SUPERCONDUCTING LOW BETA NIOBIUM RESONATOR FOR HEAVY IONS

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Abstract

A High Current Injector, as an alternate injector for the superconducting linac, is currently under development at Inter-University Accelerator Centre. To provide some cushion for velocity matching of the beams from HCI, a superconducting low beta module is also being planned for which a new niobium resonator optimized for β=0.05 operating at 97 MHz, has been designed. This resonator has the highest frequency in its class among the superconducting structures designed for such low velocity particles. The resonator has been carefully modeled to optimize its parameters. Even though the frequency of the resonator is high, its physical dimensions are large enough to allow processing of the superconducting surface effectively. The first niobium prototype has been built and bead pull measurements have been done. It will be tested at 4.2 K shortly. This paper briefly presents the resonator design and fabrication; results from bead pull measurement and expected beam energy from the system.

INTRODUCTION

Presently the 15 UD Pelletron accelerator injects heavy ion beams into the superconducting booster linac at Inter-University Accelerator Centre (IUAC) [1]. In order to provide larger beam currents at high charge states than are currently available from the Pelletron accelerator, a high current injector (HCI) is being developed. In figure 1, a block diagram of the HCI system is shown. The high temperature superconducting electron cyclotron resonance (HTS-ECR) ion source [2] will inject heavy ion beams of mass to charge ratio (A/q) =6 at an energy of ~8 keV/u into a room temperature radio frequency quadrupole (RFQ) [3] which will accelerate it to ~180 keV/u. The beam would be further accelerated through a drift tube linac (DTL) section [4] which will have half a dozen tanks, the maximum number that can be accommodated in the new HCI-hall. The expected maximum energy at the end of the DTL section is around 1.8 MeV/u. However, long term stable operation may require restricting its operation to ~1.5 MeV/u only. This corresponds to a velocity β (=v/c)=0.056, which is very close to the lower velocity cut off of the quarter wave resonators employed in the linac [5]. In order to provide some cushion for velocity matching of the beams from HCI into the linac, a superconducting low beta module (LBM) is being planned after the DTL section. The low beta module, however, will be positioned in such a way that it can accelerate beams from HCI as well as the Pelletron accelerator. A new superconducting niobium quarter wave resonator optimized for β_0=0.05 operating at 97 MHz has been designed for this module.

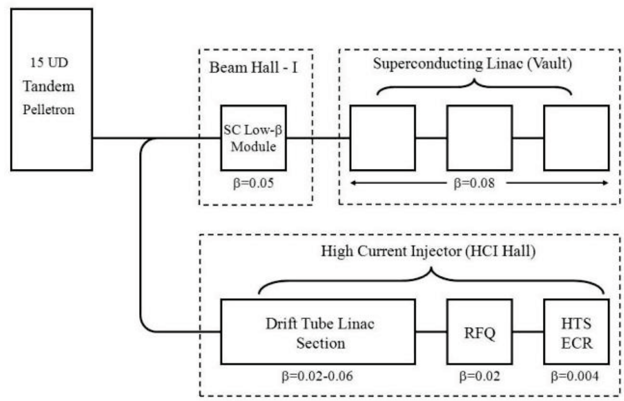

Figure 1: Block diagram of the HCI system. The dashed boxes indicate the location of the various components.

LOW β RESONATOR

Design

TEM class superconducting niobium resonators are used in linacs for accelerating heavy ions. Several variants of this class of structure have been designed and developed around the world [6]. Among them, the two gap quarter wave co-axial line resonator (QWR) is characterized by its excellent mechanical stability and broad velocity acceptance. In addition, QWRs are simpler to fabricate compared to other structures, although more number of resonators are required to reach the final beam energy. Over the past two decades many techniques have been developed to effectively address the extrinsic effects that limit the achievable accelerating gradient in niobium resonators and these have helped in pushing the gradients up [7]. Besides, it is well known that quarter wave resonators achieve higher gradients as compared to, say half wave structures [8]. Overall the QWR structure therefore offered a very good choice for the low beta resonator design.

The LBM will be located in beam hall-I (figure 1) where the ceiling height is slightly less than that in the linac vault. The overall height of the resonator was therefore an important design parameter. In order to restrict it we decided to keep the frequency high and chose 97 MHz, which is also the frequency of the quarter wave resonators used in the linac. The electromagnetic parameters of the low beta resonator were carefully optimized using Microwave Studio code [9]. The main goal in the optimization was to reduce the peak magnetic and electric fields in the resonator while maintaining high values for the shunt impedance and geometric factor, and a small value of stored energy. To achieve these, the drift tube length and accelerating gaps were chosen to obtain maximum energy gain. The central coaxial line was tapered and the tapering was gradually increased until the magnetic field reduced to a low value. Tapering the central conductor has the additional advantage of providing better mechanical stability while reducing resonance electron multipacting. In the second step of the optimization the diameter of the outer housing was gradually increased to further reduce the peak magnetic field while increasing the shunt impedance and geometric factor. However, beyond a certain diameter of the outer housing, the real estate gradient begins to suffer.

For frequency tuning of the resonator the existing slow tuner bellows design, which has been well tested and suitably modified for reliable performance [1], will be used. In table 1, the various parameters of the low beta resonator are shown. The resonator is jacketed with an outer stainless steel (SS) vessel which will hold the liquid helium needed for cooling it. This design was originally developed for the resonators employed in the IUAC-linac [5]. Details of the low beta resonator design can be found in reference 10. In figure 2, a cut away 3-D view of the resonator is shown.

Table 1: Design Parameters of the Low Beta Resonator

Resonance frequency f_0	97 MHz
Synchronous velocity β_0	0.051
Effective length L_{eff}	10.4 cm
Stored energy U_0 @ 1 MV/m	26 mJ
E_{Peak} @ 1 MV/m gradient	3.4 MV/m
B_{Peak} @ 1 MV/m gradient	64.2 G
Geometric Shunt impedance R_{sh}/Q	650 Ω
Geometry factor QR_s	16.1 Ω
Frequency tunability Δf_{ST}	100 kHz

Figure 2: Cut away 3D view of the low beta quarter wave resonator. The overall height is about 85 cm.

Niobium Prototype

After validating the electromagnetic parameters of the low beta resonator design on a room temperature copper model, the niobium prototype resonator was built. Except for the beam ports and the niobium flange that joins the tapered co-axial line to the outer housing; all other components are rolled or die-formed from sheet material. The central tapered co-axial tube was die-formed in a single length but in two halves and electron beam welded along the seam. The outer SS vessel was fabricated and then cut into two halves and brought around the resonator like a clamshell assembly. Where the niobium joined SS, flanges made of explosively bonded niobium-SS were used to provide the transition. In figure 3, the prototype niobium resonator is shown.

Bead pull measurements were performed on the niobium prototype to measure the various parameters of the resonator. The frequency tunability was measured using a mock slow tuner. In figure 4, the frequency perturbation data and transit time factor are shown. In table 2, the various parameters have been summarized.

(a) (b)

Figure 3: (a) Niobium outer housing (left) and central co-axial conductor (right), (b) low beta resonator complete with the outer SS vessel.

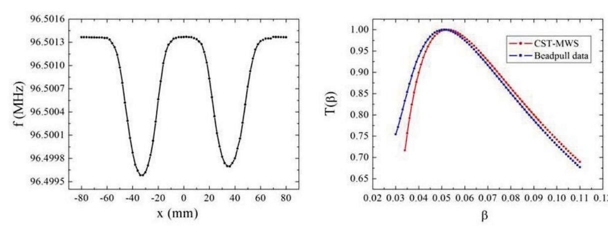

Figure 4: Bead pull measurement (left) and transit time factor (right) of the niobium prototype. The blue curve is from the bead pull measurement and the red curve is from Microwave Studio calculations.

Table 2: Parameters of the Prototype Resonator Obtained from Bead Pull Measurement.

Parameter	Measured value
f_0	96.5 MHz
β_0	0.051
U_0	26.4 mJ
R_{sh}/Q	620 Ω
Δf_{ST}	90 kHz

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LOW BETA MODULE

Numbers of Resonators

In figure 5, the final ion velocity β_f as a function of the initial velocity β_i for different number of low beta resonators in the cryomodule, all operating at the modest gradient of 5 MV/m, is shown. For finalizing the number of low beta resonators needed, we have assumed the initial velocity corresponding to an energy of ~1 MeV/u (β_i=0.046) keeping both the DTL section as well as the Pelletron accelerator in mind. At β_i=0.046 the final velocity with six resonators is ~0.056 which is very close to the lower velocity cut off of the QWRs in the linac. With eight resonators, however, the final velocity is ~0.059, which is better. At 6 MV/m gradient (not shown), this value is ~0.062. Keeping these in mind it has been decided to have eight resonators in the low beta module.

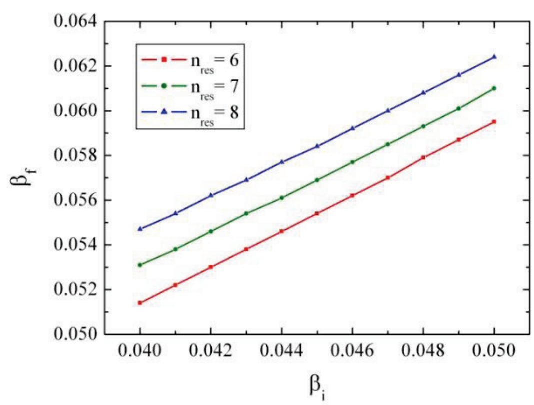

Figure 5: Final velocity β_f as a function of initial velocity β_i for different number of low beta resonators all operating at 5 MV/m accelerating gradient.

Energy Gain

Energy gain for beams from the two combinations, namely (i) HCI and superconducting linac, and (ii) Pelletron accelerator and linac, have been done. In figure 6, the energy gain for the HCI-Linac combination with and without the LBM, is shown.

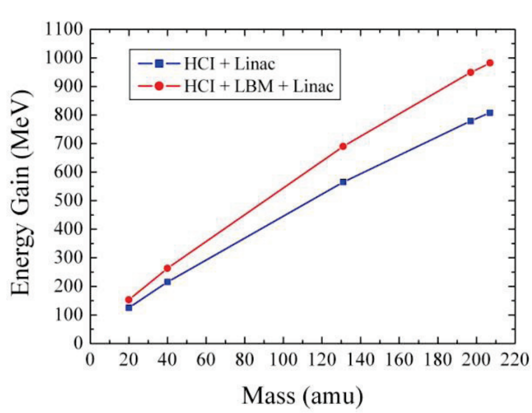

Figure 6: Energy gain as a function of ion mass for the HCI-Linac combination with and without the LBM.

For the HCI-LBM-Linac combination the beam energy out of the DTL section is taken to be 1.5 MeV/u. A foil stripper has been assumed after the DTL section for increasing the charge state of the ions. All resonators in the LBM were assumed to operate at 5 MV/m. Based on the operational experience with the superconducting linac, the QWRs in the linac were assumed to operate at 3.5 MV/m accelerating gradient.

In figure 7, the energy gain from the Pelletron accelerator-Linac combination with and without the LBM, is shown. Gas stripper in the terminal and foil stripper in the high energy dead section in the Pelletron (operating at 12.5 MV terminal potential) have been assumed. The resonator gradients in the LBM and linac are assumed to be 5 MV/m and 3.5 MV/m respectively.

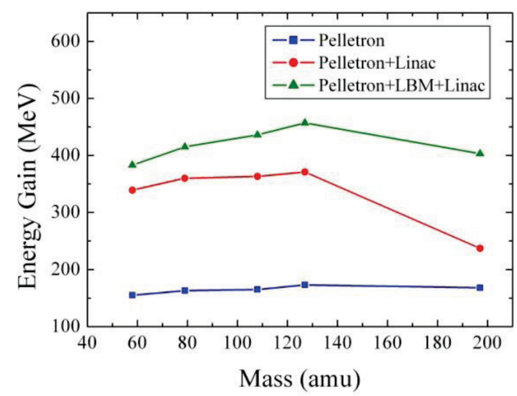

Figure 7: Energy gain as a function of ion mass for the Pelletron-Linac combination with and without LBM.

CONCLUSION

A new superconducting niobium quarter wave resonator for the low beta module has been designed and the prototype has been built. It will be tested at 4.2 K shortly.

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