MECHANICAL DESIGN OF A 161 MHZ, β=0.16 SUPERCONDUCTING QUARTER WAVE RESONATOR WITH STEERING CORRECTION FOR RIA

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Abstract

The RIA driver designed at MSU includes 161 MHz, β_0=0.16 superconducting Quarter Wave Resonators with steering correction. The rf design of the cavity was previously performed at MSU and used in beam dynamics simulations for RIA. The cavity mechanical design and final rf simulations have been performed at LNL, resulting in a double-wall structure with short length along the beam line, compatible with both separate vacuum between beam line and cryostats or unified one. This design can be easily extended to different frequencies, e.g. to obtain the 80 MHz β_0=0.085 cavity required in RIA, and it could be used also in the high intensity deuteron injector of the SPES project at LNL. The construction of the prototype has recently started. The cavity mechanical design characteristics and their influence on rf behavior will be presented and discussed.

INTRODUCTION

The RIA project requires a wide-β superconducting linac driver able to accelerate all ion masses from protons to Uranium. The low-β part of this linac can be made of Quarter-Wave resonators, taking advantage of their high performance, mechanical stability and low cost. NSCL-MSU have studied and proposed a layout including 16, β_0=0.042 and 56, β_0=0.085 QWRs working at 80.5 MHz, followed by 81, β_0=0.16 QWRs working at 161 MHz [1]. Beam dynamics simulations have demonstrated that this section can accelerate simultaneously $^{239}U^{28,29+}$ with a 20% emittance growth which is negligible compared to the one introduced by the strippers required by the linac [2]. However, all this increase was observed in the 161 MHz section due to a typical QWR steering [3] that could be compensated by a proper shaping of the QWR in the drift tube- beam port region [4]. A prototype of the RIA 161 MHz QWR with steering correction was designed and is presently under construction in collaboration between Michigan State University and Laboratori Nazionali di Legnaro. A simplified prototype without a helium vessel was successfully tested [5].

CAVITY DESIGN

The resonator shape was studied first at NSCL and used in beam dynamics simulations with realistic field, with the aim of determining the optimum correction angle; this was found to be 9°. Starting from this shape, a complete niobium cavity was designed at LNL; rf properties, mechanical properties and their interactions have been studied and optimised by means of computer simulation using the codes HFSS and I-DEAS.

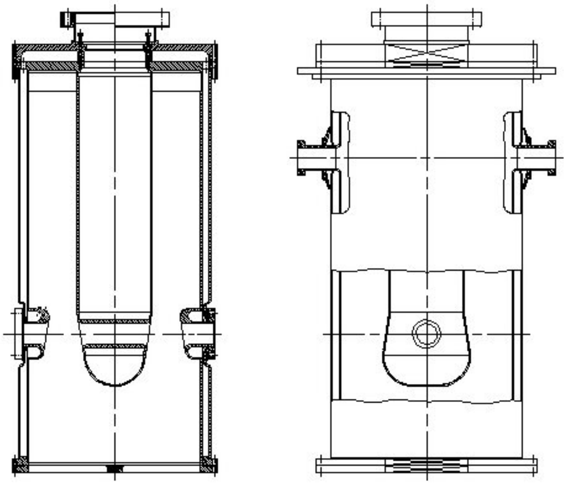

Figure 1: The 161 MHz β=0.16 MSU RIA QWR.

Mechanical Design

The resonator is a coaxial QWR with a double wall structure similar to the LNL and TRIUMF niobium QWRs [6][7]; the double wall is, at the same time, a reinforcing component of the structure and the helium reservoir. The top flange is connected to the niobium top plate, near the edge of its central opening, by means of screws. This solution was tested first in the TRIUMF QWRs and allowed reducing by about 50% the rf frequency sensitivity to helium pressure variations. The beam ports and the drift tube faces have been modified, compared to the standard LNL design, in order to produce beam steering compensation in a wide range of β. This was obtained by tapering of the final part of the inner conductor, without changing the tube perimeter, to obtain a triangular flat area for the drift tube; a cold formed end cup is welded to terminate the tube. The usual outer- to inner-conductor diameter ratio was changed from 3 to 2.31 mainly to increase the available flat surface. The beam ports, with 9° tilting angle, are terminated by means of NbTi, conflat type vacuum flanges; this allows beam vacuum separation in the cryostat without increasing significantly the cavity physical length. It should be noted

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that the active length of the resonator, 240 mm, is 84% of the real estate one.

RF Design

The rf cavity parameters, calculated by means of the code HFSS, are shown in Table 1. The significant parameters are typical of QWR structures, although the large cavity diameter leads to a relatively large stored energy. The magnetic field at the contact between the tuning plate and the resonator bottom flange is 1.5 G/(MV/m); this is acceptable at the RIA design field (E_p=16.5 MV/m) and allows good tuning sensitivity.

Frequency	f_0	161	MHz
Optimum velocity	β_0	0.16	
Stored energy	U/E_a^2	0.147	J/(MV/m)^2
Peak magnetic field	B_p/E_a	106	G/(MV/m)
Peak electric field	E_p/E_a	~5	
Shunt impedance	R_{sh}/Q_0	1620	Ω/m
Geometrical factor	R_sQ_0	34.2	Ω
Tuner sensitivity	$\Delta f/\Delta h$	6	kHz/mm
Active length	L	240	mm
Real estate length	L_{re}	286	mm

Table 1: Resonator RF parameters calculated by means of the HFSS code.

Dynamic Behaviour

Mechanical simulations have been made with the code I-DEAS; results are presented in Table 3. The material characteristics used in the simulation are listed in Table 2.

To provide modal analysis of the resonator, the total 3D model of the double wall structure was used, with the mechanical load of 1 Bar pressure between the walls. The maximum stress in the structure is well below the Nb Yield strength at room temperature.

Tensile strength	1.8*10^5	mN/mm^2
Yield strength (0.2%)	8*10^4	mN/mm^2
Modulus of elasticity	1.06*10^8	mN/mm^2
Poisson ratio	0.374	
Shear modulus	3.87*10^7	mN/mm^2

Table 2: Nb Mechanical properties used in the calculations

The mechanical frequency of the inner conductor oscillation, the lower mode of the structure, is near 280 Hz; the next mode, the outer conductor oscillation, is near 400 Hz (see Figure 2). These values are well above the frequency range of the main environmental noise and no mechanical damper is foreseen in the cavity; however, a LNL type damping mechanism could be easily welded to the stainless steel top flange, if required.

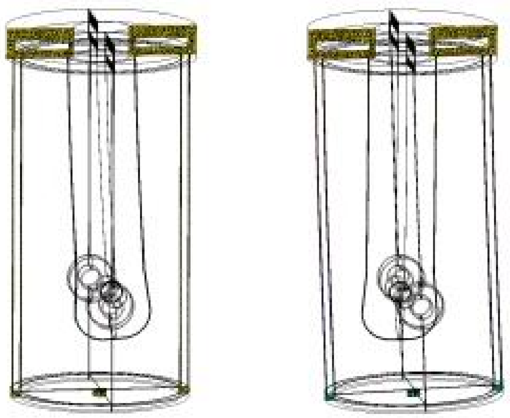

Figure 2: Lower frequency mechanical modes from I-DEAS

The frequency response to mechanical deformations has been calculated by means of the Slater theorem. This is comparable, as well as Lorentz force detuning, to the one of the LNL and TRIUMF resonators of the same family, and can be compensated by means of slow mechanical tuning in feedback.

He P detuning	$\Delta f/\Delta p$	1.5	Hz/mBar
Lorentz F. det.	$\Delta f/E_a^2$	0.66	Hz/(MV/m)^2
1Bar stress		2.83*10^4	mN/(mm^2*Bar)
mech. mode 1	$f1_{mech}$	282	Hz
mech. mode 2	$f2_{mech}$	399	Hz

Table 3: Resonator mechanical-rf parameters from I-DEAS and HFSS simulations.

DESIGN EXTENSION TO 80.5 MHZ

Using modular design and components in different linac sections, while keeping optimum performance, allows reduction of cost and risk in cavity and cryomodule production.

A very natural way to produce a modular QWR design is changing the resonators β_0 simply by changing their length (thus their rf frequency); this was previously done, e.g., at LNL [6]. The 80.5 MHz β_0=0.085 QWR and 322 MHz β_0=0.285 half-wave resonator for RIA have the same diameter inner and outer conductor as the 161 MHz QWR, and therefore can use the same mechanical design. For the 80.5 MHz QWR, the only changes from the 161 MHz cavity are the axial length, doubled to reach the lower frequency, and a reinforcing ring in the double wall outer conductor, inserted to prevent weakening of the cavity structure against helium pressure, as shown in Figure 3.

Steering correction by drift tube-beam port re-shaping, as shown in the figure, is of course possible; however, beam dynamics calculations suggest that the cavity aspect ratio allows good correction simply by a slight displacement of the beam port axis.

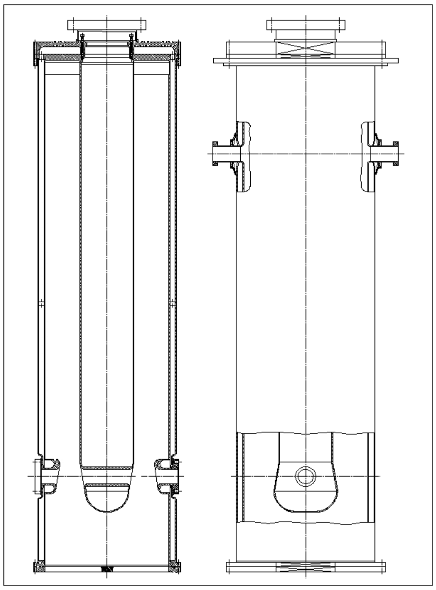

Figure 3: 80.5 MHz, β_0=0.08 QWR with steering correction (the angle in the drawing is arbitrary).

CONCLUSIONS

A 161 MHz, β_0=0.16 quarter wave resonator with steering correction was designed for the low-β section of the RIA driver. The calculated cavity parameters, both from the mechanical and rf point of view, are satisfactory and consistent to operation according to the RIA requirements. This design can be extended to the 80.5 MHz, β_0=0.085 QWR and 322 MHz β_0=0.285 half-wave resonator resonators for RIA with minor changes.

Construction of the complete resonator prototype has started and first testing is foreseen at the beginning of 2004.

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