COSY-SCL, THE SUPERCONDUCTING INJECTOR LINAC FOR COSY

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Abstract

The superconducting injector linac COSY-SCL is being designed and constructed at the Forschungszentrum Juelich. The main goal of the new injector is to fill the cooler synchrotron COSY with polarized protons as well as with polarized deuterons up to the space-charge limit at injection energy. COSY-SCL is characterized by a base frequency of 160 MHz, 25 kV ion-source extraction voltage, a pulse length of up to 500 µs, a maximum repetition rate of 2 Hz, injection into the linac at β=0.073 and injection into COSY at kinetic energies of 52 MeV for protons and 56 MeV for deuterons, respectively. The injector configuration is presented, and its main subsystems -ion source (CIPIOS from IUCF for polarized H^- and D^-), RFQ (built in co-operation with the University of Frankfurt), linac (based on half-wave resonators operating at 160 and 320 MHz)- are described and discussed. The present status of the project is reported.

INTRODUCTION

Several independent review committees have identified a much enhanced future scientific potential for the COSY accelerator facility if intensities for polarized ions could be raised to about $2*10^{11}$, which roughly corresponds to the limitation by space charge. The evaluations also showed that a different injector is needed for this purpose because the present injector, the 30 years old isochronous cyclotron JULIC, is constituting a bottle neck that would foil any attempt to reach that goal. The most suitable new injector for COSY turned out to be a superconducting (sc) linac with independently phased single-cell cavities [1].

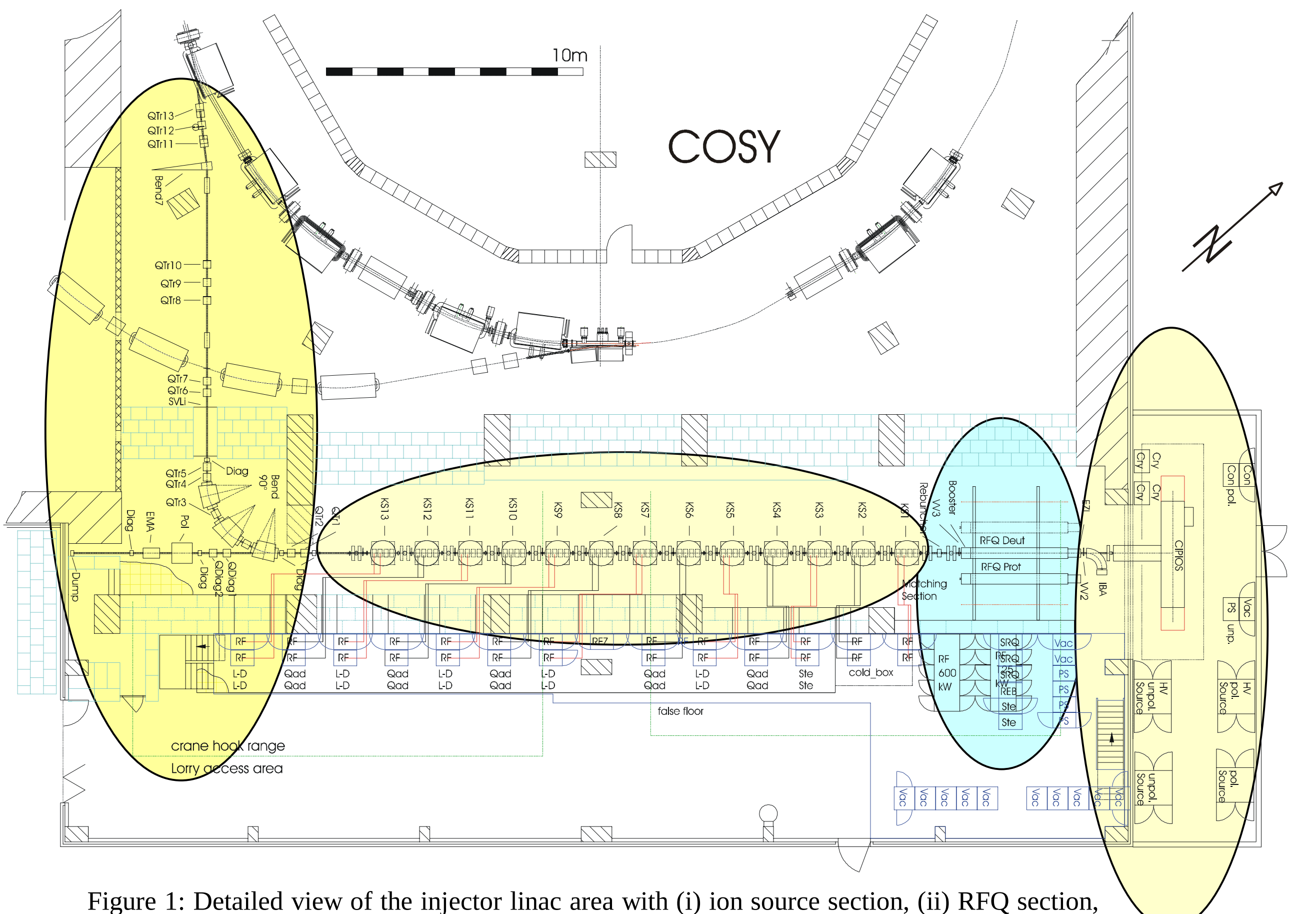

Figure 1: Detailed view of the injector linac area with (i) ion source section, (ii) RFQ section, (iii) sc linac section, (iv) transfer line to COSY and the diagnostics line (from right to left).

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LINAC CONCEPT

The new injector should be able to deliver polarized proton and deuteron beams with sufficient intensities to fill COSY to the space-charge limit at the chosen injection energy of about 50 MeV. In addition, the new injector should fit into the existing building of COSY to keep civil engineering costs low. Furthermore, construction should not interfere with the ongoing experimental program and allow a fast switching from the cyclotron to the new injector once it has been completed.

A normal conducting linac, due to its excessive length, turned out to be incompatible with the existing space limitations. In addition, a beam dynamics analysis showed that superconducting quarter-wave resonators such as in use at other facilities to accelerate heavy ions are not suitable in our energy range for light ions. Hence, a new design in form of superconducting half-wave resonator (HWR) structures was worked out.

For establishing this design, a large number of obstacles had to be overcome and new solutions for many crucial details had to be found. An international review committee scrutinized the proposed design and found that this project could make significant contributions to the development in this field of accelerator technology. Their encouragement and recommendations paved the way from design to construction.

Figure 1 shows the injector area and gives a detailed layout of the injector linac components. The cryogenic plant is not included in this picture, because the compressors will be located outside the building to sufficiently suppress mechanical vibrations.

ION SOURCES

The ion source complex located in the small annex will be able to deliver polarized and unpolarized H^- or D^- with an energy of 25 keV and pulses of up to 500 µs width at a repetition rate up to 2 Hz. Two ion sources are foreseen, a commercial multi-cusp source that is already delivered and the adapted CIPIOS source of Indiana University (IUCF). The contract for delivery has already been signed and also includes the electrostatic low energy beam-transport system. In addition, a collaboration with the INR-institute (Troitzk) was established to further improve the performance of this source. First results of this work, still obtained at IUCF, succeeded in significantly reducing the electron current emission and reached a much higher peak current as well as an increased pulse width. The product of these values will determine the number of ions that can be injected into COSY.

RFQS

The subsequent radio-frequency quadrupole (RFQ) section will be used to bunch the beam, accelerate the ions to 2.5 MeV/nucleon, and shape the phase space according to the requirements of the superconducting linac. As the velocity profiles are different, each ion species needs its own RFQ. The RFQs will be mounted alongside each other on a mechanical rail system to allow switching the ion species in less than one working day. Phase-space matching is achieved using 2 quadrupole doublets in combination with an rf-cavity, acting as a rebuncher [2]. The RFQs and the rebuncher cavity have been designed in collaboration with the University of Frankfurt/Main [3].

HALF-WAVE RESONATORS

The superconducting linac section comprises 11 unit cells plus an option for two further ones. Each cell is 1.7 m long. It contains at the outgoing end a quadrupole doublet for transverse focussing and a diagnostic box in between. The quadrupoles are designed for a maximum gradient of 45 T/m and will be operated in a pulsed mode to save electric power as well as space.

Although quarter-wave resonators have a proven record for the acceleration of heavy ions, the sensitivity of lighter ions to magnetic fields mandated the use of half-wave resonators. Four HWRs, made of ultra pure niobium and cooled close to 4 K, are grouped inside one cryostat without focusing elements. The resonators are arranged in two families. The first 20 resonators (β_{str}=0.11) operate at 160 MHz, and the following 24 resonators (β_{str}=0.2) operate at 320 MHz.

	160MHz	320MHz
β_{str}	0.11	0.2
R/Q	249	244
B_{peak}/E_{acc}	10.4	9.4
E_{peak}/E_{acc}	4.5	4

$$E_{acc} = \frac{\int_{-\infty}^{\infty} E(z)dz}{\beta\lambda}$$

Table 1: Characteristic data of the two HWR types with definition of E_{acc}.

The resonators have to provide very high acceleration gradients (6-8 MV/m) that are limited by the maximum magnetic fields tolerable inside the structure without quenching. To ensure reliable operation a design was chosen that limits the magnetic field to 80 mT in normal operation. The given acceleration gradient corresponds to 8 MV/m and will result in an average energy gain per resonator of slightly more than 1 MeV. The calculated distribution of the magnetic field in the resonator is shown in figure 2.

In close co-operation with industry, concepts for the manufacturing of such resonators have been developed. As no precedent for this type of rf-resonator exists, two companies have been selected to manufacture one prototype each. They use different manufacturing techniques for the critical 80 mT region, which ultimately will determine the performance. The final decision for the type of resonator to be used depends on the outcome of performance tests.

One of the cleaning ports at the resonator is used for rf-coupling. The coupler design has been developed in our institute and the manufacturing of a prototype is in progress. The design takes into account the pulsed operation of the linac and tries to minimize cryogenic losses for this operational mode. The coupling strength can be adjusted for the acceleration of ions or rf-conditioning of the resonators. Each resonator will be driven individually in amplitude and phase by a commercial pulsed 4 kW solid state amplifier. A prototype of this amplifier has been successfully tested.

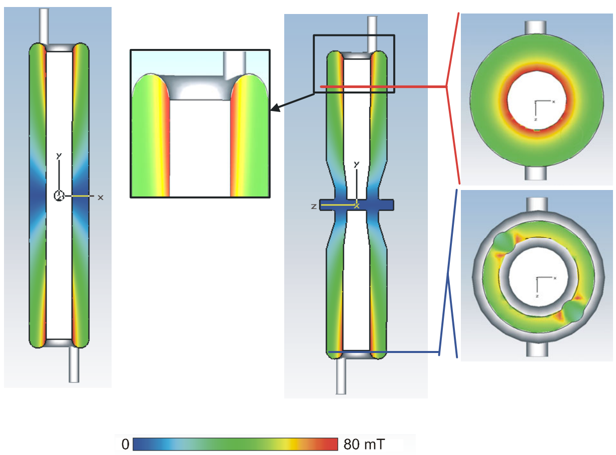

Figure 2: The magnetic field distributuion computed inside the cavity of the half-wave resonator. Sections perpendicular to (left) and in beam direction are shown with details of the most critical regions as indicated.

It is well known that superconducting resonators are very susceptible to microphonics due to their extremely narrow resonance curve. The mechanical vibration modes of the resonator have been studied with extensive simulations to arrive at a design with the necessary rf-stability for acceleration.

Another great concern in high performance super-conducting acceleration resonators for pulsed operation is the Lorentz force detuning. This effect becomes relevant as a result of the extremely high gradients reached inside such cavities, leading to a sizeable mechanical wall deformation and hence to a change of the resonance frequency well outside the allowed bandwidth. This change is proportional to the square of the peak rf-amplitude and has to be minimized by a careful choice of the structure. An extensive analysis has been carried out to establish the magnitude of this effect for the chosen design and for making appropriate design optimizations. The remaining detuning effect will be dealt with by a sophisticated adaptive feed-forward control system that employs piezo-actuators counteracting the deformation.

Also the development of an optimized cryostat is an issue of great concern as it affects to a high degree the operating costs of a superconducting injector. For a pulsed machine static losses and dynamic losses have to be carefully balanced. A further limitation exists in terms of the cryostat size, as the unit cell length may not exceed 1.7 m. This constraint is a consequence of the beam behaviour that can be expected from extensive beam dynamics simulation results. Protons and deuterons must move on stable trajectories in the required phase space during the entire acceleration process.

To conform to space requirements and at the same time keep thermal losses low, a design was developed for the cold-warm junctions of the beam ports of the cryostat, which had only a length of 60 mm. The calculated cryogenic loss of such a junction is only around 0.1 W. Figure 3 shows the results of the calculated thermal energy flow for such a cold-warm junction.

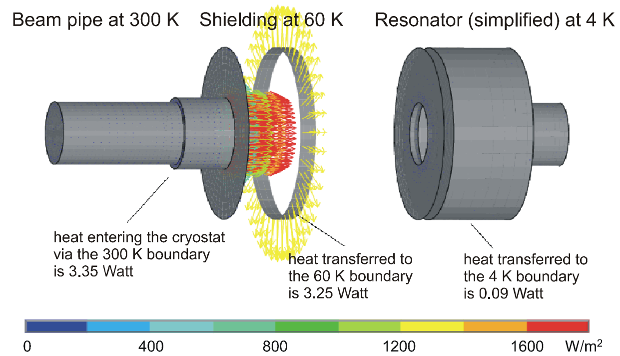

Figure 3: Calculated thermal energy flow for a cold-warm junction of the cryostat taking into account heat radiation and thermal conduction [4].

OUTLOOK

At the very end of the year 2002, due to unprecedented budget cuts imposed by the Federal Government, the Board of Directors of the Forschungszentrum Jülich has been left with no other choice but suspending the COSY-SCL project for at least two years. However, prototype work may proceed and first results can be expected during 2003/2004. The conviction that this new injector linac will be an important scientific gain for the COSY accelerator facility has not been diminished by this decision.

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