A SUPERCONDUCTING INJECTOR LINAC FOR COSY

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Abstract

For the Cooler Synchrotron COSY at the Research Center Jülich a superconducting linear accelerator will replace the existing cyclotron which presently serves as an injector for COSY. The new injector will have to deliver polarized H^- ions and polarized D^- ions for injection into COSY with an energy of at least 50 MeV. The number of particles accepted in COSY is to be risen up to the space charge limit, which is a significant improvement especially for polarized ions. The polarized ions will be generated in a colliding beams source with magnetic extraction and subsequent electrostatic deflection. After the RFQ stage (up to 2.5 MeV/u) the particles will be fed into the LINAC section which consists of about 44 independently phased super-conducting 2-gap resonators. The ions are finally guided to the COSY injection point. The main characteristics of the LINAC operation will be 2 mA peak current, 2 Hz repetition rate, 500 us ion source pulse length. A facility description is given and designs are discussed. The status of the project is reported.

1 INTRODUCTION

The Institut für Kernphysik of the Forschungszentrum Jülich GmbH is in the process of designing and developing a new SuperConducting Linac (COSY-SCL) as an injector for the cooler-synchrotron COSY [1]. Our aim is to increase the intensity of polarized proton and deuteron beams in COSY typically by a factor of 10 compared to what can be delivered to experiments at present. The improved capabilities will enable us to fully exploit the unique experimental opportunities of the facility.

The planned injector (COSY-SCL) is described comprehensively in the conceptual design report of October 2001 [2] and the design update of March 2002 [3]. It makes use of a superconducting linac, together with advanced ion sources and two interchangeable RFQ pre-accelerators for H^- and D^- ions, respectively. The present layout of the planned injector is shown in figure 1 and consists of five consecutive sections:

- Ion sources (polarized and unpolarized H^-/ D^-),
- Low-energy beam transfer (LEBT),
- RFQs and beam matching,
- Superconducting half-wave resonator (HWR) linac,
- Injection and diagnostics beamlines.

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The main characteristics of the injector are summed up and listed in table 1.

Table 1: Main characteristics of the injector LINAC

Beam pulse from ion source	$\Delta t < 0.5$ ms, $I_{peak} < 2$ mA
Repetition rate	< 2 Hz
Normalized emmittance (90%)	1.2 π mm mrad (H^-) 1.6 π mm mrad (D^-)
Ion source voltage	-25 kV for both ion species
RFQ Frequency	160 MHz
RFQ RF power	725 kW
RFQ extraction energy	2.5 MeV per nucleon
Superconducting HWR linac	
11 unit cells (13 possible), length 1.7 m per unit cell	
20 HWRs with β=0.116 at 160 MHz, $B_{peak} \leq 80$ mT 24 HWRs with β=0.2 at 320 MHz, $B_{peak} \leq 80$ mT	
Pulsed operation superimposed on low level cw	
Each cavity independently driven by a 4 kW solid state amplifier	
Cryogenic loss per HWR	80mW + losses via coupler
Cryogenic loss per cryostat	<4W
Cryoplant cooling power rating	160W (4K) 2200W (60K)
LINAC extraction energy	50 MeV for H^- 56 MeV for D^-
Beamlines	Length ≥ 23 m (to COSY)

2 ION SOURCES AND LEBT

For the delivery of short pulses of high intensity polarized proton/deuteron beams at 25 keV to the RFQ, a CIPIOS type ion source is planned. This kind of source is in routine operation for several years already at IUCF (Bloomington, Indiana, USA) where its operational characteristics have matured over time. With a modified pulsed plasma source and a new neutralizer-converter set-up, an intensity of 1.5 mA (peak) and a pulse width over 400 µs were demonstrated. At present it is envisioned either to acquire the IUCF source or to build a new source of this type in Jülich, named ISPOLIN, in collaboration with A. Belov and the INR laboratory of Russia. The experience with the compact LEBT system at IUCF using electrostatic lenses for focusing showed that such a system is capable to achieve a good transmission for the expected quality and intensity of the beam. A solenoid for final spin alignement of the polarized beams is included. For back-up purposes a commercial source providing unpolarized ions will be used.

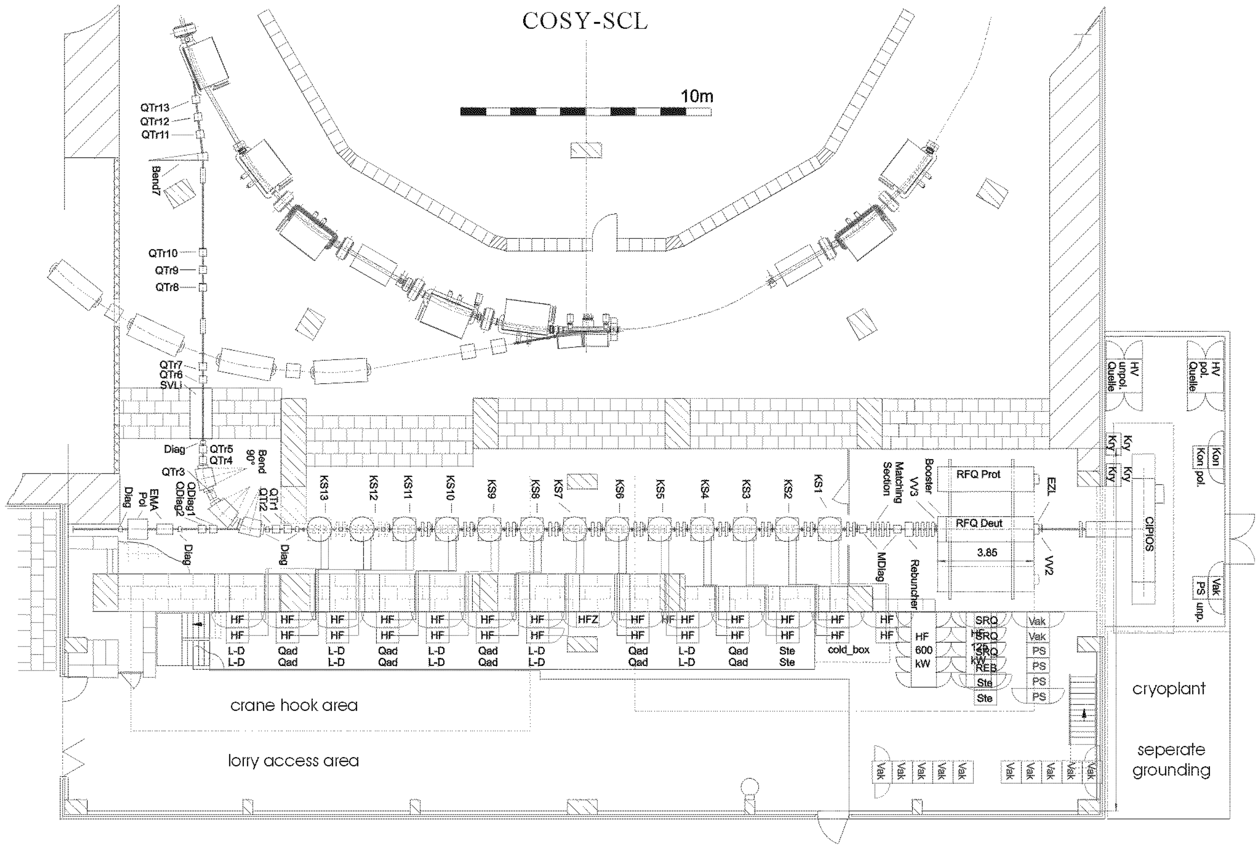

Figure 1: The present layout of the superconducting injector linac for COSY. Racks housing the electronic equipment needed for operation will be placed outside the shielded area on the ground floor and on a gallery.

3 RFQS AND BEAM MATCHING

The two different RFQ pre-accelerators required for H^- and D^- ions, respectively, are being designed to operate at 160MHz. They will be installed alongside each other on a common trolley to facilitate moving them into operating position when alternation between H^- and D^- operation is necessary. H^- ions will be accelerated to 2.5MeV and D^- ions to 5MeV. For this purpose, the actual RFQs will accelerate the ions up to 2MeV per nulceon and then be followed by equivalent booster cavities adding 0.5MeV per nucleon, thus ensuring equal beam characteristics at the exit. These pre-accelerators are designed by the IAP at the University of Frankfurt/Main [4]. After the RFQ, the beam is directed via four quadrupoles into a rebunching cavity and another four quadrupoles (of the type used in the linac unit cells) that allow to properly match the beam in transverse and longitudinal phase space into the superconducting linac.

4 SUPERCONDUCTING LINAC

4.1 QWR-based design

In collaboration with INFN-LNL a initial proposal was developed using the design of superconducting $\lambda/4$ resonators (QWRs). Such QWRs have been built there for 80MHz (β_s~0.05) and 160MHz (β_s~0.11) They are able to reach 8MV/m at 14W power dissipation in cw operation and up to 11 MV/m at maximum power [5]. Fast tuning would be straight forward via the thin bottom plate of the resonator. Each cryostat contains 4 QWRs and the transverse focussing is applied outside the cryostat at room temperature.

In response to the QWR-inherent problem of non-zero magnetic field on the beam axis, which unfortunately becomes excessive for our case with H^- and D^- ions a compensation scheme [6] had to be developed to counteract up to 1 mrad beam deflection per cavity [7]. Without compensation the beam would be completely lost within 1-2 cryostats. The compensation scheme consists of mounting the 4 resonators in one cryostat with the two inner ones being rotated by 180° around the beam axis and leads to a residual beam displacement of only ~1mm at the linac exit. However, such a compensation scheme couples the beam deflection to the accelerating field, and thus a failure of one resonator immediately would result in unacceptable beam conditions interrupting operation until the fault has been repaired. This is not acceptable in our case due to the extremely high availability required of the injector. Additional technical problems of He gas removal in the QWRs would have to be solved too and also might adversely affect reliability.

4.2 HWR-based design

HWRs have zero magnetic field on the beam axis and thus do not need a compensation scheme. Hence the failure of one resonator cannot lead to an inherent beam deflection like in the case of QWRs, but only requires retuning the RF of the remaining resonators and at the same time probably accepting a small reduction of the final energy at the linac exit.

Taking into account the electromagnetic behaviour of the cavities as well as manufacturing considerations the design rations E_{peak}/E_{av} and B_{peak}/E_{av} have been optimized. The 320MHz HWR geometry is illustrated in figure 2 and represents a reasonable compromise between acceptable electromagnetic characteristics and ease of fabrication. The total quantity of niobium required for HWRs is similar to the amount needed for QWRs, because the latter have much thicker material in particular at the connection to the LHe reservoir.

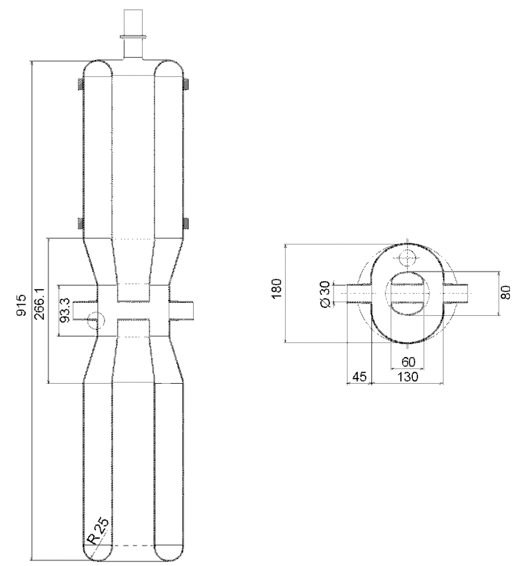

Figure 2: Geometric layout and basic dimensions of the 320MHz HWR

Each resonator will be contained in a LHe vessel that is connected to a common LHe reservoir inside the cryostat. The LHe vessel will be made of niobium or titanium to allow for fixing the outer conductor of the resonator to the vessel. This will raise its lowest mechanical eigenmode to more than 400 Hz. The lowest eigenmode of the inner conductor is expected at about 170 Hz which is well above the 100 Hz assumed commonly as limit.

The tuner will be mounted at the beam tubes and makes use of a stepper motor for presetting and an additional piezo actuator for fast tuning. An inductive coupler is planned at present. It will be mounted on a 30 mm diameter tube at the bottom of the resonator. An equivalent flange opening will be positioned at the top of the resonator. It probably will be used for evacuating the resonator volume, because we want to separate the vacuum region for the beam from that of the cryostat. These and other openings also provide access for chemical treatment and cleaning.

A very critical design parameter for a proton / deuteron linac at these rather low energies is the acceleration-free drift length between two consecutive cryostats. In our case this distance is 78cm at present. Up to ~15MeV it gives rise to a so-called parametric resonance, an effect that tends to stretch the longitudinal phase space as is described in more detail in [8]. Efforts to further reduce this drift length are still in progress for minimizing the effect of the parametric resonance.

5 PROJECT STATUS

For acquiring the polarized ion source we are still negotiating with our partners. The unpolarized ion source is expected to be delivered by November 2002. The RFQs are on order. The RF-amplifier tenders for the RFQ are being evaluated. Technical drawings of the HWRs are being completed to call for tenders to manufacture the prototype resonators. Delivery of the first RF amplifiers for the linac section is expected soon. An IQ based RF control system will be used. The frequency control circuit will operate between the pulses at low field level. Prototypes of diagnostic devices in the linac section are ordered. The quadrupoles for the transverse focusing in the linac section are basically designed, but the design of the cryostats and the cryoplant has just started. The properties of the injection and diagnostics beamlines have been evaluated based on magnets that are presently used in the existing injection beamline into COSY.

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