EXPERIMENTAL STUDY OF A 322 MHz v/c=0.28 NIOBIUM SPOKE CAVITY*

T.L. Grimm†, J. Bierwagen, S. Bricker, C.C. Compton, W. Hartung, F. Marti, R.C.York
National Superconducting Cyclotron Laboratory, Michigan State University, E. Lansing, MI, USA

Abstract

The Rare Isotope Accelerator (RIA) will accelerate heavy ions to >400 MeV/u using an array of superconducting cavities. A proposed linac design based on harmonics of 80.5 MHz will require six cavity types to cover the entire velocity range: three quarter wave resonators, one spoke cavity (half wave resonator), and two 6-cell elliptical cavities. A prototype 322 MHz niobium spoke with optimum velocity of 0.28c has been fabricated. Each spoke would generate over 1 MV at 4 K for acceleration from v/c=0.20 to 0.40. Details of the design and experimental study are presented.

INTRODUCTION

The Rare Isotope Accelerator (RIA) driver linac is designed to accelerate heavy ions to 400 MeV/u (β=v/c=0.72) with a beam power up to 400 kW [1]. To obtain these intensities, partially stripped ions are accelerated in a 1400 MV superconducting linac. A design based on the 80.5 MHz harmonic requires six cavity types as shown in Table 1 [2]. Two of the cavity types were developed for other linacs and the remaining four are variants of these two. This paper presents the design and experimental results of the 322 MHz niobium spoke cavity with an optimum β, β_{opt}=0.28.

Table 1: Overview of RIA Driver Linac Cavities (80.5 MHz harmonic).

β_{opt}	f(MHz)	Type	Status
0.041	80.5	$\lambda/4$	Developed for INFN Legnaro [3]
0.085	80.5	$\lambda/4$	Prototype in Fall 2003 [4]
0.160	161	$\lambda/4$	Prototype in Summer 2003 [4]
0.285	**322**	**Spoke $\lambda/2$**	**Demonstrated in 2002**
0.49	805	6-cell Elliptical	Demonstrated in 2002 [5]
0.63	805	6-cell Elliptical	Developed for SNS [6]

*Work supported by Michigan State University
†grimm@nscl.msu.edu

DESIGN AND FABRICATION

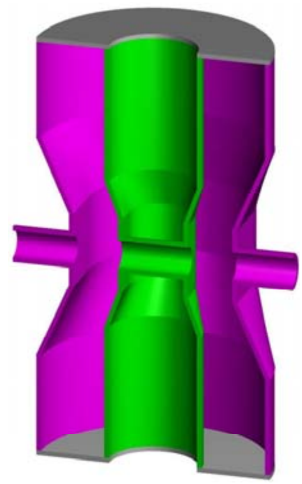

Figure 1: Cross section of spoke

The spoke cavity (or half-wave resonator) design is based on coaxial tubes that are formed using dies and mandrels. Sheet and plate niobium of RRR>150 was used. The inner and outer tubes, 24 cm and 10 cm inner diameter, are formed from 2 mm sheet. The beam ports and rf coupling ports are identical and at the median plane, which requires capacitive coupling for the rf. The beam aperture is 3 cm. These four ports are the only access to the cavity for chemistry and high-pressure rinse. They are indium sealed providing beamline and cryostat vacuum isolation. No helium vessel is required for this prototype to quickly verify electromagnetic performance and address multipacting and microphonic issues. Lorentz detuning is not a concern for RIA since it is a cw machine.

Table 2: Design parameters of spoke

Design Specifications	
Type	$\lambda/2$
β_{opt}	0.285
f (MHz)	322
V_{acc} (MV)	1.04
T (K)	4.2
Q_o	2.5×10^8
P_o (W)	21.8
U (J)	2.68
R/Q (Ω)	199
R_s (nΩ)	244
E_{peak} (MV/m)	16.5
B_{peak} (mT)	45.3

Table 2 shows the electromagnetic design parameters of the cavity [7]. A single-spoke cavity with two accelerating gaps was chosen to cover the velocity range from v/c=0.20 to 0.40. While multi-spoke structures could decrease the number of units, it would require more than one cavity type of increased complexity [8]. Figure 2 shows the effective accelerating voltage of the driver linac cavities through the acceleration chain.

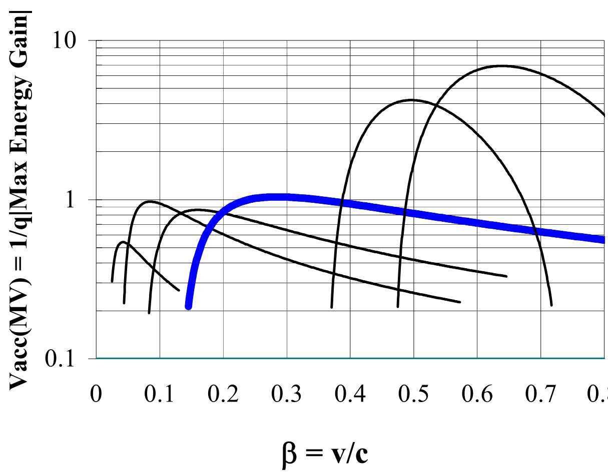

Figure 2: Effective accelerating voltage of driver linac cavities. The 322 MHz spoke is shown boldfaced/blue.

Electron beam welding with pressure less than $3x10^{-5}$ torr was used to join the niobium parts. All parts were etched >10 µm prior to welding. Figure 3 shows all of the niobium parts before final electron beam welding. After welding was complete, a final etch of 120 µm using pumped and chilled 1:1:2 buffered chemical polish was performed. Next the cavity was high-pressure rinsed for an hour and allowed to dry in a Class 100 cleanroom. Finally the vacuum ports and antennae were attached and the cavity installed on the dunking Dewar insert prior to testing as shown in Figure 4 [9].

Figure 3: Niobium parts before final welding.

Figure 4: Spoke cavity on the dunking Dewar insert.

EXPERIMENTAL RESULTS

The electric field profile along the beam axis was measured using a bead pull technique and is shown in Figure 5. The field unflatness was relatively small at 2.5 %. During the first test in December 2002, the input and pickup couplers were fixed with coupling strengths, Q_{ext}, of $1.4x10^{9}$ and $1.6x10^{11}$ respectively.

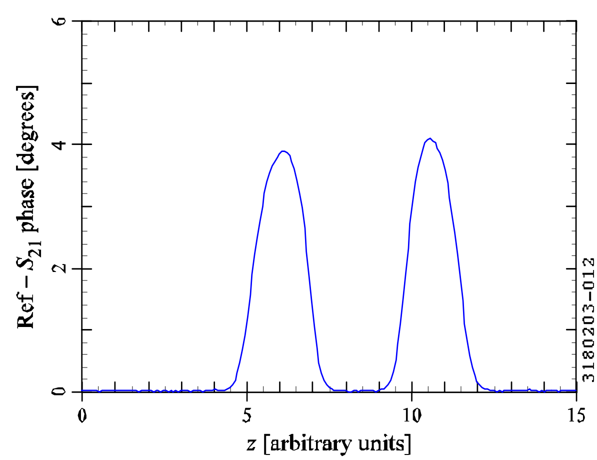

Figure 5: Bead pull measurement showing the electric field profile along the beam axis.

No bakeout of the cavity was performed and the base pressure was $1.6x10^{-8}$ torr at which point the cavity was cooled to 4.3 K. Conditioning took about 1 hour to remove multipacting barriers at peak electric fields, E_p, of 0.25-0.45 MV/m. These barriers were consistent with calculations showing one-point multipacting on the outer conductor at the high electric field region.

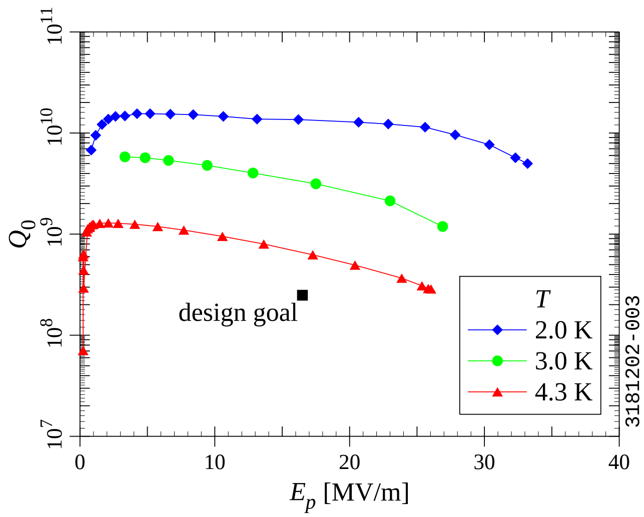

Figure 6: Cavity quality factor versus peak electric field.

The cavity quality factor, Q_0, was measured versus peak electric field at 2-4.3 K and shown in Figure 6. The design goal for operation at 4.3 K is also shown in Figure 6 with performance significantly exceeding it. In March 2003, the cavity was retested with a higher input Q_{ext} of $5x10^9$. Similar peak fields were obtained, and a residual surface resistance of 5 nΩ was confirmed.

Measurements of frequency detuning due to microphonics, pressure and the Lorentz force were made. Since the helium vessel will further stiffen the cavity, the values reported here are upper limits to those anticipated in an operating linac. The pressure detuning was –264 Hz/torr, and the Lorentz detuning coefficient (in terms of E_p) was –1.56 Hz/(MV/m)^2. Microphonics measurements show a total frequency shift of ±4 Hz due to several driving terms such as the cleanroom blowers with vibrations at 14 and 50 Hz, and the turbo pump at 458 Hz.

CONCLUSION/FUTURE PLANS

The 322 MHz spoke has significantly exceeded design specifications at 4.3 K of Qo>$2.5x10^8$ and peak electric fields greater than 16.5 MV/m. An extremely low residual surface resistance of 5 nΩ was measured which opens up the possibility of economically operating this cavity at less then 4 K. Multipacting barriers were easily conditioned without baking or adjustable power couplers. Measured frequency detuning due to microphonics, pressure and Lorentz force were at acceptable levels for RIA and would likely be smaller once a helium vessel is added.

Designs are underway to incorporate a titanium helium vessel, tuner and high power coupler, and test the cavity under realistic operating conditions in a RIA horizontal cryomodule. A prototype cryomodule is under construction for the RIA 6-cell structures that can be modified for the spoke cavity [10]. To date, four of the six cavity types for the 80.5 MHz RIA driver linac have been demonstrated and the remaining two should be tested in 2003.

ACKNOWLEDGEMENTS

The authors are grateful to Peter Kneisel (Jefferson Laboratory) and Alberto Facco (INFN Legnaro) for their advice and guidance.

REFERENCES

[1] "The Rare-Isotope Accelerator (RIA) Facility project", C.W. Leemann, in Proceedings of the XX International Linac Conference, Monterey, CA (2000).
[2] Proceedings of the RIA Driver Workshop II, Argonne, IL (May 2002).
[3] "Completion of the LNL Bulk Niobium Low Beta Quarter Wave Resonators", A. Facco and V. Zviagintsev, in Proceedings of the 9th Workshop on RF Superconductivity, Santa Fe, NM (1999).
[4] To be presented at the 11th Workshop on RF Superconductivity, Lubeck/Travemunde, Germany in September 2003.
[5] "Status Report on Multi-Cell Superconducting Cavity Development for Medium-Velocity Beams", W. Hartung, C.C. Compton, T.L. Grimm, R.C. York, G. Ciovati, P. Kneisel, these proceedings.
[6] "Superconducting Prototype Cavities for the Spallation Neutron Source (SNS) Project", G. Ciovati, P. Kneisel, K. Davis, K. Macha and J. Mammosser, in Proceedings of the 8th European Particle Accelerator Conference, Paris (2002).
[7] Analyst, Simulation Technology and Applied Research, Inc., WI (http://www.staarin.com).
[8] "The RIA Driver Linac", K.W. Shepard, in Proceedings of the XXI International Linac Conference, Gyeongju, Korea (2002).
[9] "Superconducting RF Activities at NSCL", T.L. Grimm, W. Hartung, H. Podlech, and R.C. York, in Proceedings of the 10th Workshop on RF Superconductivity, Tsukuba, Japan (2001).
[10] "Cryomodule Design for the Rare Isotope Accelerator", T.L. Grimm, M. Johnson, R. C. York, P. Kneisel and L. Turlington, these proceedings.