The FAIR proton linac

O. Kester
GSI and Goethe-Universität, Germany

Abstract

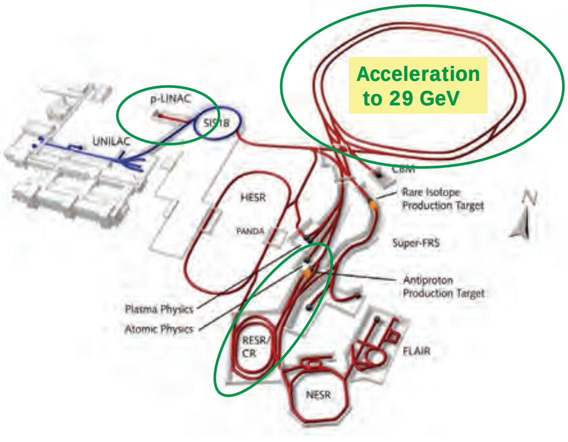
FAIR – the Facility for Antiproton and Ion Research in Europe – constructed at GSI Helmholtzzentrum für Schwerionenforschung GmbH in Darmstadt comprises an international centre of heavy ion accelerators that will drive heavy ion and antimatter research [1]. FAIR will provide worldwide unique accelerator and experimental facilities, allowing a large variety of fore-front research in physics and applied science. FAIR will deliver antiproton and ion beams of unprecedented intensities and qualities. The main part of the FAIR facility is a sophisticated accelerator system, which delivers beams to different experiments of the FAIR experimental collaborations – APPA, NuSTAR, CBM and PANDA – in parallel. The accelerated primary beams will then be employed to create new, highly exotic particles in a series of experimental programmes.

Introduction

In the PANDA experiment, collision of the antiproton beam with the internal hydrogen gas-target will be possible. In order to generate the required intensity of antiproton beams, the proton beam intensity must be driven to $2*10^{12}$ per spill. Those intensities cannot be delivered by the existing UNILAC but a high intensity proton linac injector is required for the SIS18. A significant part of the experimental programme at FAIR is dedicated to antiproton physics and for some experiments up to $7 \cdot 10^{10}$ cooled antiprotons per hour are required. Taking into account the pbar production and cooling rate, this is equivalent to a primary beam of $2 \cdot 10^{16}$ protons/h to be provided by the chain of accelerators comprising the proton linac and the two synchrotrons SIS18 and SIS100 (see Figure 1).

The driver accelerator of FAIR is the fast ramping, superconducting heavy ion synchrotron – SIS100 – that allows the acceleration of the most intense beams of stable elements from protons (30 GeV) to uranium (10 AGeV). SIS100 is installed in a 20 m deep tunnel, which is designed for the installation of the SIS300 synchrotron in a later stage of the project. The CBM – Plasma- and Biomat-experiments are directly supplied with primary beams from the SIS100. Two target stations for the generation of secondary beams (antiprotons and RIBs) allow the conversion of primary ions. The intensities of secondary beams will increase by a factor of 1,000-10,000 as compared to currently available beams. With beams of antiprotons, a variety of experiments is planned at FAIR. Antiprotons are produced in high-energy collisions of nuclei. The common technique uses a set of 10 cm long nickel rods, which are bombarded with proton beams. SIS100 will deliver proton beams with 29 GeV to the target. At 29 GeV beam energy, one out of ten-thousand protons will produce an antiproton. About 10^8 antiprotons per spill are expected and injected into the collector ring (CR) for beam preparation via stochastic cooling. The maximum rate of cooled pbars is limited by the stochastic cooling power since the cooling time scale is proportional to the number of hot pbars for a sufficiently high signal-to-noise ratio. Typical cooling times in the case of a non-ideal signal-to-noise ratio are about five seconds. During the stochastic cooling process in the CR, the SIS100 can be used to accelerate ion species different from protons.

Figure 1. Overview of the FAIR Facility and the steps required for the production and accumulation of antiprotons

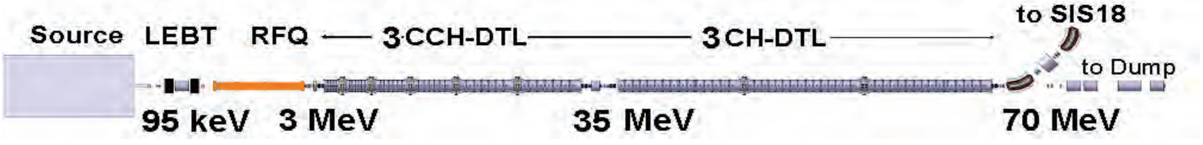


The FAIR proton linac design

For the high-intensity proton beams, as required for antiproton production, a dedicated 325 MHz proton linac delivering 35 mA and 70 MeV protons is needed [2]. The structure and elements of the p-linac are depicted in Figure 2. The FAIR proton injector has to provide at least 35 mA at the final energy with a repetition rate of 4 Hz. A 2.45 GHz ECR source generating 100 mA of 95 keV protons is employed, followed by a Radio-Frequency Quadrupole (RFQ). The subsequent Low-Energy Beam Transport (LEBT) is based on two-solenoid magnetic focusing and provides the required separation of H^{3+}, H^{2+}, and H_2 fractions from the proton beam. At present, a 4-rod RFQ and a ladder-RFQ are under investigation at the University of Frankfurt. The RFQ beam dynamics layout is based on the New-Four-Section-Procedure which drops the constant-focusing strength scheme [3].

At 3 MeV, the beam is accelerated by three coupled crossed-bar (CH) resonators to 36 MeV where a dedicated section for beam diagnostics is installed [4]. The remaining three CH-resonators perform the final acceleration to 70 MeV where the beam enters the transfer channel towards the SIS 18. Although at SIS18 injection a current of 35 mA is required, a maximum design current of 70 mA for the linac was chosen. If the stochastic cooling power is increased in future, the accelerator chain will demand higher proton linac currents.

Figure 2. Overview of the 70 MeV p- linac of FAIR

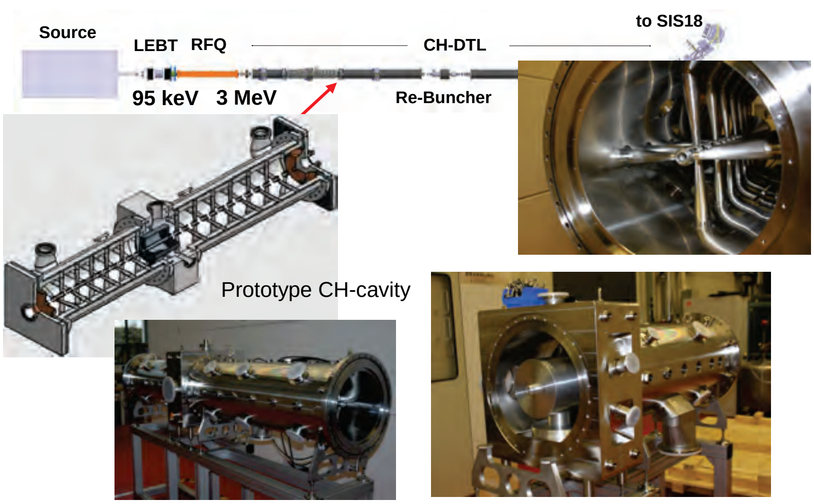


Modern H-type cavities offer highest shunt impedances of resonant structures of heavy ion linacs at low beam energies < 20 MeV/u and enable the acceleration of intense proton and ion beams. One example is the interdigital H-type structure. The crossed-bar

H-cavities extend these properties to high energies even beyond 100 MeV/u. Compared to conventional Alvarez cavities, these crossed-bar (CH) cavities feature much higher shunt impedance at low energies. The design of the proton linac is based on those cavities. As usual for H-mode structures, the beam dynamics lattice is derived from the KONUS beam dynamics [5].

Three coupled CH-DTL perform the first stage of acceleration to the energy of 36 MeV. At this energy, space charge effects are of reduced importance and KONUS offers the possibility to build long lens free sections. The coupled structures consist of two CH-DTL connected through a single cell resonator. This intertank section oscillates in the Alvarez mode and the large drift tube houses an electromagnetic quadrupole triplet. The radius of the single cell resonator has to be adjusted so that the resonance frequency of this unit matches the adjacent CH cavities. The first coupled CH has been fabricated (see Figure 3) and low level RF-tuning has been performed with respect to frequency and field flatness. The low-energy part consists of 13 gaps, followed by the coupling cell and by the 14 gap high energy part. The whole cavity has an inner length of about 2.8 m and an inner diameter of about 360 mm. For all structures, the power consumption is expected to be lower than 1 MW, although it is expected to feed the structures with a 3.0 MW-class klystrons.

Figure 3. Prototype cavity of the 325 MHz CH-structures of the FAIR p- linac



The KONUS design has been optimised in order to fulfill the transverse acceptance requirements of the SIS18 of about 5 mm mrad at 70 MeV injection energy. The injection into the synchrotron is planned by a multiturn injection scheme. The horizontal acceptance of the SIS 18 will be filled by a 35 mA within a normalised brilliance of 16.5 mA/μm, while a momentum spread of less than 1% is required. The maximum repetition rate is fixed at 4 Hz.

To determine the beam brilliance and the beam losses due to alignment errors, an error analysis has been performed. The error study comprises the DTL section, i.e. after the end plate of the RFQ. With this analysis mechanical tolerances and the design robustness against random errors can be determined. The errors include quadrupole rotation, translation, and variations of operational parameters such as voltage and phase oscillations of the amplifiers. The simulations show that the present design is robust against errors. At present, only three pairs of XY steerers are planned along the linac, one pair after the RFQ and two pairs at the end of the diagnostics sections. The design, mechanical integration, and data acquisition of the phase probe and BPMs in the p-linac are challenging. These four-button BPMs are partially to be integrated into the end drift tubes of the CH-cavities. Special care must be taken for the suppression of primary RF leeking into the drift tube that houses the BPM. Therefore, a ferrite shield is expected to reduce this effect.

References

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