The 7-Gap Resonators for the High Current Injector of the Heidelberg Test Storage Ring TSR

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Abstract

A High Current Injector for the TSR at MPI für Kernphysik is under construction. As a part of the injector eight 7-gap resonators with high shunt impedance are being developed. These resonators (f_0=108.48 MHz) are designed for the synchronous velocities of β_s=3.7%, 4.5%, 5.1% and 5.7%. Low power models with scaling factors of 1:2.5 were built in order to study the characteristics of these new resonators. Following low level measurements to optimize the voltage distribution and eigenfrequency, a power resonator was built and successfully tested at 80 kW (duty cycle of 25%). At this power, a maximum resonator voltage of 1.75 MV was reached. This paper describes the design of the resonators and gives some details of measurements.

1 INTRODUCTION

Laser cooling experiments with ultra cold beams [4] of $^9Be^+$ and $^7Li^+$ are limited by the low currents delivered from the tandem accelerator. The injection currents of $^7Li^+$ and $^9Be^+$ ions, usually less than 1μA, can only be accumulated by multiturn injection in the storage ring, resulting in an increase in intensity by at most a factor of 10.

A new injector, consisting of a CHORDIS ion source[5], two RFQs [3] and eight 7-gap resonators [1] presently under construction will result in an increase of the stored Li^+ and Be^+ - currents by factors up to 1000. In figure 1 the layout of the injector is shown.

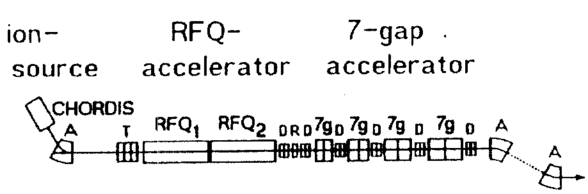

Figure 1: *The scheme of the high current injector. T= quadrupole triplet, D=quadrupole doublet, 7g=7-gap resonators, A=deflection magnet, R=rebuncher*

2 LAYOUT OF THE 7-GAP ACCELERATOR

Based on the proven design of the normal conducting Heidelberg 2-gap Spiral Resonators [6] of the postaccelerator, other types of resonators with two or six spirals, providing three or seven accelerating gaps have been developed [1, 2]. The lack of flexibility due to the transit time factor curve is compensated by an increased shunt impedance resulting in a much higher effective accelerating voltage per resonator. Based on measurements for a high velocity prototype of a 7-gap resonator, an effective accelerating voltage of 1.4 MV for a low β-resonator, operating at 80 kW rf power with 25% duty cycle is expected. The design aim of the new high current injector is in a first phase an output energy of 13.7 MeV (β=6.4%) for $^7Li^+$ and 9.7 MeV (β=4.8%) for $^9Be^+$. Assuming an injection energy of 0.5 MeV/u from the RFQ these energies can be reached with eight resonators for Li^+ or four resonators for Be^+. To simplify construction, four pairs of identical resonators were designed following the velocity profile of the accelerated ions.

Beam dynamics calculations have been done to match the injection of the beam from the RFQ and to optimize the acceptance of the linac. Based on these calculations, the resonators will be arranged in four modules, each module consisting of two resonators and one quadrupole doublet (see figure 1). The synchronous velocities are about 3.7%, 4.5%, 5.1% and 5.7%. An acceptance of 40 π mm mrad was calculated with this arrangement. To minimize particle losses, the matching section must include a rebuncher to compensate the time spread of the beam and two quadrupole doublets to match the beam to the linac (see figure 1). The calculated transmission is 98%.

Adjusting the output parameters of the second RFQ for injection, figure 2 shows the longitudinal and transverse phase space after the last 7-gap resonator.

3 THE LOW POWER RESONATOR

Construction of a low power resonator scaled 1:2.5, was required for optimizing the field distribution and shunt impedance as well as for the adjustment of the eigenfrequency

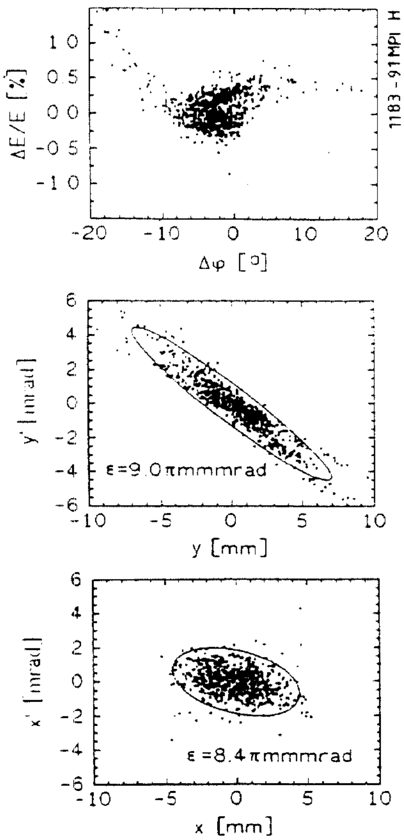

Figure 2: *Longitudinal and transverse phase space of the beam after the 7-gap resonators*

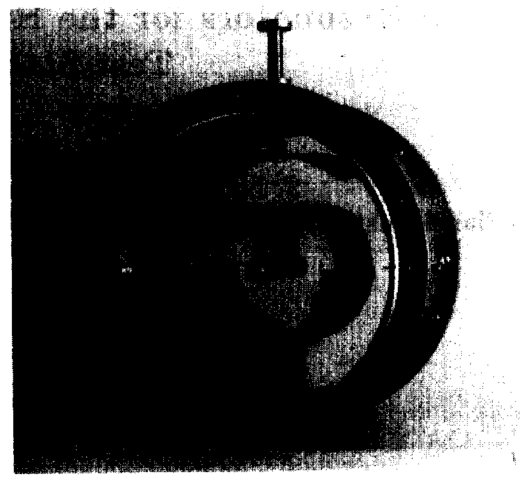

Figure 3: *The low power model with a scaling factor of 1:2.5*

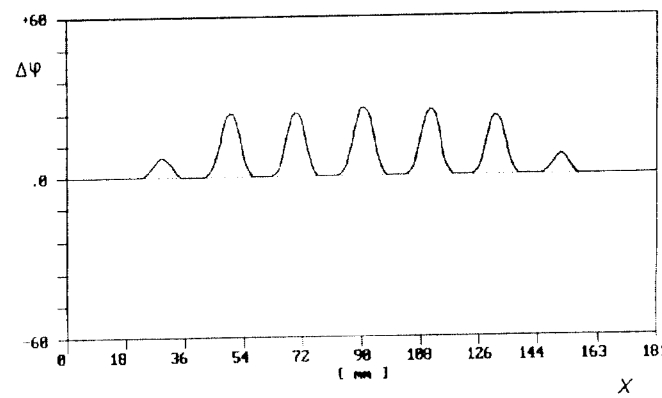

Figure 4: *Phase distribution of the push pull mode*

to 108.48 MHz. The low power resonator is shown in figure 3. In contrast to other multi-gap resonators, which are basically composed of identical spiral resonator arms, the 7-gap resonator has a single resonance structure.

The resonance structure consists of a copper half shell with three arms attached on both sides. Drift tubes are added to the ends of the spiral arms. Consecutive drift tubes have opposite potential.

The field distribution in the gaps, the eigenfrequency and the shunt impedance have been optimized by rotating the circular part of the copper arms within the half shell. Due to this special design, tuning does not affect the alignment of the drift tubes along the beam axis.

Figure 4 shows a spectrum of the symmetrical field distribution at the required eigenfrequency taken by the bead perturbation method, where the phase shift $\Delta\varphi$ between resonator and generator signal is measured as a function of the location of the bead in the resonator. From this phase shift, the amplitude of the electric field and the shunt impedance of the full scale resonator can be calculated by low level measurements at the model resonator.

When tuning the resonator to the push pull mode at the required frequency, attention must be paid to other modes near to the push pull because of mixing effects. The six arms with drift tubes correspond to six coupled oscillators and produce closely spaced modes. The nearest mode to the push pull mode differs in frequency by more than 13 MHz and no mixing effects were observed.

A tuning plate (see figure 3) opposite to the arms was added to compensate for frequency shifts due to temperature changes. A frequency range of ± 2.5 MHz can be reached by moving this plate. For the full scale resonator, a range of ± 1 MHz is expected.

Copper segments are fixed at both ends of the half shell to correct for frequency shifts due to small construction tolerances. These segments can compensate frequency deviations of up to ± 5 MHz (respectivly ± 2 MHz for the power resonator) without changing the shunt impedance and field distribution.

At the low power resonator a shunt impedance of 170 $M\Omega/m$ was measured.

4 THE POWER RESONATOR

A full scale power resonator was constructed based on the results of the bead perturbation measurement. Figure 5 shows the open resonator. Segments on both sides of the half shell allow tuning of the resonator to the required eigenfrequency of 108.48 MHz. The tuning plate, extending into the resonator from below, is clearly visible.

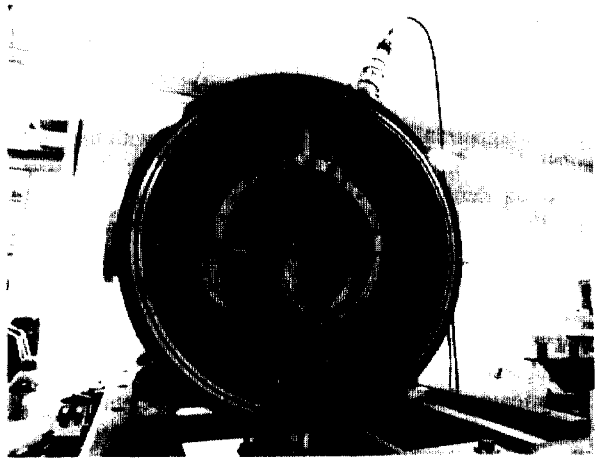

Figure 5: *The power resonator with segments at the half-shell and the tuning plate*

RF power is coupled into the resonator at one of the three legs which connect the resonance structure to the tank, where the magnetic field is maximal. An input power of about 80 kW generates a maximum voltage of 1.75 MV, which agrees to the calculated shunt impedance from the low power resonator.

Further power tests were carried out with up to 100 kW rf power at a duty factor of 25%. Neither ponderomotive forces nor multipactoring problems have been observed. The tuning plate was able to compensate for all eigenfrequency shifts due to variation of temperature. The following table summarizes the characteristic parameters of the 7-gap resonators.

frequency	f	108.48 MHz
quality factor	Q	5000
shunt impedance	Z	100 MΩ/m
maximum rf-power	P	80 kW (1:4)
maximum resonator voltage	U_0	1.75 MV
effective accelerator voltage	U_{eff}	1.4 MV
length	L	0.4m - 0.7m
drift tube diameter	r	20 mm

5 OUTLOOK

After the successful testing of the first full power resonator, tuning of the remaining three low power prototypes is nearly complete and construction of the remaining power resonators has already begun.

In the second phase, an ECR source can be added to the high current injector to accelerate highly charged heavy ions. The 7-gap resonators of the high current injector are designed in such a way that the output beam can direcly inject into the existing post accelerator for further acceleration. This will allow high current acceleration to energies above the Coulomb barrier of heaviest elements.

6 ACKNOWLEDGEMENT

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