BEAM DYNAMICAL ASPECTS OF THE POWER ENHANCEMENT FOR THE 150 MHZ RESONATORS OF PSI INJECTOR 2

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In the PSI Injector 2, the number of turns has been reduced from 85 to 82 by almost doubling the RF-power fed to the 150 MHz resonators. This results in a reduced beam emittance of the extracted 72 MeV proton beam. As a consequence, a substantial reduction of the crucial losses in the extraction region of the 590 MeV Ring cyclotron could be achieved. This modification was one of several essential steps to raise the beam intensity to 2 mA.

INTRODUCTION

The PSI Injector 2 is equipped with four accelerating RF-structures; two resonators at 50 MHz and two at 150 MHz. The latter were originally used in decelerating mode as part of a flattop system. Ten years ago, the flattop system became obsolete. Above an intensity of 0.7 mA, the space charge forces induce a self-stable rotational well [1, 2], which transforms the beam bunch into a round charge distribution in the mid-plane. Such a round shape corresponds to a very narrow phase width of less than two degrees. Switching off the 150 MHz resonators reduced the number of turns from 99 to 92. Their use in accelerating mode yielded another reduction to 85 turns. The recent increase of the voltage in these resonators resulted in a further reduction to 82 turns.

MOTIVATION OF VOLTAGE ENHANCEMENT

Fig. 1 shows the voltage distribution as a function of radius inside both the 50 MHz (main) resonators and the 150 MHz resonators. The 50 MHz voltage distribution shows a peak voltage steadily growing with larger radius. The 150 MHz resonators show a cosine like half wave distribution forming an amplitude maximum at half way without any significant contribution to beam acceleration in the injection and extraction regions.

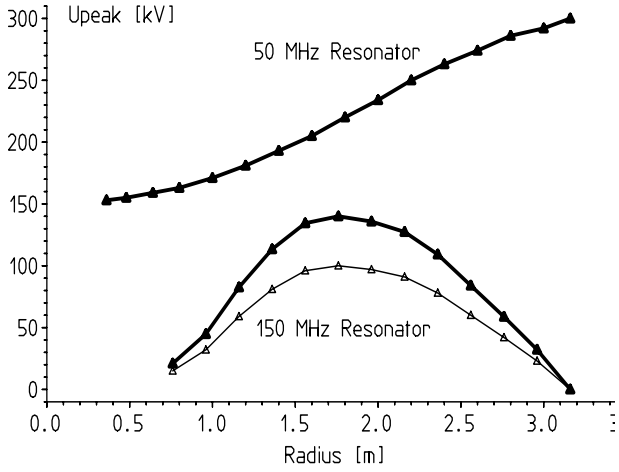

Fig. 1: Radial distribution of the RF amplitudes in the two resonator types of the PSI injector 2. The bold curves show the final setting. The fine line shows the values before the power enhancement of the 150 MHz amplifiers took place.

Only a voltage raise in the main cavities would widen the gap between the last two turns. Since the extraction losses strongly depend on the width of this extraction valley, a power enhancement in the main resonators would be highly desirable. However, both main resonators already run at their outermost power level and any further raise in the RF voltage would induce damage by overheating. We must therefore strongly consider the replacement of the existing 150 MHz by another pair of 50 MHz resonators.

VOLTAGE RAISE IN THE 150 MHZ RESONATORS

A higher voltage in the 150 MHz-structures is also favorable. The charge distribution across a single beam bunch has been described in [1]. A dense core, which defines the bunch size, is wrapped by a halo of two tails which extend to twice the central bunch diameter. The velocity distribution in a bunch is such that fast particles form the outer boundary of the proton bunch and are decelerated by the focusing space charge forces whereas slow particles form the inner boundary and are accelerated. Since all bunches are aligned in the radial direction, there is a chance that slow particles leave the halo of their origin bunch and join the neighbouring inner bunch as fast particles. In a similar way, fast particles on the outer boundary move to the subsequent bunch as slow particles.

However, due to the space charge driven longitudinal focusing in Injector 2, the resulting growth in energy spread remains hidden. It is visible only after extraction, while traversing the 72 MeV beamline that transforms it into a longitudinal growth of the bunch. In the 590 MeV Ring cyclotron, where no longitudinal focusing exists, the extraction losses depend on the bunch length and therefore on the superposition of the space charge effects and of the energy spread in the injected beam.

Throughout the whole radial range, the chance of particle exchange depends on the distance between subsequent turns. Reducing the number of turns in Injector 2 therefore leads to a reduction of the tails in the energy spread and consequently to reduced longitudinal tails in the Ring cyclotron. Lower relative extraction losses allow for higher beam intensity since the absolute extraction losses have to be kept constant. The voltage raise in the 150 MHz resonators will therefore allow a raise of the extracted 590 MeV beam intensity

REALIZING THE 150 MHZ VOLTAGE RAISE

A RIE1-scan of the last seven revolutions of Injector 2 is presented in Fig. 2. The bold line shows the well established beam pattern consisting of subsequent groups of three peaks separated by a wider gap. This arrangement, created by an appropriate choice of the number of turns as well as the betatron oscillation invoked at injection, enables extraction of the 2 mA proton beam with extremely low losses.

The fine lines in Fig. 2 visualize the change of the beam cross section with varying beam current. The collimator KIP2 raises the injected beam intensity by moving its cutting edge to smaller radii. This yields a one-sided growth of the beam cross section. Horizontal focusing transforms the transversal bunch boundaries across Injector 2. At selected turns, where the local parameters match the injection values, we find a “magic valley”, whose depth remains independent of the beam intensity.

During acceleration, the beam is not centred, but oscillates with an amplitude of up to 5 mm. The oscillation phase is chosen such that, at the entrance of the electrostatic extraction element EID, it has the value of 3π/2 for the last but one turn and π/2 for the last turn. This setting provides a widening of the gap by two amplitudes. Since the scanning probe RIE1 is located half a betatron oscillation in advance, the excursions are inverted and it depicts the last valley as the narrowest one, but it becomes the widest one at the extraction point.

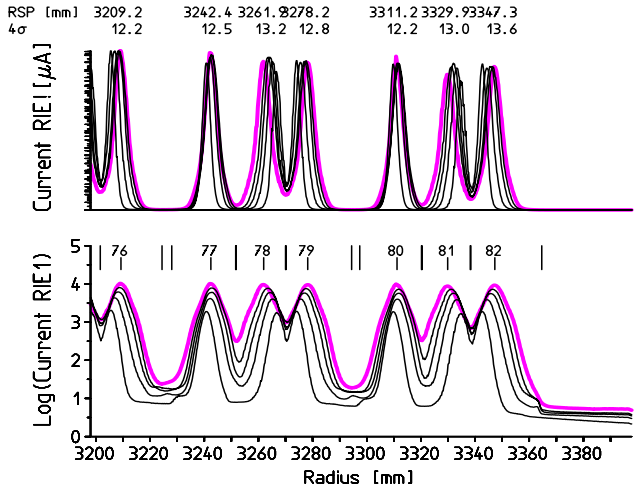

Fig. 2: Charge density dependence of the last seven turns in Injector 2 (steps of 0.4 mA). The bold line shows the pattern for 1.8 mA.

Due to the betatron frequency ν_r of 1.34 in the extraction region, we have to skip a whole group of three turns to meet similar conditions. The raise of the voltage therefore has to be performed accordingly. Since the previously available voltage level of the 150 MHz resonators yielded a reduction of seven, the enhanced setting had to provide a reduction of ten turns. To achieve this, the voltage had to be raised by a factor of 1.4, corresponding to a doubling of the power to be delivered by the amplifier [3].

YIELD

Fig. 3 shows the effect of the power enhancement on the extraction losses in the Ring cyclotron. The losses are monitored by the ionisation chamber MRI11. At the production level of 1.8 mA, the voltage enhancement reduced the losses by 30 to 40 %. After subsequent tuning of the machine, an intensity of more than 1.9 mA could be accelerated with the same absolute losses as before.

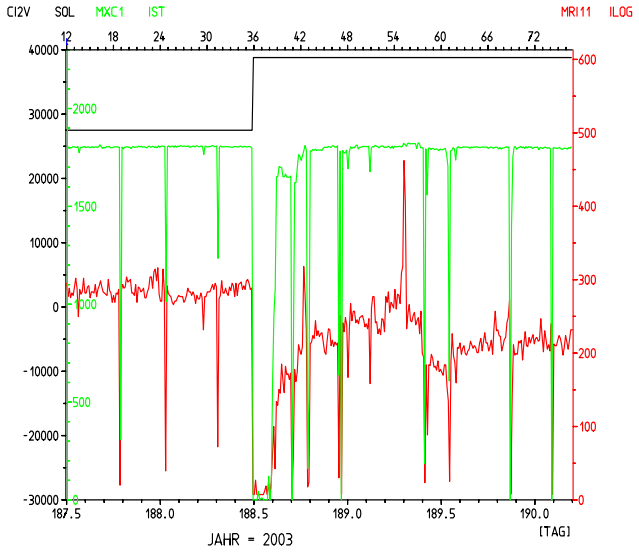

Fig. 3: Data logging of the power enhancement. The top line marks the resonator voltage step. The intermediate line shows the proton current, which was tuned for 1.8 mA. The bottom line displays the beam losses represented by the monitor MRI11.

CONCLUSIONS AND OUTLOOK

Reduction of the number of turns in Injector 2 improves the quality of the beam delivered to the Ring cyclotron. The replacement of the 150 MHz resonators by 50 MHz will be an essential step to prepare Injector 2 for acceleration of a beam suitable to produce intensities beyond 2 mA at 590 MeV.

ACKNOWLEDGEMENTS

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