INVESTIGATION OF THE BEAM DYNAMICS LAYOUT OF THE FAIR PROTON INJECTOR*

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Abstract

The FAIR facility at GSI requires a dedicated proton injector for the production of secondary high intensity antiproton beams. This 325 MHz, 70 MeV machine will be the fist linac based on CH cavities with the application of the KONUS beam dynamics. Two different options for the beam dynamics layout above 35 MeV are under investigation including loss and error studies. Finally different RFQ output distributions are used to evaluate the effect of the injection current on the main linac.

INTRODUCTION

Main Parameters

The antiproton physics program at FAIR requires an intensity up to 7 10^{10} p-bar/h which, taking into account the p-bar production and cooling rate implies a primary proton beam of 2 10^{16} p/h. This intensity is far beyond the capabilities of the existing UNILAC and, for this reason; a dedicated proton injector has to be built. The primary proton beam is limited by the space charge limit of the SIS18 which can be expressed as [1]

$$N_{sis} = 4.305 \cdot 10^{13} \cdot \beta^2 \gamma^3$$

While the p-bar rate is dominated by the stochastic cooling time which is proportional to the particles number if a sufficiently high signal/noise ratio is assumed. During the time needed for the cooling, the SIS 100 can be used to accelerate ion species different from protons: as one can see from Fig. 1 an output energy of 70 MeV allows to get close to the saturation of p-bar avoiding any jump in RF-frequency resulting in a considerable cost saving.

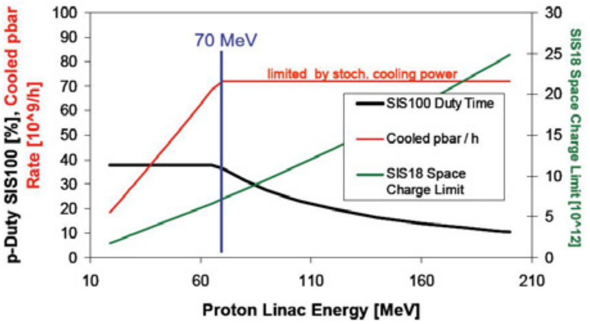

Fig. 1: Dependence of the SIS18 space charge limit the as a function of the proton energy (green) and the corresponding relative duty time for proton delivered by the SIS100 (black); the achievable rate of cooled p-bars is shown by the red curve.

A multiturn injection scheme is foreseen to transfer the beam into the SIS18: assuming a filling factor of 60 % at the chosen energy of 70 MeV the requirements for the brilliance can be expressed as

$$B_n = \frac{I}{\beta\gamma\varepsilon_x} = 16.4\, mA/\mu m$$

Even though a 35 mA injection current would fill 60 % of the SIS18 horizontal acceptance, the design of the linac foresees an input current up to 70 mA: this will provide flexibility in the multiturn injection scheme as well as safety margins in linac operation.

The choice of 325.2 MHz (3 times UNILAC frequency) as the operating frequency was also stimulated by the capabilities of the 3 MW klystrons developed for JPARC.

Cavity design and development

The choice of CH-DTL cavities is justified by the higher shunt impedance compared to classical DTL as one can see from Fig. 2.

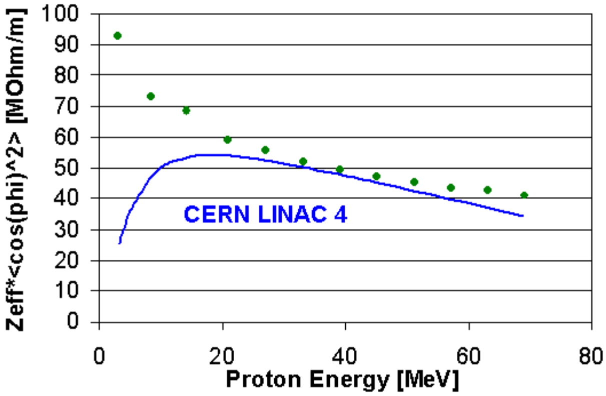

Fig. 2: In the dot curve, the expected effective shunt impedance of the FAIR proton injector compared to CERN LINAC 4 shown in the continuous curve.

Moreover, the development of coupled CH cavities [2] allows to profit from the development of the JPARC klystron and to simplify the RF equipment. A first scaled model of the second resonator of the FAIR proton injector built at IAP-Frankfurt has proved the validity of the innovative coupling concept [3]. Technical drawings of the first full size cavity have been started.

BEAM DYNAMICS LAYOUT

Basic Layout

The general layout of the FAIR proton injector is sketched in Fig. 3. An ECR source delivers a 95 keV proton beam with a current up to 100 mA. After the acceleration by a 4-rod RFQ to 3 MeV the beam is matched to main linac by an independently phased

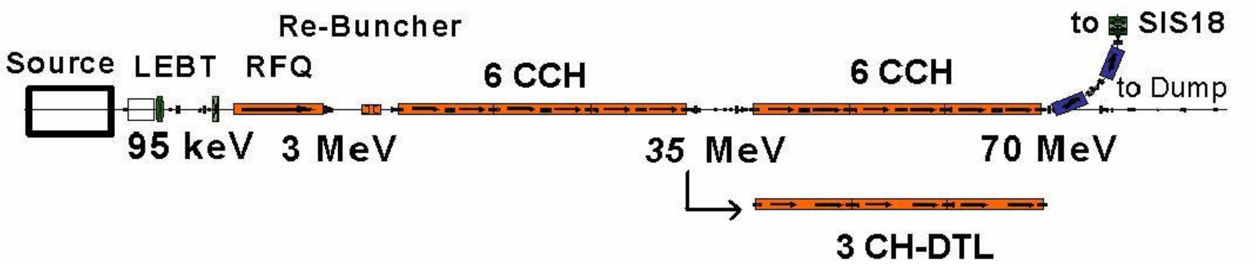

Fig. 3: the two proposed schemes for the FAIR Proton injector.

resonator for bunching. The matching section includes as well a xy-steerer, a phase probe and two focusing elements, placed in frwont and beyond the buncher respectively.

The main linac consists of 12 CH-sections grouped in 6 pairs of coupled structures: each resonator is made of two CH cavities connected by a coupling cell which hosts a triplet and which distributes the input power. A 1.5 m long transport section for diagnostic is foreseen at 35 MeV behind of the first 3 coupled resonators.

RFQ Output Distributions and results

The design was tested with two different RFQ-Output distributions with a current of 45 and 70 mA, respectively: In order to have the most realistic results both distributions were generated with the Parmteq code and ideal distributions were used only for the early design.

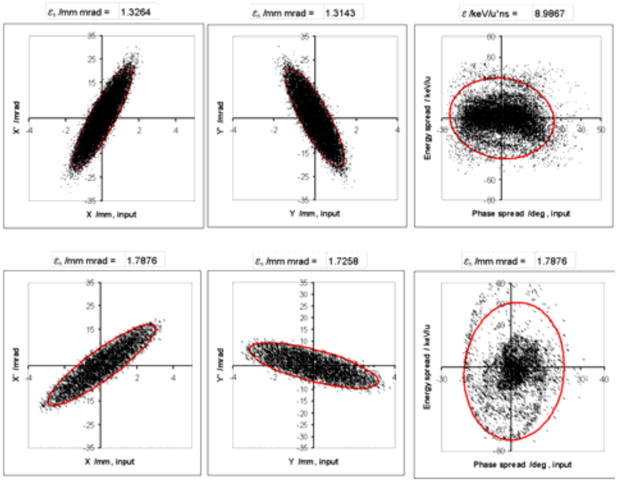

Fig. 4: The RFQ-output distribution for 45 (top) and 70 mA (bottom). The ellipses contains 95 % of the particles.

Table 1: RFQ-output parameters at 45 and 70 mA

PARAMETER	45 mA	70 mA
RMS ε norm X-X' mm mrad	0.262	0.362
RMS ε normY-Y' mm mrad	0.26	0.357
RMS ε normΔΦ- ΔW keV/ ns	1.292	1.58

The 70 mA distribution is characterized by a strong filamentation in the longitudinal phase space due to the high accelerating gradient of the designed RFQ. This problem doesn't occur with the second distribution which instead presents higher inclinations of the beam ellipses in the transverse plane. Anyway in both cases the settings of the quadrupoles placed in the matching section allows transverse matching into the main linac.

The difference in the longitudinal input distribution is visible at the output of the linac as well as shown in Fig. 6. The emittance in the 70 mA case is larger due to the worst initial conditions: thus, in both cases the requirements for the injection into the SIS18 are respected

Alternative Layout

One of the main advantages of the KONUS beam dynamics [3] is the possibility to build long sections without any focusing element. This gives the possibility to reduce the number of focusing elements in the high energy section of the linac, reducing the number of quadrupoles from 42 to 33. Moreover, this allows the construction of non coupled cavities leading to a general simplification of the mechanical design.

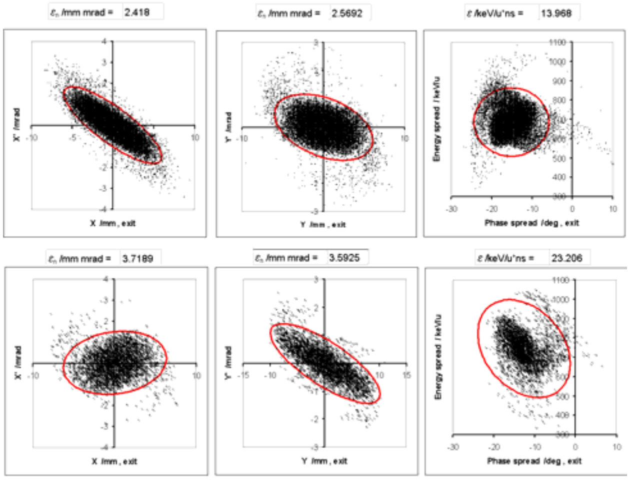

Fig. 5: The output distribution at 70 MeV for the 45 mA (top) and 70 mA (bottom) RFQ-Output current.

The output plot shown in Fig. 6 shows how this scheme permits to fulfil the requirements for the multiturn injection into the SIS18 within the requirements of the FAIR program: the emittance in the horizontal plane is 2.1 mm mrad with a current of 45 mA, which is 30 % more of what is required by the operation settings.

Table 2: The rms parameters as dependence of the input current at the output of the proton linac

PARAMETER	45 mA	70 mA
RMS ε norm X-X' mm mrad	0.383	0.657
RMS ε normY-Y' mm mrad	0.409	0.650
RMS ε normΔΦ- ΔW keV/ ns	2.09	2.82

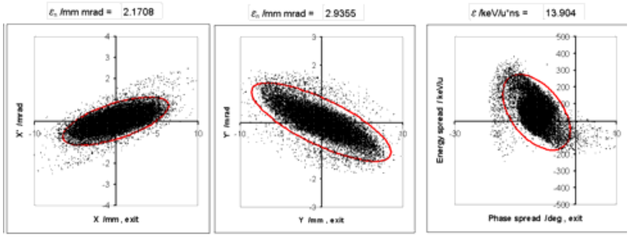

Fig. 6: The CH-DTL output distribution for the 45 mA case with simple CH cavities in the high energy section of the proton injector.

LOSS AND ERROR STUDIES

In order to evaluate the robustness of both designs against fabrication errors and oscillations from the power supplies, a complete error study was performed on the main linac: investigated parameters are:

- Quadrupole translations in the transverse plane;
- Quadrupole rotation in the 3D space;
- Single gap error;
- Klystron voltage and phase oscillations.

Quadrupole translation is applied separately to each lens while rotations are applied to the each triplet. The errors, including amplitude and phase are generated randomly with a Gaussian distribution cut at 2 •. Previous investigations [5] have shown that only quadrupole translations represent a major risk in terms of beam losses and emittance degradation while the single tolerances were fixed at

- Transverse displacements: Δx, Δy = ± 0.1 mm;
- Pitching and yawing angles : ΔΦx, ΔΦy = 0.1 mrad;
- Rolling angle : ΔΦz = ± 0.5 mrad
- Sinle Gap field: _Egap/Egap = ± 5%;
- Klystron field _Eklys/Eklys = ± 1%;
- Klystron phase _klys = ±1˚.

1000 runs were performed with a 100000 particles RFQ-output distribution to evaluate the effect of all the source of errors when applied at the same time.

Figures 7 and 8 show the rms variation with respect the nominal case for the two alternative solutions, assuming 45 mA at the entrance of the proton linac: as one can see the results are comparable both in the transverse and well as in the longitudinal plane. Further investigations are in progress in order to choose the best layout within the scheduling time of the FAIR proton injector whose construction is expected to begin within 2010 while the commissioning phase will be started in 2013.

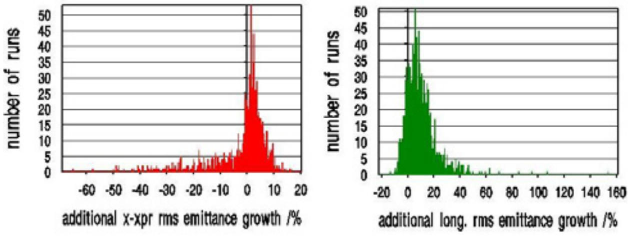

Fig. 7: The rms variation with respect the nominal case for the design based on 12 coupled CH-DTL.

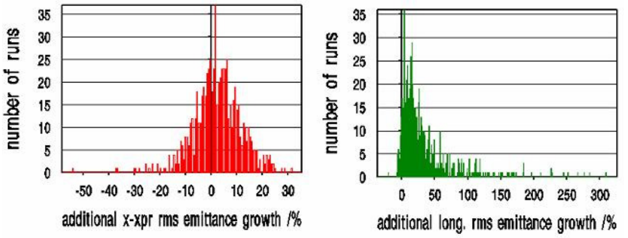

Fig. 8: The rms variation with respect the nominal case for the design based on 6 coupled CH-DTL and 6 standard CH.

CONCLUSION AND MILESTONES

The GSI Proton injector will be the fist machine based on CH-DTL cavities in combination with the KONUS beam dynamics. The beam dynamics layout has been designed assuming an input current up to 70 mA, twice the value required during operation. Two different layouts are under investigations, the first one based only on coupled cavities and a new one which foresees three standard cavities in the high energy section. Beam dynamics investigations including loss studies show that both designs can fulfil the requirements of the FAIR physics program and they are robust with respect to error tolerances. At present time, IAP is producing the technical drawing of the second resonator of the proton injector after validating the coupling scheme with the construction of a scaled model.

The construction of the FAIR Proton injector is expected to be start within 2010 while the commissioning phase is planned for 2013.

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