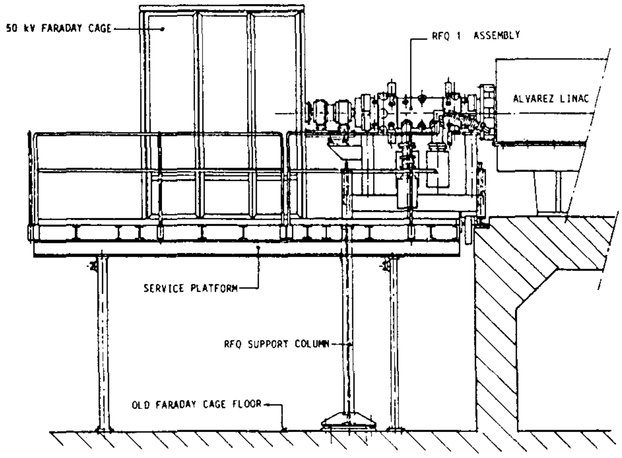

Fig. 1. Layout of RFQ 1 facility

The RFQ output beam has been analysed in 1983 on an experimental set-up[2]. In this paper, only measurements concerning the matching to Linac 1 will be reported. The delicate installation problems are delt with in some detail and the global layout of the new preinjector for Linac 1 is shown. Some results of the performance RFQ1 - Linac 1 are presented at the end.

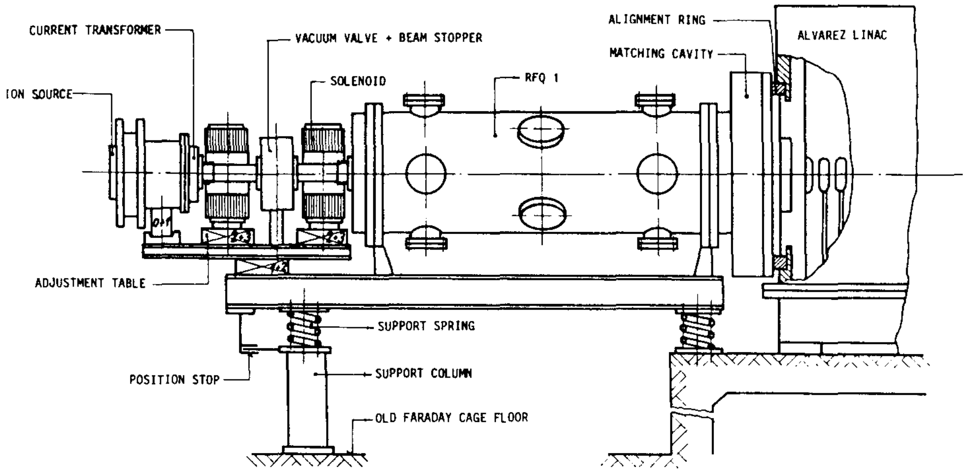

Fig. 2. RFQ Assembly bolted on the Alvarez Linac (schemaric presentation)

Installation and Alignment

Fig. 1 shows the layout of the RFQ1 project, with the RFQ assembly bolted to the over 25 years old Alvarez Linac. The service platform inside the old 520 kV Faraday cage carries the new 50 kV one, some RF equipment and the vacuum roughing pumps. The RFQ assembly however, such as shown in Fig. 2, is mechanically isolated from the platform and the Faraday cage, having its own support system. The reason for this is to protect as much as possible the Alvarez tank and guarantee the alignment regardless of the activities on the platform. All electric cables are flexibly connected to the RFQ; they are coming from the cable-tray above the RFQ which leaves the platform floor free for transport and manipulation of heavy objects.

All components of the RFQ assembly (Fig. 2) are mounted on a common underframe so that the assembly can be transported and aligned to the drift-tube Linac as an independent mechanical unit. The alignment inside the assembly is made via adjustment tables. In Fig. 2 the two digits near each table indicate the number of possible translatory movements (first digit) and the number of rotational movements around the main axis. Due to the restricted space the table arrangement is somewhat complicated. Tests with proton beams showed that a positioning precision of ± 0.25 mm between solenoids and RFQ cavity is quite sufficient. A much better precision (± 15 µm) is needed for the vane-to-vane position. This was achieved with a three point vane fixation and a flexible copper strip (for electrical and thermal vane-to cavity connection) welded on before the final vane adjustment[4]. With this arrangement, both the RF field symmetry and frequency stayed unchanged over a period of one year and survived the transport and the installation on the Alvarez Linac 1. The rationale for the whole RFQ mechanical design was to make the support and adjustment structures statically defined or if that was not possible, the redundant supports were replaced by springs with a known load-deformation function. The advantage of such systems is that it is easy to define and contrôle the displacements of structural elements and consequently have a better long term stability.

To align the RFQ1 to the Linac 1, it was necessary to create a sighting line parallel to the proton beam outside the Linac tanks. For this purpose four optical targets were installed, two on columns bolted to foundation plates at each end of the first Linac tank, and the other two on special frames bolted to the RFQ cavity. The proton beam line was defined with the help of the measured positions of drift-tubes inside the first Linac tank. The statistical error here was contained in ± 0.25 mm. With the four optical targets it is now possible to check the alignment of the RFQ any time, even during operation. The reading on the targets, of course, is correct with vanes in horizontal and vertical position; a spirit level can measure this to better than 0.01 mrad, or, in our case, 20 µm on the beam axis.

Dictated by the beam optics requirements, the RFQ assembly must be directly bolted to the Alvarez Linac tank. No space was given for an element sufficiently flexible to make the two accelerators mechanically independent which would make possible the usual alignment via cross tables. In our case it was necessary to insert a special "alignment" ring between the two accelerators. The ring fits tightly into the existing port-hole on the Linac tank and, with its inner diameter, on a shoulder machined on the matching cavity. By machining the ring so that the two sides are, if necessary, not parallel and the hole is excentric to the outer diameter, it is possible to correct the RFQ position error both for the translation in the plane perpendicular to the beam axis and the tilt around the intersection point. In our case the ring has a 0.9 mm excentricity and two parallel sides.

The alignment work was done in three successive operations, each operation consisting of bolting the RFQ assembly to the old Linac, evacuating to ~1 Torr the first Linac tank and the RFQ, reading the alignment error via optical targets, disconnecting the RFQ from the Linac and inserting a new "alignment" ring. The final alignment error is within .3 mm and .5 mrads. Because the reproducibility of the alignment due to the design of the old Linac tank is not better than 0.2 mm, an additional alignment step would be of noadvantage. After two months, a survey check showed that the position of the RFQ is stable.

The spring support system, schematically presented in Fig. 2 is needed to protect the Linac tank, which was not designed to carry the RFQ assembly, from mechanical overloading. To keep the stresses in the tank wall inside elastic limits, a tilt of 0.2 mrads of the RFQ assembly is all that is permitted, meaning that a rigid support near the solenoids may be dangerous because the shift of the platform could be greater than 0.6 mm. A sufficiently "soft" spring on the contrary can easily absorb such a movement but it cannot take all the accidental or additional loads produced by replacing an ion pump or the source. In such cases, the structure is protected by stoppers which limit the movement of the RFQ assembly near the solenoids to ± 0.2 mm. Because the position of these stoppers must be stable, they are not mounted on the platform but on the support-column which is bolted to the building floor. For this reason, but also to prevent the transmission of vibrations, the service platform is isolated from the supporting system.

RF-Aspects

RF-field symmetry, obtained by a straightforward procedure[3], remained constant despite of the operating frequency readjustments and mechanical shocks caused by several transfers. A necessary condition, however, is the synchronous movement of the eight piston tuners; occasional corrections on the basis of shaft-encoder readings were necessary to counter stepping-motor imperfections.

Incorporating the RFQ and the matching cavity to the Linac 1 RF system presented no particular problems due to their modular design with independent feedback loops. There was some multipactoring in the matching cavity induced from multipactoring in tank 1; RF conditioning and careful timing cured these instabilities.

The RF systems of the Linac tanks cannot deliver sufficient power to accelerate the full RFQ beam: tanks 2 and 3 saturate for beam currents in excess of 35 mA and the droop in tank voltage due to beam loading causes a typical droop in output beam intensity. A second power amplifier for each tank (initially provided but deliberately eliminated to simplify the feedback) should be reinstalled if beam intensities above 35 mA at 50 MeV are required.

Operation RFQ1 - Linac 1

Between RFQ1 and Alvarez tank 1, there is no space for any beam diagnostic equipment, except a beam transformer. Therefore the properties of the RFQ1 beam had to be studied on an experimental set-up and known prior to the installation. These measurements have already been reported[2]. From these measurements and connected beam transport computations, one has derived the emittances at the exit of the RFQ (before the matching cavity and quadrupoles). These emittances were then, in turn, used for beam matching computations between the RFQ and Linac 1.

Fig. 3, shows the computed horizontal and vertical emittances at:

a) the RFQ output, b) the position corresponding to Linac input (note the slight mismatch which is then corrected with quadrupoles in tank 1) and c) the position of emittance measurement (app. 15 cm downstream of Linac input).

Fig. 4 are the photos of the corresponding emittance measurements, which compare fairly well with Fig. 3c.

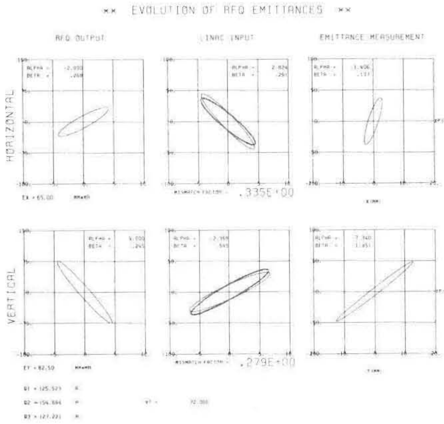

Fig. 3. Computed emittances

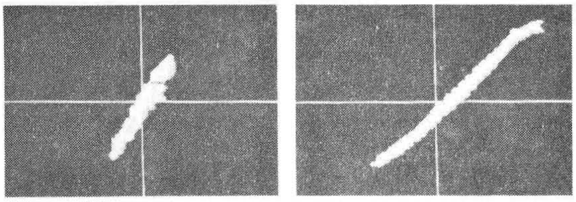

Fig. 4. Measured horizontal and vertical emittances

The efficiency of the matching cavity has also been tested by bunch length measurements, using a fast probe[5]. Fig. 5 shows the bunch widths as function of the voltage of the matching cavity. The beam intensity was approx.70mA and the measurement was made at 15 cm downstream of the Linac 1 input position.

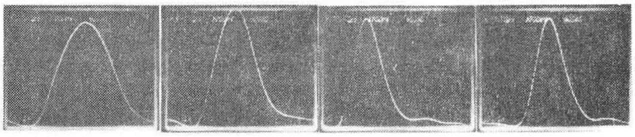

Fig. 5. Bunch width (36°/div.) for matching cavity voltages (keV): a) 0, b) 52, c) 118, d) 127

There has been no difficulty in injecting the RFQ1 beam into Linac 1: 7 mA out of Linac 1, at 50 MeV, have been obtained right from the beginning. The focussing in Linac 1 was then set to predetermined values and only the first few quadrupoles of tank 1 readjusted to improve the matching. Typical figures of the first tests have been 50 mA out of RFQ1 and about 45 mA accepted and accelerated to 10 MeV (output of tank 1). In principle, no losses occur any more after 10 MeV; in our case, however, typical droops in beam intensities attributable to uncompensated beam loading showed up (see RF-aspects).

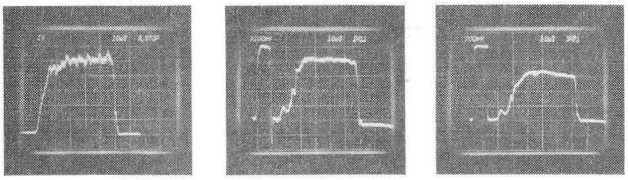

Fig. 6. Beam intensities (20mA/div.) at a) RFQ input, b) RFQ output, c) tank 1 output

Higher beam intensities have also been tried out. The photos of Fig. 6 show the intensities at RFQ input, tank 1 input and at 10 MeV. The acceleration of ~65 mA out of ~80 mA injected into Linac 1 is satisfactory, given the circumstances. It is believed, however, that the injection losses into Linac 1 will progressively be brought to a 10% level, which is the value estimated by matching computations (a "no loss match" has not been possible even on paper, given the geometry at tank 1 input).

The emittance, energy and energy spread of the 50 MeV beam have rapidly been checked during the early measurements and found correct. Some troubles with Linac 1 and the impossibility to repair them during the PS operation period have prevented us to supply this paper with adequate photos.

Conclusions

As mentioned in the introduction, the RFQ1 project is now terminated, although beam measurements on the complex RFQ1 - Linac 1 will certainly continue. Tentatively, one would summarize the experience gained during the project as follows:

1. The adopted solutions to match beams of the order of 100 mA in and out of the RFQ seem adequate.
2. No breakdown problems have been encountered with nominal electric fields in the order of 25 mV/m between vanes.
3. Approximately a twice the nominal power could be fed into the RFQ without breakdown.
4. The mechanical stability seems well guaranteed by avoiding statically undefined situations.
5. An operating pressure in the RFQ of the order of 10^{-6} Torr seems sufficient.

References

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