THE SUPERCONDUCTING INJECTOR LINAC FOR THE COOLER-SYNCHROTRON COSY AT FZ-JUELICH

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Abstract

The Institut für Kernphysik of the Forschungszentrum Jülich (FZJ) has started with the design and development of a superconducting injector linac for the cooler-synchrotron COSY to replace the cyclotron JULIC. The project aims to increase the intensity of polarized proton and deuteron beams in COSY typically by a factor of ten compared to what can be provided at present. The improved capabilities will enable us to fully exploit the unique experimental opportunities of the facility, and thus significantly strengthen and extend its scientific viability. The new injector makes use of a super-conducting linac, together with advanced ion sources and two inter-changeable RF-Quadrupole (RFQ) pre-accelerators for H^- and D^- ions, respectively. The linac design is based on a superconducting half-wave resonator (HWR) structure with independently phased cavities and separated functions to deliver both polarized and unpolarized pulsed H^- and D^- beams at a kinetic energy between 50 and 60MeV for charge-exchange injection into COSY. The beam current will be 2mA (peak) in pulses lasting up to 0.5ms at a repetition rate of 2Hz. The planned layout of the injector is presented and its design specifications are discussed, together with the present status of the project.

1 INTRODUCTION

The Institut für Kernphysik of FZJ is in the process of designing and developing a new SuperConducting Linac (COSY-SCL) as an injector for the cooler-synchrotron COSY [1,2]. 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. Progress in the last months was achieved concerning final mechanical structure calculations, error investigations and matching section.

COSY-SCL is described comprehensively in the conceptual design report of October 2001 [3] and the design update of March 2002 [4]. 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 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	< 2Hz
Normalized emmittance (90%)	1.2 π mm mrad (H^-) 1.6 π mm mrad (D^-)
Ion source voltage	-25kV for both ion species
RFQ Frequency	160MHz
RFQ RF power	725kW
RFQ extraction energy	2.5MeV per nucleon
RFQ acceptance	~ 3.5 π mm mrad
Kilpatrick factor	< 2.0
Superconducting HWR linac	
11 unit cells (13 possible), length 1.7m per unit cell	
20 HWRs at 160MHz, β=0.116, $B_{peak} \leq 80$mT ≅ 8MV/m 24 HWRs at 320MHz, β=0.2 $B_{peak} \leq 80$mT ≅ 8MV/m	
Pulsed operation superimposed on low level cw	
Each cavity independently driven by a 4kW solid state amplifier	
Linac extraction energy	50MeV for H^- 56MeV for D^-
Beamlines	Length ≥ 23m (to COSY)

2 ION SOURCES AND LEBT

For the delivery of short pulses of high intensity polarized proton/deuteron beams at 25keV 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 1.5mA (peak) and a pulse width over 400µs were demonstrated. At present it is envisioned either to acquire the IUCF source or to build in Jülich a new source of this type, 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. A multicusp ion source from IBA will be used to provide unpolarized H^-/D^- beams and connected to the LEBT system via a 90° bending magnet.

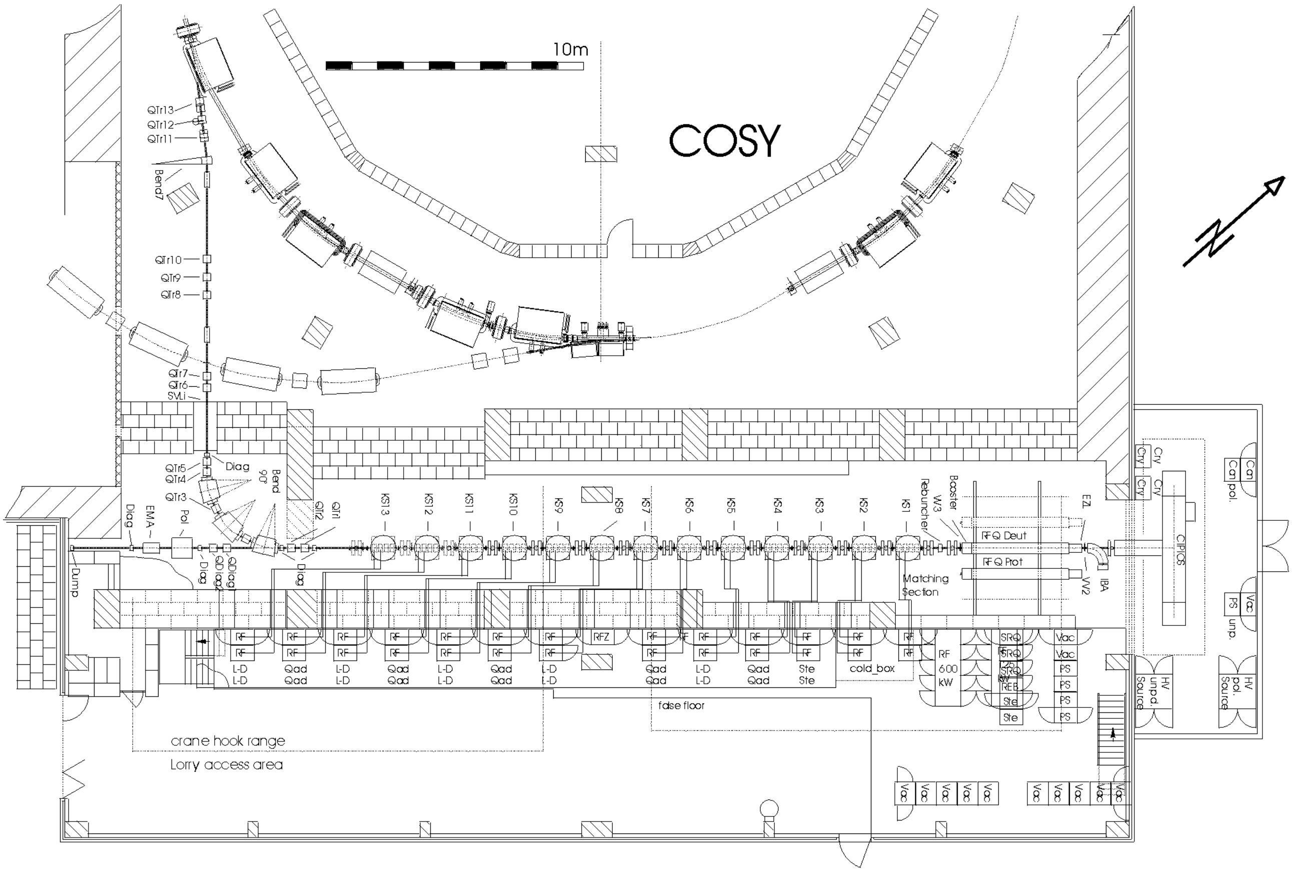

Figure 1: The present layout of the superconducting injector linac for COSY. Racks housing the electronic equipment needed for operation will be placed outside the shielded area on the ground floor and on a gallery.

3 RFQS AND BEAM MATCHING

As the extraction voltage remains the same for H^- and D^- ions, two different RFQ pre-accelerators are required They 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. Final energy will be 2.5MeV per nucleon. 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, developed and constructed under the responsibility of A. Schempp from the University of Frankfurt/Main [5]. Behind the RFQ, the beam is directed through a quadrupole doublet into a rebunching cavity and then via another doublet into the first resonator to properly match the beam in transverse and longitudinal phase space into the superconducting linac.

4 SUPERCONDUCTING LINAC

The layout of the linac is inspired by the QWR-based design of ALPI at INFN-LNL [6]. However, this design could not be adapted to the H^-/D^- requirements. and an HWR-based design was chosen. Four resonators will be mounted in one cryostat. Quadrupole magnets for transverse focusing and diagnostic devices will be placed between the cryostats.

Taking into account the electromagnetic behaviour of the cavities as well as manufacturing considerations, the design ratios E_{peak}/E_{av} and B_{peak}/E_{av} have been optimized. The 160MHz 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.

Calculations for evaluating the properties of the HWRs have been carried out. Assuming a wall thickness of 2mm, a Lorentz force detuning of $-2.2\text{Hz}/(\text{MV/m})^2$ for $\beta=0.11$ and of $-4.9\text{Hz}/(\text{MV/m})^2$ for $\beta=0.2$ was found. The corresponding tuning sensitivities are 75kHz/mm and 440kHz/mm, respectively. The tuning forces in both cases are calculated to be smaller than 1.3kN/mm. For prototyping we selected a wall thickness starting from 3mm sheet material. Hence, after forming and etching the walls at the thinnest point will be well above 2mm thick. The Lorentz force detuning will then not exceed the calculated values. On the other hand, the tuning force will be between 1.3kN/mm and 2.8kN/mm, as is shown in figure 3, a value that is still manageable using piezo actuators.

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 frequency to more than 400Hz. The lowest eigenmode of the inner conductor is expected at about 170Hz, which is well above the 100Hz assumed commonly as limit.

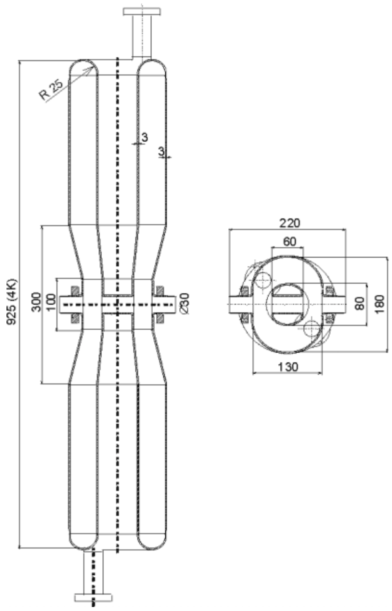

Figure 2: Geometric layout and basic dimensions of the 160MHz HWR.

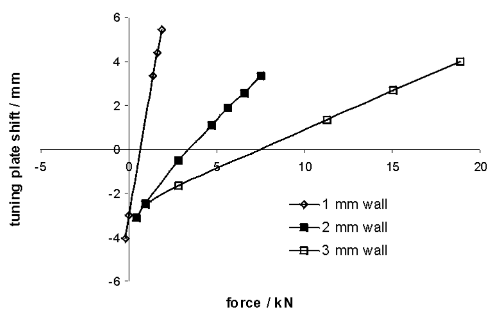

Figure 3: Shift of tuning plate due to applied force. The slope for 2mm thick walls corresponds to 1.3kN/mm, the slope for 3mm thick walls to 2.8kN/mm.

The tuner will be mounted at the beam tubes and makes use of a stepper motor for presetting with an additional piezo actuator for fast tuning. An inductive coupler is planned at present. It will be mounted on a 30mm 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 cavity, because we want to separate the vacuum region of 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 ion energies is the acceleration-free drift length between two consecutive cryostats. In our case this distance is 78cm at present. Up to ~20MeV it gives rise to the so-called parametric resonance, an effect that tends to stretch the longitudinal phase space as is described in more detail in [7]. Efforts to reduce this drift are still in progress for minimizing the effect of the parametric resonance.

Error and sensitivity studies assuming randomly distributed field and positioning errors show that we can expect maximum trajectory displacements of up to 4 mm. A concept to minimize this displacement is currently being investigated.

5 PROJECT STATUS

We are still negotiating to acquire the polarized ion source. The unpolarized ion source is expected to be delivered by November 2002. The RFQs are on order. Also the RF amplifier for the RFQs is ordered. Technical drawings of the HWRs are completed and the call for tenders to build the prototype resonators has been sent out. The prototype of the first 160MHz RF amplifier for the linac is delivered and being tested. 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, other ones have been made and are now being tested. The quadrupoles for the transverse focusing in the linac section are designed, and production of a prototype has started. However, the design of the cryostats and of the cryoplant is still in the concept phase. 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. Detailed planning for implementing the changes of the building has started.

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