TUNING OF THE PSI 590 MeV RING CYCLOTRON FOR ACCEPTING AND ACCELERATING A REBUNCHED 72 MeV PROTON BEAM

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Abstract

In the past year the production of a 1.42 MW proton beam at a relative loss level of 10^{-4} at PSI's high power proton facility became routine operation. In addition, the inaugurated buncher based beam injection into the 590 MeV Ring cyclotron made a remarkable step forward. In particular, an almost dispersion free setting of the beamline region around the 500 MHz rebuncher in the 72 MeV transfer line has been established and a perfect matching of the dispersion into the Ring cyclotron has been achieved. This buncher-operation optimized facility setting could be advanced up to the ordinary stable standard 2.2 mA production proton beam. With the buncher voltage turned on, at the moment the beam, extracted from the Ring cyclotron is limited to below 1 mA due to raising losses, mainly generated by space charge induced distortions of the beam bunches. For a better understanding of these effects a substantial effort in modelling of the accelerated beam is under way. In particular, the influence of the trim coil fields is partly implemented into the OPAL simulation code and the insertion of an additional bunch shape monitor in the Ring cyclotron is proposed.

INTRODUCTION

PSI's three stage accelerator facility is on the way to reach proton beam currents beyond 3 mA [1]. To achieve higher intensities longitudinal and transversal effects have to be considered. In transversal direction the gap between the last two turns can be broadened by raising the voltage of the RF amplitude yielding a reduction of the number of turns. Along propagation direction in contrast the bunch length will reach the boundaries of the phase acceptance of the Ring cyclotron at about 2.7 mA despite the installed flattop system. In order to longitudinally shrink the bunches a rebuncher [2] has been inserted in the middle of the transfer line between Injector 2 and the Ring cyclotron. The diagnostic elements involved in the tuning of the Ring cyclotron for the acceleration of the bunched beam are shown in Fig. 1.

DEMANDING MATCHING CONDITIONS

The beam bunches leave the Injector 2 at a phase width of 1.5 RF-degrees. While travelling across the 56 m long 72 MeV transfer line to the Ring cyclotron the bunches elongate to a 4σ phase width of 40 RF-degrees. Due to the high charge density the acceleration of the rebunched beam imposes stringent boundary conditions on the beam properties in the buncher region and for the matching of the beam at the injection into the Ring cyclotron.

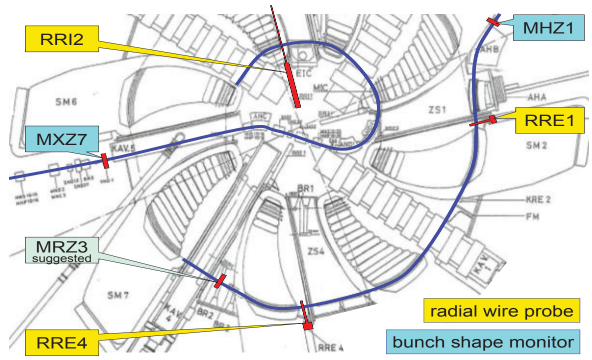

Figure 1: Bunch shape monitors and radial wire probes involved in the tuning of the PSI Ring cyclotron for the acceleration of a bunched beam. The proposed new time structure probe MRZ3 is labelled in mint.

Dispersion Free Section at the Buncher Position

In a matched beam, each particle moves along the equilibrium trace corresponding to its velocity. While crossing the buncher the slow particles are converted into fast ones and vice versa, but leave there position unchanged, yielding the fact, that the particles start to oscillate around the equilibrium trace according to their obtained velocity. To avoid this effect the dispersion D and the dispersion gradient D' have to remain zero in the buncher surroundings. This condition has been achieved in the 72 MeV Beam line by optimising the R-matrix elements r16 and r26 of the initial beam conditions and by adjusting the first quadrupole triplet QXA1/2/3 at the beginning of the beamline (Fig. 2).

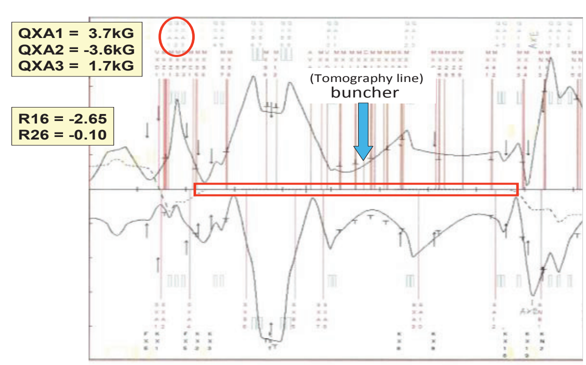

Figure 2: TRANSPORT-fit of the 72 MeV-transfer line with dispersion free buncher region.

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Fine Modelling of the Matching into the Ring

The injection into the Ring cyclotron has been modelled carefully by means of TRANSPORT [3] calculations. To check the accuracy of the fitted dispersion line, we make use of the fact, that the phase of the emittance-rotation along the first turn can be split into sections that correspond to the phase advance from one turn to the other in the accelerator. Hence, the accuracy of the dispersion fit can be verified by varying the injection energy into the Ring cyclotron and measuring the radial shift of the peaks shown by the radial wire probe. This displacement must match the fitted transversal displacement monitored by the dispersion line in the TRANSPORT fit.

Proper Matching of the Beam into the Ring

The verification of the (not proper) matching of the high intensity production setting of the 72 MeV transfer line is shown in Fig. 3. Because of the mismatch the fit shows an excursion of the dispersion line, stretched over the eight sector magnets. The verification yields a congruent superposition at every 8th turn since Qr equals 1.12 in the injection region. By optimizing the initial beam conditions and by adapting the quadrupoles in the transfer line a TRANSPORT-fit of a properly matched injection into the Ring was calculated. The verification of this calculation is displayed in Fig. 4. The measured current of the radial wire probe shows an equidistant shifted peak pattern as a function of the varied injection energy.

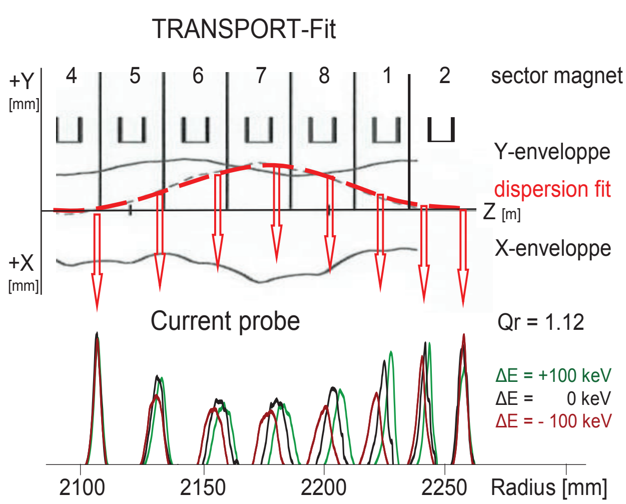

Figure 3: TRANSPORT fit of the dispersion line and radial wire probe scan of three injection energies at the common high intensity production setting. The exact superposition at the first and at the 8th turn corresponds to the Qr of 1.12 in the Ring injection region.

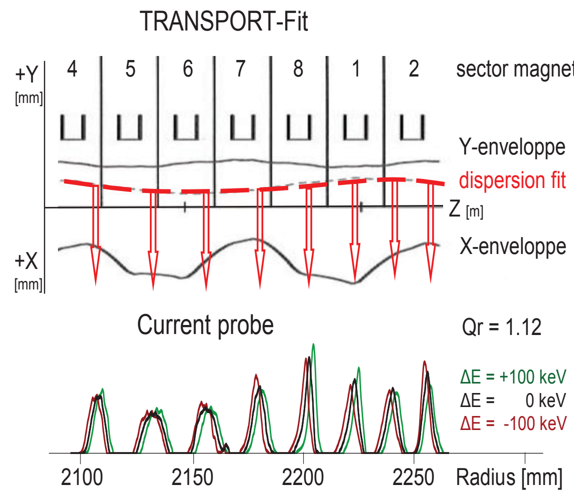

Figure 4: Proper dispersion matching of the beam injection into the Ring cyclotron. In the matched state an injection energy variation yields a uniform displacement of all turns of the radial wire probe scan.

The method can be used as well for the verification of the envelope fits. The transversal momentum in the horizontal and – by use of a three wire probe [4] – in the vertical direction of each turn of the radial wire probe can be back projected into the first revolution displayed in the TRANSPORT fit. If all the 17 peaks of the wire probe RRI2 and additionally 2 times 4 peaks of two current monitors are evaluated, the accuracy of the TRANSPORT envelope fit can be checked by a very narrow grid of measured values as shown in Fig. 5.

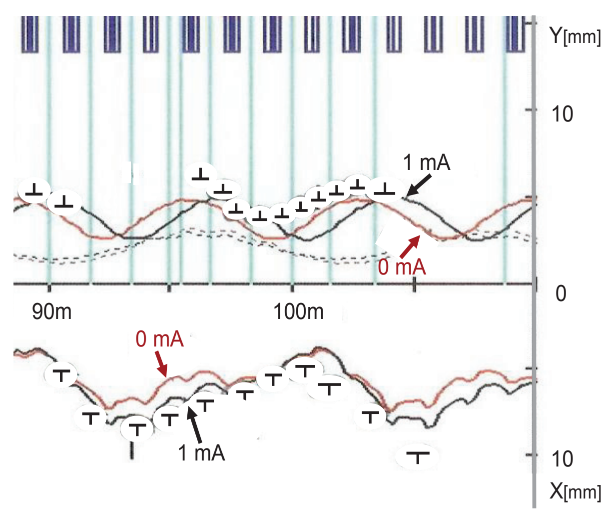

Figure 5: TRANSPORT-fit of the injection into the Ring cyclotron with back projected data of the envelopes analyzed from the peaks of three radial wire probes placed in the centre region.

CURRENT LIMITATION

Up to now the intensity of the bunched proton beam is limited to 0.8 mA despite the achieved nearby dispersion free beamline section at the buncher place and a proper envelope and dispersion matching of the beam into the Ring cyclotron. The radial wire probe at injection reveals clear signs of a mismatch yielding a "pumping" of the bunch width after turn 17 (Fig. 6). Additionally the radial three wire probe placed right before the electrostatic extraction channel EEC (Fig. 1) shows that this mismatch ends in a significant widening of the cross section yielding a growth of the losses, which are presently limiting the beam current depending on the applied buncher voltage.

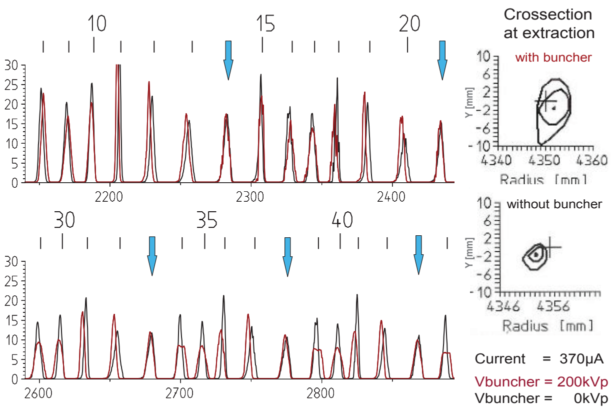

Figure 6: Superposition of radial current probe scans at the injection region of the Ring cyclotron with active (red) and inactive (black) buncher. Up to turn 17 the peaks match fairly well. Subsequently the red peaks start "pumping" and oscillating around the black ones. According to the betatron frequency that moves from 1.3 to 1.7 the peaks match exactly after every 7 to 5 turns indicating that the buncher phase is adjusted correctly.

PREPARING THE OPAL CODE DATA BASE FOR PRECISION SIMULATIONS

For a better understanding of the acceleration process the existing database for the OPAL simulation tool [5] will be significantly improved. As a result of the TRANSPORT fits and its verification by means of the radial wire probes the initial beam conditions for the injection into the Ring cyclotron are well known. In a next step the code will be prepared to mirror a real setting of the main field, means the setting of the main coils and the contribution of every single trimcoil. A test of the accuracy of this new implementation has been successfully performed with the reproduction of the asymmetric field bumps generated by individual feeding of trimcoil pairs by independent power supplies. The implementation of these field bumps allowed simulating exactly the measurements taken in 1974 at the commissioning time of the Ring cyclotron.

PROPOSED NEW BUNCH SHAPE MONITOR AT EXTRACTION REGION

In order to get longitudinal information of bunches at the extraction region a bunch shape monitor [6] labelled MHZ1 was installed after the two bending magnets AHA and AHB (Fig. 1). Due to the strong focusing layout of their pole etches the beam transversally shrinks at the probe place towards a horizontal waist and therefore shows a bunch width of about 5mm/mA independently of the beam cross section measured by the radial wire probe RRE1. To get suitable information about the beam bunch properties at extraction an additional bunch shape monitor is proposed to be installed using a flange formerly needed for the dismounted beam stopper BR2. The data taking is challenging in this environment, as the extraction region is charged by vagabonding RF power, a high DC-voltage field, and plasma clouds. But as the embodiment of the bunches is the key parameter for understanding the acceleration process and thus for being able to bear down the obstacles against achieving higher currents, it is worthwhile to invest into a probe technique that is able to manage these boundary conditions.

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