THE 70 MEV PROTON LINAC FOR THE FACILITY FOR ANTIPROTON AND ION RESEARCH FAIR

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Abstract

A significant part of the experimental program at FAIR is dedicated to antiproton (pbar) physics requiring up to $7 \cdot 1010$ cooled pbars per hour. Taking into account the pbar A production and cooling rate, this is equivalent to a primary proton beam of $2 \cdot 10^{16}$ protons per hour to be provided by a 70 MeV proton linac preceding two synchrotrons. It has to deliver a pulsed proton beam of 35 mA of 36 μs duration at a repetition rate of 4 Hz. The normalized transverse emittances must not exceed 2.8 mm mrad and the total relative momentum spread must be less than 0.1%. The normal conducting DTL comprises 12 Crossed-bar H-cavities (CH) fed by six RFpower sources in total. The basic layout of the linac as well as the overall cost estimate has been completed including several reviews by external committees. A technical report has been completed in March 2006. This paper gives a general overview on the status of the project.

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Abstract

A significant part of the experimental program at FAIR is dedicated to antiproton (pbar) physics requiring up to $7{\cdot}10^{10}$ cooled pbars per hour. Taking into account the pbar production and cooling rate, this is equivalent to a primary proton beam of $2{\cdot}10^{16}$ protons per hour to be provided by a 70 MeV proton linac preceding two synchrotrons. It has to deliver a pulsed proton beam of 35 mA of 36 µs duration at a repetition rate of 4 Hz. The normalized transverse emittances must not exceed 2.8 mm mrad and the total relative momentum spread must be less than 0.1%. The normal conducting DTL comprises 12 Crossed-bar H-cavities (CH) fed by six RF-power sources in total. The basic layout of the linac as well as the overall cost estimate has been completed including several reviews by external committees. A technical report has been completed in March 2006. This paper gives a general overview on the status of the project.

INTRODUCTION

For the various pbar experiments at FAIR an ultimate number of up to $7{\cdot}10^{10}$ cooled pbar/h is 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 a proton linac and the two synchrotrons SIS18 and SIS100 (Fig. 1). The achievable primary proton rate is limited by the space charge limit (SCL) in the synchrotron SIS18 being filled by horizontal multi-turn injection (MTI). Accordingly, the number of primary protons per SIS100 spill scales as the SCL of SIS18. The maximum rate of cooled pbars is limited by the stochastic cooling power since the cooling time scales proportional to the number of hot pbars. Typical cooling times in 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. The proton linac energy of 70 MeV allows for the maximum rate of cooled pbars (Fig. 2). Increasing the proton energy does not change the cooled pbar rate but it disengages SIS100 cycle time, since the stochastic cooling time is longer than five seconds in this case. For a multi-ion facility like FAIR the choice of the proton injector energy is a trade-off between efficient use of accelerator cycle times and of linac economics.

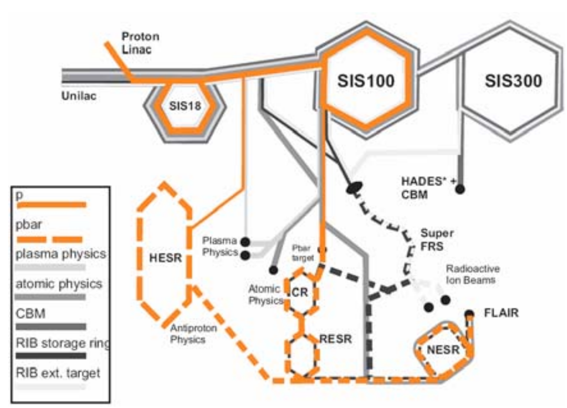

Figure 1: Schematic overview of the accelerator chain to provide cooled antiprotons at FAIR.

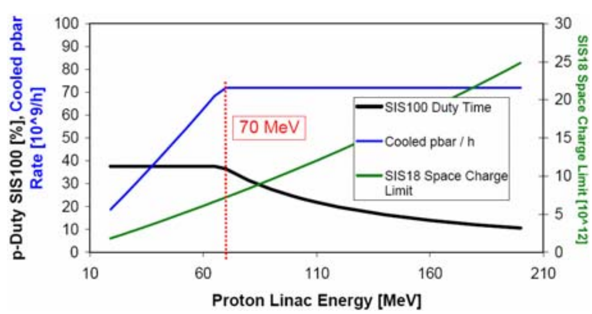

Figure 2: Dependence of the space charge limit of proton beams in the SIS18 (green curve) and corresponding relative duty time for primary proton beam delivery by the SIS100 (black) as function of the proton linac energy. The achievable rate of cooled pbars is presented by the blue curve.

The choice of a proton energy of 70 MeV delivered by the proton linac is an adequate compromise. It results in a proton duty cycle of the SIS100 synchrotron of 38% and allows for linac operation at a single RF-frequency, i.e. 352 MHz. The minor increase in gain in SIS100 cycle time at energies in excess of 70 MeV does not pay for the required jump in RF-frequency and the resulting increase of overall system cost. Although at SIS18 injection a current of 35 mA is required a maximum design current of 70 mA for the linac was chosen. In case that the stochastic cooling power is increased in future the accelerator chain will demand for higher proton linac currents. The normalized transverse emittance of the linac was set to a design value of 2.8 mm mrad. A current of

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35 mA results in a proton linac beam pulse length of 36 µs equivalent to the filling time in the SIS18 within one MTI cycle, i.e. 18 turns (14 effective turns); thus the space charge limit is reached. The conceptual layout of the proton linac is depicted in Fig. 3 and its main parameters are listed in Tab. 1.

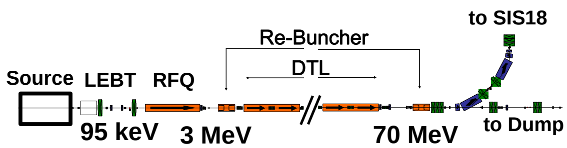

Figure 3: Conceptual layout of the proton linac of FAIR comprising a proton source, an RFQ, and a Drift Tube Linac (DTL) based on 12 CH-cavities.

Table 1: Parameters of the FAIR proton linac design.

Source	H+, 95 keV, 100 mA
LEBT (2-solenoid foc.)	95 keV, 100 mA, ε=1.8 µm*
RFQ (4-rod)	3 MeV, 90 mA, ε=2 µm*
DTL (352 MHz, rt)	12 CH-cavities, 70 MeV
current	70 mA (design)
	35 mA (initial operation)
emittance	2.8 µm*
rel. momentum spread	$\leq \pm 1 \cdot 10^{-3}$
RF-pulse	70 µs
max. beam pulse	36 µs
max. repetition rate	4 Hz
	*(norm., 100%)
Overall linac length	≈ 30 m

FRONT-END

Currently a duoplasmatron proton source is planned to be used for the FAIR proton linac. The extraction energy is 95 keV and the proton fraction must be at least 100 mA. It is foreseen to integrate an $H_{1\text{-}3}^+$-molecule filter into the 2-solenoid LEBT, which allows the determination of the H^+, H_2^+, and H_3^+ fraction of the total beam current using the Time-Of-Flight technique. A promising alternative is a 3 GHz ECR ion source as currently used at CEA/Saclay [1]. Extensive measurements of horizontal beam emittances at its LEBT exit as well as on the space charge compensation revealed highly stable and reproducible beam properties that fit to our requirements [2,3].

At frequencies above 300 MHz RFQs of the 4-vane type are commonly in use. The investment cost for these RFQs are usually significant. As an alternative, a 4-rod type RFQ is much simpler in mechanical design and thus less expensive. However, it has not been built so far for frequencies above 300 MHz. The University of Frankfurt gained huge experience on 4-rod RFQs. For the proton linac both cavity types were considered and conceptual designs are completed for both cases [4,5]. Comparisons on beam dynamics performances were done using DYNAMION simulations based on Gaussian input distributions.

The results of the 4-rod RFQ are very promising. With a maximum surface electric field of less than two Kilpatrick (E_k) a transmission of accelerated particles of 86% is reached. The normalized transverse emittance is well below the design value of 2.0 mm mrad. A cold model of the 4-rod RFQ with eight stems and elliptical electrodes was built [4] in order to verify the results of simulations on the RF-properties. It has been demonstrated that differences in the voltages of the upper and lower rods could be eliminated by proper adjustment of the stem slope. The closest parasitic oscillation mode was found to be a dipole mode at 410 MHz.

Although the 4-rod cavity is the proposed option for the proton linac, design studies on a 4-vane RFQ are still ongoing at the Institute for Theoretical and Experimental Physics (ITEP) in Moscow [5]. With respect to transmission and emittances the design values are almost achieved. Transverse emittances of accelerated particles are higher by 25% with respect to the 4-rod RFQ and also some non-accelerated particles are fully transmitted. The longitudinal output emittance is comparable to the respective value of the 4-rod RFQ. The maximum surface electric field strength of the 4-vane cavity still exceeds the value of $2 \cdot E_k$. In order to assure save operation conditions the field strength needs to be lowered in further iterations of the design. This should be possible by a moderate increase of the overall length by about 20 cm.

DRIFT TUBE LINAC

The main linac, preceded by a rebuncher for longitudinal beam matching, comprises 12 Crossed-bar H-mode cavities (CH) accelerating the beam to its final energy of 70 MeV. CH-cavities represent the extension of well established Interdigital H-cavities to higher particle velocities [6,7]. In connection with the applied KONUS beam dynamics they provide high effective shunt impedances which in turn allow for a compact and cost efficient linac. In order to reduce the number of RF-power sources the 12 CH-cavities are grouped to six independent pairs of RF-coupled cavities (Fig. 4). A cold model of a single CH-cavity has been built and is currently tested [8]. This year a 2:1 model of a cavity-pair will be constructed followed by a prototype pair in 2007 [7].

Each pair will be powered by one klystron with a peak power of up to 2.5 MW of which about 50% is needed for beam loading compensation. Together with the klystron for the RFQ in total seven klystrons will be used for the proton linac. Currently a market survey on existing klystrons with performances close to our requirements is done.

Transverse beam focusing is accomplished in quadrupole triplets installed between the cavities. The beam dynamics layout is in progress. Full transmission of a 70 mA beam was achieved in simulations showing an acceptable growth of the emittances in all three dimensions. In order to assure operation within the design emittance of 2.8 mm mrad a beam dynamics design for a total output current of 90 mA is in preparation. An extended diagnostic section after the 6th CH-cavity is

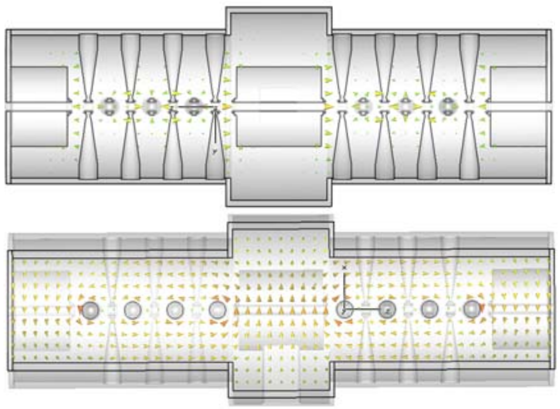

Figure 4: Pair of RF-coupled CH-cavities together with the electric (upper) and magnetic (lower) field distribution as obtained from simulations using Microwave Studio®.

integrated into the DTL. It includes transverse scrapers to eliminate particles with large emittances with respect to the beam core.

Additionally, an advanced error analysis study has been initiated. Parameters that enter into beam dynamics simulations will be subject to errors following a Gaussian distribution. Many runs will be made with different assumptions on errors in quadrupole alignments & gradients as well as in RF-amplitudes & phases. The results of these studies will provide realistic beam loss scenarios and enter into the specifications of the requirements to the RF-control system and to the alignment tolerances.

After the last CH-cavity a rebuncher will minimize the momentum spread at the linac exit. The rebuncher is followed by a 90°-inflection to inject the beam into the existing beam transfer line from the UNILAC to the SIS18. It is conceived also as a momentum filter including a horizontal slit in its centre where the dispersion D_x is at maximum while the horizontal beta-function β_x is at its minimum. In order to define properly the remaining momentum spread after the inflection a ratio of $D_x^2/\beta_x \geq 28$ m must be provided. With the current design a ratio of 40 m is achieved.

STATUS OF THE PROJECT

In February 2005 a first dedicated Technical Report (TR) on the FAIR proton linac has been released. It has been reviewed twice by a Technical Advisory Committee in the same year. Simultaneously the total project cost was estimated and a so-called Cost Book has been established. This process was accompanied and reviewed by a Cost Review Committee. These reviews lead to several changes in the layout especially to a completely new RF-alimentation scheme. Additionally, the overall cost was reduced by about 25% thanks to these reviews. In March 2006 an improved edition of the TR [9] has been completed including the suggested changes of the committees. Currently it is reviewed and it is expected to be released within this year.

Parallel to the accelerator design the planning for the civil construction of the linac tunnel as well as for the supply building is ongoing (Fig. 5). The required spacing has been defined as well as the type and amount of media to be provided to the buildings ("load list"). The layout of the beam dump area in forward direction with respect to the DTL remains to be done.

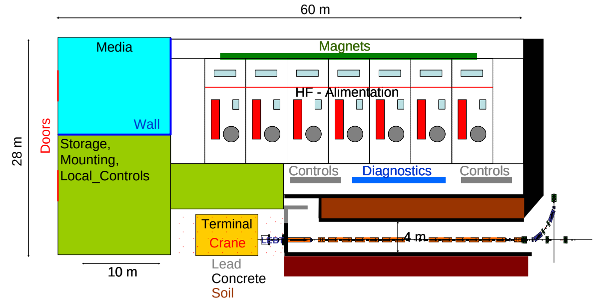

Figure 5: Current layout of the one-floor complex housing the linac tunnel and the supply building.

For the end of this year the start of construction of an RF-test stand is foreseen. A prototype klystron as well as a prototype power converter is expected to be delivered in April of 2008. Excessive testing of the coupled CH-cavities will follow in the subsequent months.

REFERENCES

[1] R. Gobin et al., *Saclay High Intensity Light Ion Source Status*, Proc. of EPAC2002, p. 1712, Paris, (2002).

[2] R. Hollinger et al., *High-Current Proton Beam Investigation at the SILHI-LEBT at CEA/Saclay*, these proceedings.

[3] M. Galonska et al., *Computer Simulations of a High-Current Proton Beam at the SILHI-LEBT*, these proceedings.

[4] A. Schempp et al., *CDR for a 352 MHz Proton RFQ for the new GSI Proton Linac*, Int. Rep. S-05-4, Frankfurt University, (2005).

[5] D. Kashinsky et al., *Conceptual Design of 352 MHz RFQ Structure Based on the Four Vane Cavity with Coupling Windows for GSI Proton Linac (Part 2)*, GSI Preprint, (2005).

[6] Z. Li et al., *Design of the R.T. CH-Cavity and Perspectives for a New GSI Proton Linac*, Proc. of the XXII Linac Conference, Lübeck, Germany, (2004).

[7] U. Ratzinger et al. *A 70-MeV Proton Linac for the FAIR Facility Based on CH – Cavities*, these proceedings.

[8] G. Clemente et al., *Status of the 70 MeV, 70 mA CH Proton-DTL for FAIR*, Proc. of EPAC2006, Edinburgh, (2006).

[9] *FAIR Baseline Technical Report*, Vol. 2, GSI Darmstadt, Germany, p. 335, (2006), to be released.