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IMPROVED PERFORMANCE OF THE MUNICH HEAVY ION POSTACCELERATOR

E. Nolte, R. Geier, U. Ratzinger, W. Schollmeier,
S. Gustavsson, N. Gärtner and H. Morinaga
Fachbereich Physik, E17, Techn. Universität München, Germany

Abstract

Improvement of the shunt impedance and of the phase acceptance of the Munich heavy ion post-accelerator are described. The shunt impedance has been increased by using slimmer drift tubes, by mounting more drift tubes and by installing a drift tube configuration with flat gap voltage distribution along the resonator axis. The phase acceptance has been increased by means of a three-harmonics double-drift buncher on the high-energy side of the tandem. The phase acceptance of the system buncher-booster is about 70%.

Introduction

In order to increase the energy of the heavy ion beams from the Munich MP tandem, a post-accelerator after the tandem is used successfully since seven years. The booster is a linear rf accelerator of the Interdigital H-type structure [1-3]. Such structures have very high shunt impedances which in the velocity range from 0.05 c to 0.10 c are by more than a factor three larger than those of other competing normal-conductive accelerators.
The aim of the present work was a further increase of the shunt impedance of our IH structure in order to obtain higher accelerating voltages. The shunt impedance can be increased by reducing the effective capacitance of the cavity and by reducing the power losses of the rf currents in the resonator walls.

Since the maximum negative ion currents injected into our tandem are restricted by the life time of the carbon stripper foils in the terminal, the other aim was the increase of the intensity of the postaccelerated beams by installing a more efficient buncher. The ideal modulating voltage is saw-tooth shaped. The bunching of the beam can be achieved on the low (LE) or the high energy (HE) side of the tandem. If the buncher is installed on the LE side, a beam monitor is needed on the HE side of the tandem in order to control the phase of the beam bunches. This monitor is necessary because of the long drift times of the low-velocity ions, because of instabilities of the injector power supplies and of the accelerating field gradients in the tandem. In the case of a HE buncher, a beam monitor is not needed. Since our facility MP tandem-postaccelerator is also used for accelerator mass spectrometry, i.e. for the detection of microscopic beams, the use of a beam monitor would be difficult. Therefore and because of the long actual drift path tandem-poststripper-postaccelerator and because of the resulting time spreading of the LE bunched heavy ion beams between poststripper and postaccelerator, in our case the buncher is installed on the HE side of the tandem. (For other types of experiments, e.g. with ultrashort beam pulses, the chopping and bunching system on the LE side of the tandem is also used [1-3]). The needed voltages are provided by resonant circuits. Because of the high quality factor, it is not possible to apply a saw-tooth voltage in one single resonator. A saw-tooth shaped voltage, however, can be obtained by a superposition of several harmonics according to a Fourier analysis.

In this contribution, we describe the increase of the shunt impedance as a result of a constant gap-voltage distribution, the construction of a three-harmonics double-drift buncher, which approaches the saw-tooth shape by the superposition of three harmonics and the use of a drift path between the resonators, and the experience with the postaccelerator.

The Beam Line System

Fig. 1 shows the beam line system of the heavy ion postaccelerator at the Munich MP tandem. The booster is installed in the 10 degree line of the first switching magnet. The poststripper is positioned close to the image slits of the tandem analysing magnet. The HE buncher is in the 10 degree line about 20 m before the booster. The postaccelerated ion beams are analysed by means of an achromatic beam deflection system consisting of two 90 degree magnets and a magnetic quadrupole singlet in the symmetry plane of the achromator.

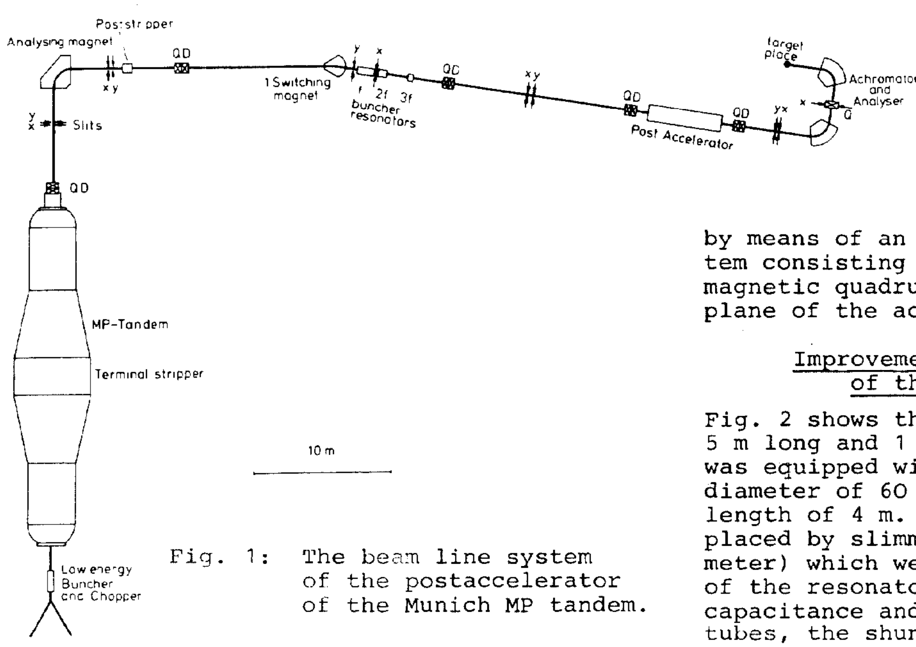

Fig. 1: The beam line system of the postaccelerator of the Munich MP tandem.

Improvement of the Shunt Impedance of the Postaccelerator

Fig. 2 shows the postaccelerator tank. It is 5 m long and 1 m in diameter. Originally, it was equipped with drift tubes with an outer diameter of 60 mm which were mounted over a length of 4 m. These old drift tubes were replaced by slimmer drift tubes (40 mm in diameter) which were mounted over the total length of the resonator. Due to the reduced resonator capacitance and the large number of drift tubes, the shunt impedance $Z \cdot T^2$ (T transit

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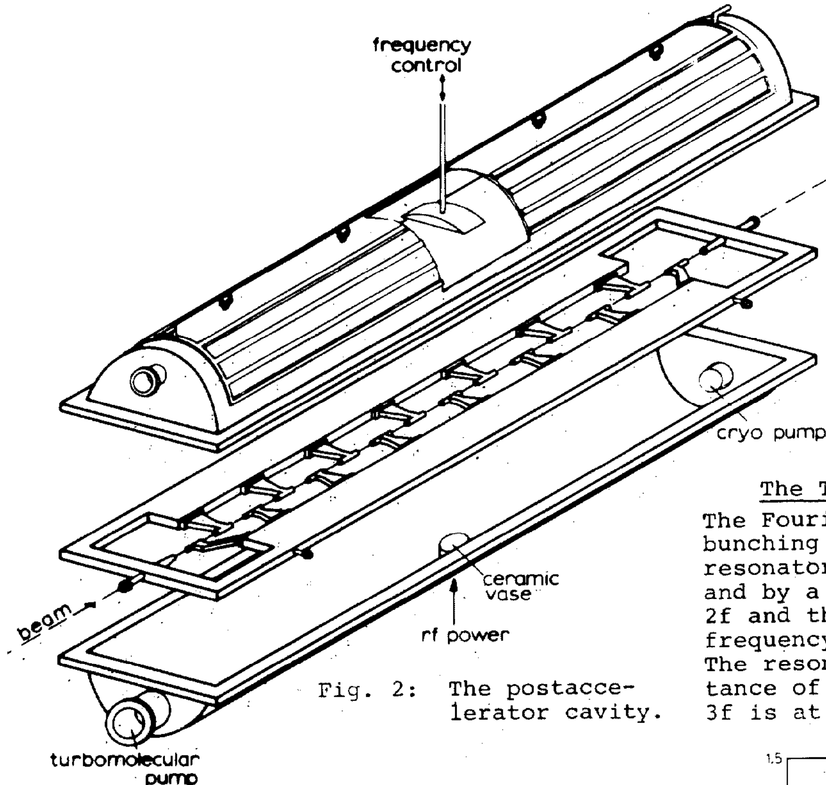

Fig. 2: The postaccelerator cavity.

time factor) increased from $Z\cdot T^2 = 14\ M\Omega/m\cdot\beta^{-0.83}$ to $Z\cdot T^2 = 18\ M\Omega/m\cdot\beta^{-0.83}$ ($\beta=v/c$, v mean particle velocity, $0.05 \le \beta \le 0.10$) [1-3].
These values of the shunt impedance were obtained for equal lengths of drift tubes and gaps, i.e. for g/L=0.5 (g gap width, L periodic length). The resulting distributions of the gap voltages and of the rf wall currents were then strongly peaked in the first half of the cavity since the resonator capacitance was mainly concentrated there because of the larger number of gaps and the smaller gap widths there. This peaked current distribution caused unnecessary power losses.
The gap voltage distribution could be flattened by reducing the gap capacitance at places of high gap voltages and by increasing the gap

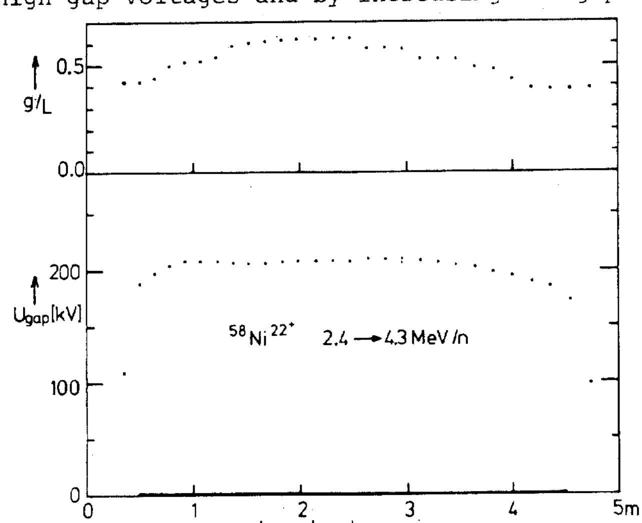

Fig. 3: Gap voltage distribution and ratio g/L along the resonator axis (g gap width, L periodic length).

capacitance at places of low gap voltages by means of varying the ratio g/L. How well this procedure functions is seen from fig. 3, where the gap voltage and the ratio g/L are plotted along the resonator axis. By varying g/L in the range from 0.4 to 0.6, it was possible to obtain a gap voltage distribution which is flat within ±10%. Caused by the mounting of the end drift tubes, the induced voltages of the end gaps are half of that of the other gaps. By this way, the shunt impedance increased to $Z\cdot T^2=19\ M\Omega/m\cdot\beta^{-0.83}$. E.g., for a mean particle velocity of $\beta=0.1$, the shunt impedance is as high as 130 MΩ/m.

The Three-Harmonics Double-Drift Buncher

The Fourier analysis of the saw-tooth shaped bunching voltage was achieved by three buncher resonators with the frequencies f, 2f and 3f and by a drift path between the resonators f, 2f and the resonator 3f [4]. f is the resonance frequency of the booster and is about 80 MHz. The resonators f and 2f are both at a distance of 20 m from the booster, the resonator 3f is at a distance of 17.5 m from the booster.

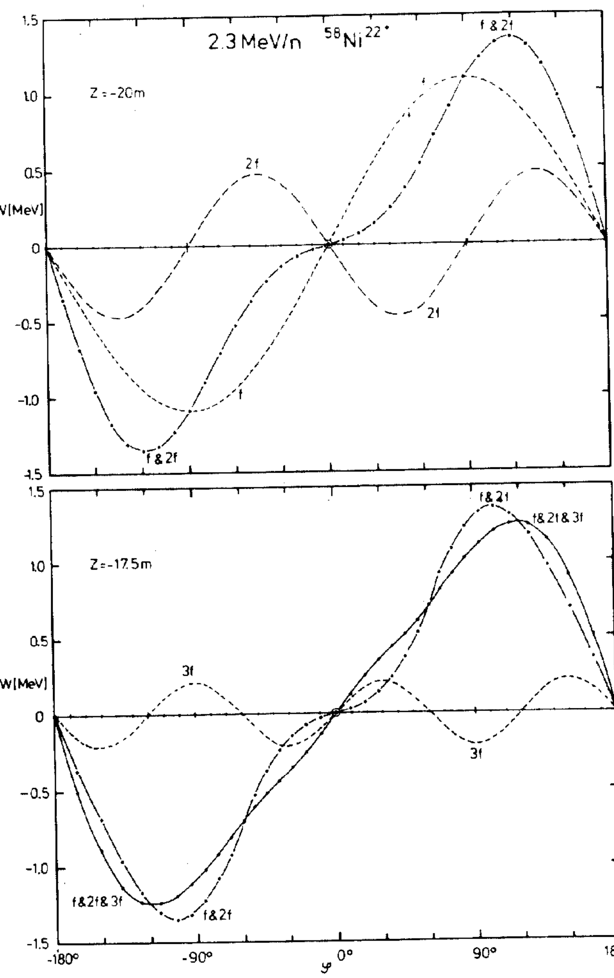

Fig. 4: Energy modulation of the beam by the three-harmonics double-drift buncher in the energy-phase plane at the place of the resonators f, 2f (z=-20 m) and at the place of the resonator 3f (z= -17.5 m).

The buncher cavities are tunable $\lambda/4$ coaxial resonators. Fig. 4 shows the energy modulation of the beam in the energy-phase plane at the places of the resonators f, 2f (z= -20 m) and of the resonator 3f (z= -17.5 m). The resulting modulation of the beam by all three harmonics is shown as a solid line. It is seen that the functional dependence is almost linear over the wide range of 270°.
About 70% of the beam intensity are thus accepted by the booster.

Operation of the Postaccelerator

The postaccelerator has been used for seven years in standard beam time operation for about 20% of the tandem beam times, corresponding to more than 4000 h of operation. It showed up to be very reliable. There was no serious breakdown of the booster. Table 1 gives a survey of the postaccelerated ion beams. Beams from oxygen up to germanium were postaccelerated. Caused by the high shunt impedance of the booster, the needed rf power input is moderate. For an accelerating voltage of 5 MV, e.g., the rf power input is only 34 kW.

By means of the combination LE chopping and bunching system - HE buncher - postaccelerator, bunched beams with widths of subnanoseconds up to seconds were obtained.

Future Developments

When an accelerating structure is scaled up or down, the shunt impedance varies with $x^{-1/2}$, where x is the scaling factor. From the point of view of the shunt impedance, the structure should be as small as possible. The beam hole diameter of our actual drift tubes is 30 mm. For short accelerators with lengths below 3 m, it seems possible to us to use beam hole diameters of 15 mm. We plan, therefore, to add to the existing booster a new structure which is half-scale with respect to the diameters of the tank and of the drift tubes and which has a length of 3 m. The resonance frequency of the new structure will be 2f, i.e. twice the value of the old cavity. For identical ion velocities, the product of shunt impedance and resonator length of the 2f-booster, which is inversely proportional to the rf power input, is expected to be by a factor 1.2 smaller than that of the f-booster.

Table 1 Postaccelerated heavy ion beams

beam	source current [nA]	tandem voltage [MV]	charge state tandem postacc.	beam energy [MeV] tandem postacc.	postacc. voltage U·T [MV]	rf power [kW]	target current [part.nA]
^{18}O +)		9.8	$4^+ \longrightarrow 7^+$	44 ⟶ 78	4.8	31	
^{36}S +)		9.8	$8^+ \longrightarrow 14^+$	88 ⟶ 155	4.8	31	
^{40}Ca	100	9.9	$9^+ \longrightarrow 16^+$	98 ⟶ 173	4.7	30	2
^{46}Ti	20	11.3	$9^+ \longrightarrow 18^+$	113 ⟶ 199	4.8	31	0.4
^{58}Ni	100	12.0	$11^+ \longrightarrow 22^+$	142 ⟶ 250	4.9	33	2
^{60}Ni	100	12.4	$11^+ \longrightarrow 22^+$	146 ⟶ 259	5.1	36	2
^{64}Ni	100	12.1	$12^+ \longrightarrow 22^+$	157 ⟶ 276	5.4	40	1
^{70}Ge	100	12.4	$13^+ \longrightarrow 24^+$	171 ⟶ 302	5.4	40	0.4
					6.6	60	

+) guide beam for microscopic ^{36}Cl beams.

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