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The Beta-Beam Rapid Cycling Synchrotron

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In order to ask for physicians requests, some neutrinos facilities are under studies to produce pure, intense, well collimated neutrinos beams with a well determined energy spectrum. One of them, the Beta-Beam project, is based on neutrinos production by radioactive ion beams decay after acceleration. The paper is focused on one step of the complex, namely the low energy ring required for accumulation and injection of ion beams between the post-acceleration linac of the EURISOL complex (dedicated complex for radioactive ion beam production) and the CERN PS. Studies on the definition and the optimisation of the ring are given, starting by optical structure then differents simulations concerning beam dynamics, ie multiturn injection, synchronous acceleration with beam losses localization and intensity, fast extraction, chromaticity with eddy currents correction and space charge effects.

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1. Introduction

The Beta Beam concept for the production of pure electron neutrino (or antineutrinos) beams through the decay of radioactive ions was proposed in 2002 [1].The principles of a facility based on existing CERN machines for acceleration of radioactives ions to high energy before storage in a decay ring to be build was explored in the following months. Th objective was to do a conceptual design study covering all accelerator physics aspects to demonstrate the feasability of this facility. IPNO is one of the laboratory participating in this study, it is in charge of the design of the new low energy ring required for bunching and acceleration of ion beams before injection in the existing PS and SPS of CERN. The present paper presents the principles study of beam dynamics which have been done on this ring, the Rapid Cycling Synchrotorn of the Beta Beam [2].

2. RCS general parameters

The RCS accelerates He and Ne ion beams from 100 MeV/u to a maximum magnetic rigidity of 14.47 T.m (that is the rigidity of 3.5 GeV protons) with a repetition rate of 10 Hz. The threefold symmetry lattice proposed is based on FODO cells with missing magnets providing three achromatic arcs and three sufficiently long straignt sections for accomodating the injection system, the high energy fast estraction system and the accelerating cavities. The number of dipoles has been increased to obtain a transition energy allowing acceleration of protons up to 3.5GeV and they have been split into two parts separated by a drift space where absorbers are installed to intercept the decay products. Finally the physical radius has been adjusted to 40m in order to facilitate the synchronization between the CERN PS and the RCS and therefore the transfer of bunches from one ring to the other. As a consequence of these changes, the ring is composed of 60 short dipoles and 48 quadrupoles. A schematic view of the RCS layout is schowm in Figure 1 and the main parmeters are summarized in Table 1.

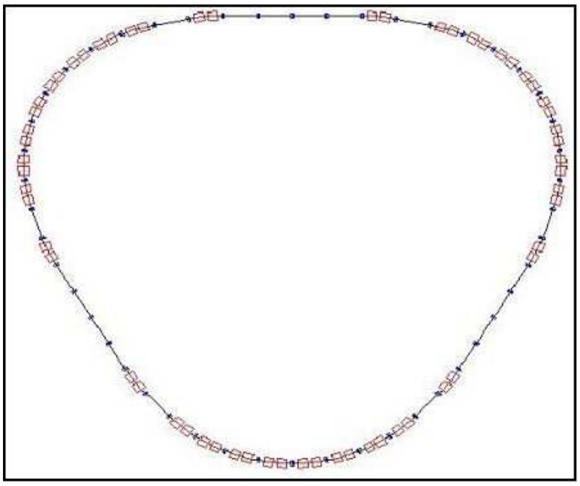

Figure 1 . Schematic layout of the ring

Circumference	251.31 m
Superperiodicity	3
Physical radius	40 m
Injection energy	100 MeV/u
Extraction energy	14.47 T.m (3.5GeV eq proton)
Repetition rate	10Hz

Table 1 . Main parameters of the ring

3. Optical design

The RCS is partitionned into 24 FODO cells, 6 in arcs and 2 in a straight section. The betatron phase advance per cell (i.e quadrupole strength) and the length of the 2 sections without dipoles in the arcs have been adjusted sa as to cancel the dispersion function in long straight sections and th obtain, with only two quadrupoles families, a working point located in a region of the tune diagram which is free of systematic resnnances up to the fourth order.Lattices function of one period calculated with BETA [3] are shown in figure 2. Dipoles are only 1.4m long in order to obtain a maximum magnetic field of 1.08T and therefore ta avoid a large ramping rate for the 10Hz operation. Quadrupoles have a length of 0.4 m and a maximum gradient of less than 11 T/m.

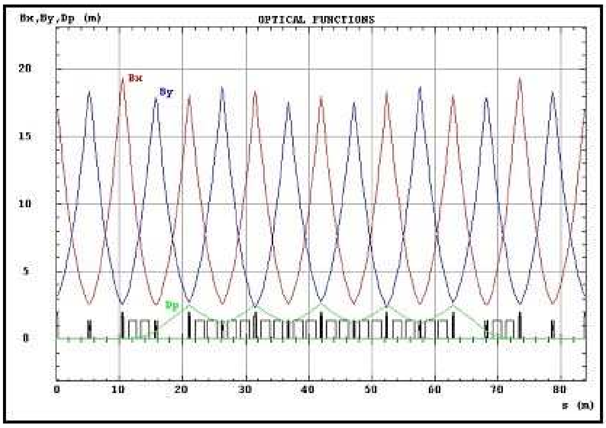

Figure 2 . Optical functions for one superperiod

The diluted transverse emittances in the RCS after multi-turn injection are calculated from the emittances required in the PS at the transfer energy with a possible blow-up of 20 %.

3. Injection

It is assumed that the ion source delivers a beam pulse of 50 μs. The revolution period of ions at 100 MeV/u being 1.96μs, the injection process takes place over several (26) turns in the machine and is therefore referred to as multi-turn injection. Ions are injected into one of the long straight section by means of an electrostatic septum and at least 2 pulsed kickers producing a local closed orbit bump which places the distorded orbit near the septum for the first injected turn and which moves it away from the septum on subsequent turns until it has collapsed and which moves it away from the septum on subsequent turns until it has collapsed. The aim of the injection process is to maximise the number of injected ions within the specified transverse emittance. Optimum filling in the horizontal phase space is achived when incoming ions are injected with a position and a slope which minimize their Courant and Snyder invariant. In the vertical phase space the dilution os obtained by a betatron function mismatch and a beam position offset. The figure 3 shows the diluted emittances in transvers phase spaces after mltiturn injection, obtained with the Winagile code. We obtain an injection efficiency of 80% after optimization.

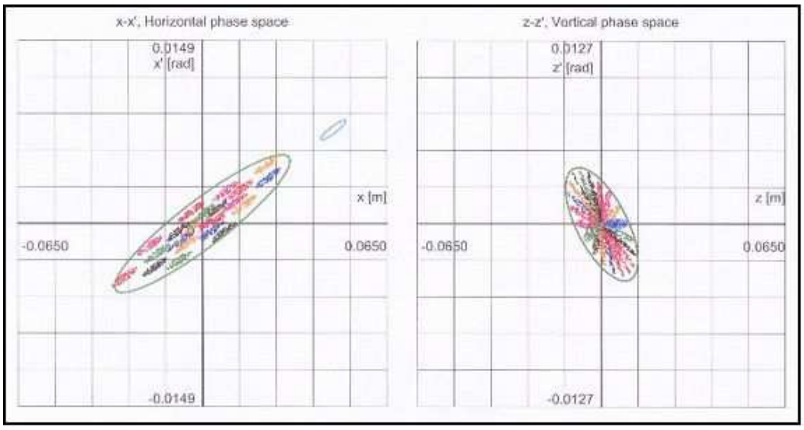

Figure 3 . Phase space distributions of the multi-turn injected beam (left : horizontal plane, right : vertical plane)

4. Acceleration

The Programs for RF voltage and synchronous pahse are determined by the following requirements :

- In order to maintiant the central trajectory on the reference orbit, the energy gain per turn must be linked to the variation of the mgnetic field.
- The voltage must provide a sufficient bucket area to enclose all the longitudinal emittance.
- The trapping process must be optimized to minimize the beam losses.
- At extraction the bunch must be matched to the bucket of the next machine.

After injection the circulating beam is continuous and occupies a rectangle in the longitudinal phase space. To capture the injected beam, one stationnary bucket is created. During trapping, the magnetic field is clamped at is minimum value for a periodof few ms and the synchronous phase is zero. The RF voltage is optimized to obtain a beam rotation of about 90° and a momentum spread as small as possible before the acceleration phase.

When the magnetic field starts to ramp, the synchronous phase is shifted and the beam is accelerated. The program of the rise of the RF voltage and the synchronous phase variation are defined to obtain a sufficiently large bucket area and to minimize losses. Finally, at the end of the cycle, the bunch is manipulated so as to be matched to one of the PS RF buckets.The RF cycle has been simulated and optimized with the code ACCSIM developed at TRIUMPH [4]. The figure 4 shows the variation of the synchronous phase and voltage during cycle for He ions.

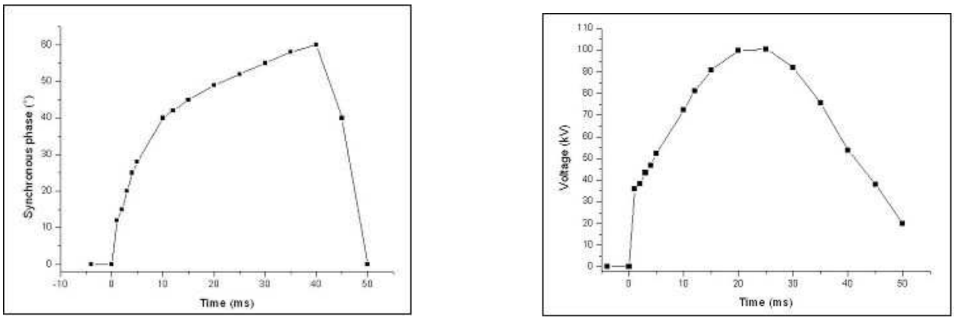

Figure 4 . Synchronous phase and voltage evolution during cycle for He ions

5. Conclusion

Several beam dynamics studies have been investigated in order to assess the feasability of the RCS, in addition to studies presented here. Unavoidable magnets misalignements and dipole field errors can affect the RCS closed orbit. Distortions to be expected have been statistically estimated assuming standard error tolerances and a correction system has been defined. In fast ramping machines such as the Beta-Beam RCS, eddy currents induced in metallic vacuum chamber walls by the time varying magnetic field produce various field components acting on the beam. In dipoles vacuum chambers, one important component is a sextupole which modifies the natural chomaticity of the ring. Their effects have been estimated and it has been shown that they could be compensate for so that they do not pose problems from the point of view of beam dynamics. Finally, after injection , ions beams are extracted in a single turn and directed towards the CERN PS. A fast extraction system consisting of fast kickers and septum magnets has been defined to produce the deflection angle required to eject the beam from the ring. All the beam dynamics studies made on the RCS have shown that there’s no issues on this ring. The present technology completely allows the realisation of this RCS.

References

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