Recent Performance of the LNS Four-Rod RFQ2 Acceleration of Gold and Xenon Beams

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Abstract

A four-rod RFQ structure replacing the LNS four-vane existing cavity, has been ordered to the PET company (Darmstadt-Germany) for acceleration of low current pulsed heavy ion beams having a charge to mass ratio from 0.5 to 0.25. Acceleration would occur from 12.5 keV/u to 200 keV/u.

The RFQ2 has been successfully operating: in a first step as an experimental set up since december 1992 for testing the RF behaviour of the structure and the qualities of the accelerated beams (transmission efficiency, transverse emittances, momemtum spread) and in a second step for delivering gold and xenon beams to the accumulator ring MIMAS. More recently iron beam was produced for physics.

The paper describes also the modifications of the transport beam lines from the source to the RFQ, then to the accumulator ring (a debuncher cavity was added for longitudinal matching of the beams).

1. INTRODUCTION

At the LNS, heavy ions are accelerated by a pre-injector consisting of an EBIS source (DIONE) and a RFQ structure, then are accumulated in the MIMAS ring before being accelerated to the final energy of 700 MeV/u in the SATURNE synchrotron .

The RFQ1 built in 1983 belonged to the early 4-vane designed structure coupled to a manifold [1] and was suffering for a lake of stability, reliability and reproduceability when operated for heavy ion such as Ar 16+ or ions of lower charge to mass ratio (multipactoring on manifold tuners and sparking in the cavity occured, conditioning was lost after a few days of shut down). Conditioning periods of several weeks were required to prepare acceleration for instance of Kr 28+ which corresponded to the best performance of this accelerator.

Therefore it was decided in 1991 to replace this accelerator by a new structure taking advantages of the latest developments in the field, in order to improve the reliability of the heavy ion pre-injector. Since the 200 MHz frequency was to be kept, two major different candidates were possible: the direct coupled 4-vane structure used now in many laboratories and the 4-rod structure developped at Frankfurt.

The designed features were fixed to be: same input energy, larger transverse acceptance, maximum RF power of 200 kW, same housing, low duty cycle but multipulse operation, acceleration of charge to mass ratio as low as 0.25, easy conditioning and maintenance. The injection into the accumulator ring required also a small momentum spread $(\Delta P/P \leq \pm 5.10-3)$. To achieve this last requirement, a separate debunching cavity was placed behind the RFQ, because additional cells in the struture necessitated to much room. Finally, at equal performances on the paper, the 4-rod structure was chosen for reasons of cost, short time delivery, simplicity of operation and was ordered to be designed, built and tested by the PET company .

2. RFQ BEAM DYNAMICS-MAIN PARAMETERS

Designed parameters, very similar to existing 4-rod RFQ designs [2],[3], were obtained using PARMTEQ calculations and are summarized in the following table.

$f = 200$ MHz
$U = 21.2$ A/q Kv ($\varepsilon = q/A$)
Wout=200.keV/u
cell number : 252
electrode length : 134cm
aperture radius : 3.7 mm - 3. mm
synchronous phase : 90 ° - 24 °
energy spread $\Delta W/W = \pm 1.75\ 10^{-2}$

low ε case - (q/A= 0.25)
normalized acceptance An=1.2 π mm.mrad
input parameters $\alpha = 0.$
$\beta = 0.0013$ cm/mrad
output parameters
$\alpha x,y = -1.16,\ 1.46$
$\beta x,y = 0.0095,\ 0.0125$ cm/mrad
$E = 50\ \pi$ mm.mrad
$\Delta W = \pm 3$ keV/u
$\Delta\varphi = \pm 11^{\circ}$ (90 % of beam)

high ε case - (q/A= 0.5)
normalized acceptance An=1.6 π mm.mrad
input parameters $\alpha = 0.$
$\beta = 0.0012$ cm/mrad
output parameters
$\alpha x,y = -1.03,\ 0.28$
$\beta x,y = 0.0071,\ 0.0051$ cm/mrad
$E = 70\ \pi$ mm.mrad
$\Delta W = \pm 3.3$ keV/u
$\Delta\varphi = \pm 9.5^{\circ}$ (90 % of beam)

3. BEAM OPTICS

Low and high energy (12.5 - 200 keV/u) beam transports that were already existing had to be modified to match the new accelerating structure. As can be seen on the list of parameters, input beam conditions are very severe. In both dimensions the matched beam is close to a waist and the beam sizes at the entrance of the RFQ are very small.This requires for high accurracy alignment of the structure and optical elements as well as for provision of steering and profile monitor devices.

Beam degradations could be caused by aberrations of the optical system if designers do not care enough.

3-1- Low energy beam optics.

The LEBT consists of a translating section from the source to the RFQ made of two bending magnets. Focusing is provided by Einzel electrostatic lenses. The first bending magnet separates most of the unwanted charge states and other species from the beam. They are removed by means of a slit having a variable aperture.

As already mentionned, input matching conditions to the RFQ2 are very different from the primary RFQ1 ones and have required additionnal optic elements. An extra Einzel lense was calculated to be located as close as possible to the entrance of the RFQ structure: it is called L5.The optics calculations were done using a beam enveloppe code like TRANSPORT and a multiple particle beam code to check to the aberrations since the beam could be wide in some lenses and especially in L5 [4].

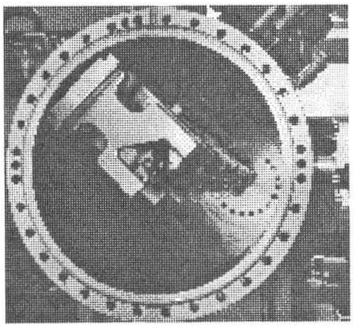

Fig 1 :

Figure 1: is a view of the structure from the exit: it can be seen at the rear the low energy part of the cavity where the tank has been manufactured in such a way that the vacuum chamber which houses the L5 lens is mechanically tight to the tank to get a perfect alignment and to shorten the distance between this lense and the structure.

Both the tank and the last chamber of the LEBT have the same pumping system. This chamber, that also contains beam diagnostics which allow to check the beam entering the RFQ, is pumped down through the visible holes.

3-2- High energy beam optics.

At the exit of the RFQ, the beam is not diverging in both planes but converging in the horizontal plane and diverging in the vertical plane. This situation which seemed better in appearence turned out to be troublesome because the convergence is so strong that the waist occurs after a few centimeters.

A triplet lens was designed to handle the beam in order to match it to the debuncher which presents a restricting aperture and to the rest of the existing transport line. Figure 2 shows the RFQ , the triplet and the debuncher. Different sets up of the quadrupoles are needed whether the debuncher cavity is on or off [5]. No room was available to install steering dipoles in this part of the line and we designed extra windings placed close to the poles of the quadrupole triplet to provide dipole components.

After 10 meters of transport, the beam is analyzed with a 51° bending magnet: it allows, i- to separate the species (charge and mass), ii-to tune the debuncher ,iii- to measure the energy spread of the beam

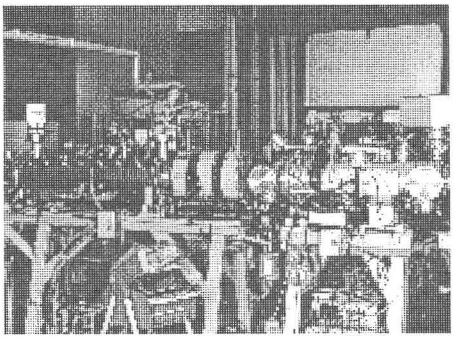

Fig 2: view of the RFQ and front end of HEBT

3-3- Beam instrumentation.

In order to obtain as much information as possible, appropriate instrumentation is used: some new devices were developped for this purpose.

Beam currents are measured at the input and the output of the RFQ with retractable Faraday cups (interceptive device) and current transformers (non-interceptive device) that were put under vacuum. The beam current is also measured at other places along the transport lines like after the analyzing bending magnet. We noted that different stopping materials used in manufactoring the Faraday cups can give different secondary electron emission depending upon the kind of ions that is collected (gold seemed to be peculiar and are to be investigated). As a conclusion, attention must be paid when one uses this device and correct electron suppresser voltage is required.

Tunable slits are setted in the LEBT to remove the unwanted ions and also to limit the transverse emittance.

Profile monitors (multi-wire collectors) are also intensively used all along the transport lines, leading to a good knowledge of the beam dimensions and positions in both horizontal and vertical planes. As already pointed out beam alignment and beam sizes in electrostatic lenses are crucial, so steering stations combining either electrostatic dipoles or magnetic dipoles with profile monitors are placed in front of, and behind the RFQ2 accelerator.

The momentum analyzing station, located behind the RFQ uses the same kind of multi-wire profile monitor and a slit, leading to a resolution of $\Delta W/W = 9.10-4$.

Two emittance measuring stations have been designed. They are identical in their principle and located at the entrance and exit of the RFQ. They can measure the horizontal or the vertical emittance, but since the apparatus is costly, we unfortunately have to dismount it from a place to another one when needed. The basic principle of the measurement which uses a slit and a multi-wire collector, stepping across the beam is wellknown, but it is worth to know that the wire spacing is only 300 μm in our case .This leads to a high definition of the core of the beam and the results give excellent informations on the aberrations and the brilliance of the beam.

The measurement is fully computerized on a PC station and is transportable. Software was especially designed for conviviality with the operator and is very interactive. The measurement is very accurate and the speed depends upon the statistics that one wants. Rough measurements are also possible by changing the stepping across the beam . Typical step value is 200 μm [6].

4. COMMISSIONING OF THE RFQ

The commissioning included 3 stages.The first one concerned the RF cold tests and the powering at low RF level of the cavity (required power to accelerate ions of q/A=0.5) and of powering the debuncher (100W). The second stage was dedicated to beam tests with ions of q/A=0.5 (nitrogen ions N 7+ have been chosen). The last stage concerns the powering of the RFQ at maximum RF power, scalled from the results of stage 2, and capable later on to accelerate ions of q/A=0.25. Both first and second stages were made with the attendance of the designer A. Schempp.

4-1-Low RF level tests

We started with cold test measurements of the Q value and of the resonance frequency which can be adjusted with a plunging motorized tuner. Q0 value, measured at 3db, is 2800. Flattening of the longitudinal fiekd, already done at the manufacturer home, was checked again.

It was followed by DC conditioning, without water cooling , up to about100W.

Then AC conditioning at 10Hz was performed and 100kW was reached in one day work, by raising step by step the RF power and controlling the outgassing. Cautions were taken during the manufactoring to get very clean surfaces and previous tests concerning the outgassing of the copper deposit were done before approval of the process.

During conditioning , the vacuum pressure stood at 6.10-7 torr and real behaviour showed up at 120kW. Consequently, repetition rate was gradually reduced to 2 Hz and powering to 140 kW was obtain after a few days without any more trouble.

4-2- Beam tests

The first tests have been performed with N 7+ and the only real encountered difficulties concerned the radial matching and the steering in the LEBT. Transmission efficiency started at 60% for 48 kW of RF power. Maximum efficiency of 80% was obtained with 67 kW.

First beam was accelerated in the MIMAS ring one month later and Kr 26+ (ε=0.31) was delivered to physics in december 1992.

input emittances (90 % of beam current)
Eh =150 π mm.mrad
Ev =150 π mm.mrad

output emittances (90 % of beam current)
Eh =60 π mm.mrad
Ev not yet measured
$\Delta W/W = \pm 1.510 - 2$ without debuncher
$\Delta W/W = \pm 0.910 - 2$ with debuncher
transmission efficiency > 80%

4-3- High power tests

Powering to the maximum level took longer time since we had to compensate the smaller transmission efficiency for low values with more RF power. We also decided to check the flattening of the field but no test on asymetry were done. The L5 lense was redesigned and preferred to solenoid for costs reasons, and depolarization of lithium beams[7].

It took 2 months to reach 250kW, even if the accuracy in power measurement is 10% . X ray emission showed up forcing us to protect the persons against it with a 3 mm thick lead coverage. This X-ray emission corresponds to the signature of conditioning which is attained only after sparking effects. 300 kW of input power was required to get linear proportionnality between the field inside the cavity versus the input power.

6. CONCLUSION

It was almost a bet to design, construct, test and use successfully for physics the RFQ2 ordered one year earlier. Acceleration of Kr 26+ was obtained in december 92. RF conditioning to the maximum required power took longer since more power than expected by scaling from q/A=0.5 to q/A=0.25 was needed.

Measured transmission, emittance and energy spread are in agreement with the calculations. The major goals have been achieved and the RFQ2 proved to be a very reliable and fexible linear accelerator capable of operating in the wide range of conditions with minimum care and maintenance.

Au 50+ ($3.5 e\mu A$), Xe 33+ ($9. e\mu A$), and Fe 20+ ($7. e\mu A$) were successfully accelerated this year.

Investigations are carried on the apparent degradation of the Q value at high RF power, surrely not due to heating of the structure because of the very low duty cycle. Nevertheless sparking when occurs is never destructive but seems to ease for later on conditioning.

Acknowledgements

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