CONCEPTUAL DESIGN OF A LOW-β SC PROTON LINAC*

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Abstract

In this paper we discuss the conceptual design of a low-β superconducting proton linac based on multi-gap spoke resonator structures. We have demonstrated the feasibility of using superconducting accelerating structures throughout a proton linac for high-peak current applications. The injection energy for this linac is assumed to be 6.7 MeV, which equals the output energy of the CW RFQ built for the Low-Energy Demonstration Accelerator now operating at Los Alamos. The beam is accelerated to 109 MeV using multi-gap spoke resonators. Both 2-gap and 3-gap cavities are used in three accelerating sections with geometric-β values of 0.175, 0.2, and 0.34. Higher beam energies can be achieved by transitioning to elliptical superconducting cavities to further accelerate the beam. Preliminary beam-dynamics simulation results are shown and discussed.

1 LINAC DESIGN AND LAYOUT

This work was completed for the Advanced Accelerator Applications (AAA) program to develop an entirely superconducting (SC) linac for the Accelerator-Driver Test Facility (ADTF). The ADTF will require a 600-MeV 13.3-mA CW beam. We discuss only the design of the low-energy part of this linac using multi-gap spoke resonators to accelerate the beam from 6.7 MeV to 109 MeV [1]. Elliptical superconducting cavities will be used to accelerate the beam to higher energies. Table 1 shows the details of the accelerator design layout. The design and operating parameters were selected assuming an input beam from the LEDA CW RFQ operating at Los Alamos. A relatively detailed cryomodule layout was required to minimize the cryomodule length. Figure 1 shows schematic layouts of the cryomodules including the RF. Figure 2 shows a more detailed drawing of a Section 2 cryomodule. Figure 3 shows a cutaway view of a Section 1 2-gap resonator designed for ADTF [2]. Transverse focusing is achieved through the use of SC solenoids inside each cryostat. Using low-β SC structures has many practical advantages. Some of these are significant electrical power savings, reduced beam losses due to larger structure apertures, and increased reliability due to the use of lower-power RF systems.

The number of multi-gap spoke resonator types and other design parameters were chosen so as to efficiently capture and accelerate the RFQ beam. The geometric-β and number of gaps/cavity of the Sec. 1 cavities were chosen to give reasonable transit-time factors at low beam velocity and to give a cavity geometry that can successfully be manufactured. Additionally, we attempted to avoid beam envelope instabilities and to provide a nearly current-independent focusing lattice. We are presently examining designs that use only two types of spoke resonators (β=0.175 and β=034).

Our studies showed that at low beam velocities we could not readily take full advantage of the high accelerating gradients available with SC cavities. We found it necessary to adiabatically ramp the accelerating gradients to avoid excessively high longitudinal phase advances and resulting beam losses. It should be noted that our choice of parameters is probably not yet optimized.

Table 1: Superconducting Linac Design Parameters

	Section 1	Section 2	Section 3
Structure Type	2-gap spoke	3-gap spoke	3-gap spoke
Frequency (MHz)	350	350	350
Cavity Geometric Beta	0.175	0.2	0.34
Cavity Bore Radius (cm)	2.0	3.5	4.0
L-cavity (active) (m)	0.10	0.20	0.33
L-cavity (physical) (m)	0.20	0.30	0.43
L-magnet (m)	0.15	0.15	0.15
L-warm-space (m)	0.30	0.30	0.30
L-cryomodule (m)	4.23	5.80	6.62
L-cryoperiod (m)	4.53	6.10	6.92
L-focusing period (m)	2.26	3.05	3.46
Cav/cryomodule	4	6	6
Cav/section	32	48	48
No. of cryomodules	8	8	8
DW/cav (MeV)	0.08 – 0.35	0.34 - 0.78	0.86 - 1.40
Synchronous Phase (deg)	-45 to –32	-32	-32 to –28
EoT (MV/m)	1.13 - 4.16	2.02 - 4.68	3.06 - 4.76
Win,section (MeV)	6.7	14.17	43.54
Wout,section (MeV)	14.17	43.54	109.04
DW/section (MeV)	7.47	29.37	65.50
Section Length (m)	36.21	48.82	55.39
No. of Cavities / RF Generator	1	2	2
No. of RF Generators / Sec	32	24	24
Magnet Type	SC Solenoid	SC Solenoid	SC Solenoid
Magnet Field	1.80 - 2.32 T	2.50 - 4.00 T	4.00 - 5.40 T

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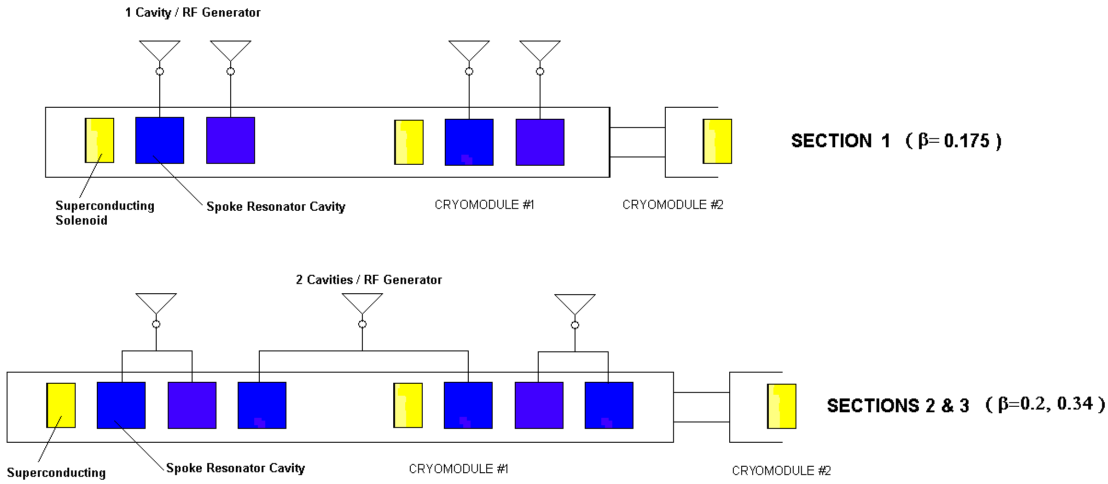

Figure 1: Cryomodule and RF Layout for the Muti-Gap Spoke Resonator Sections.

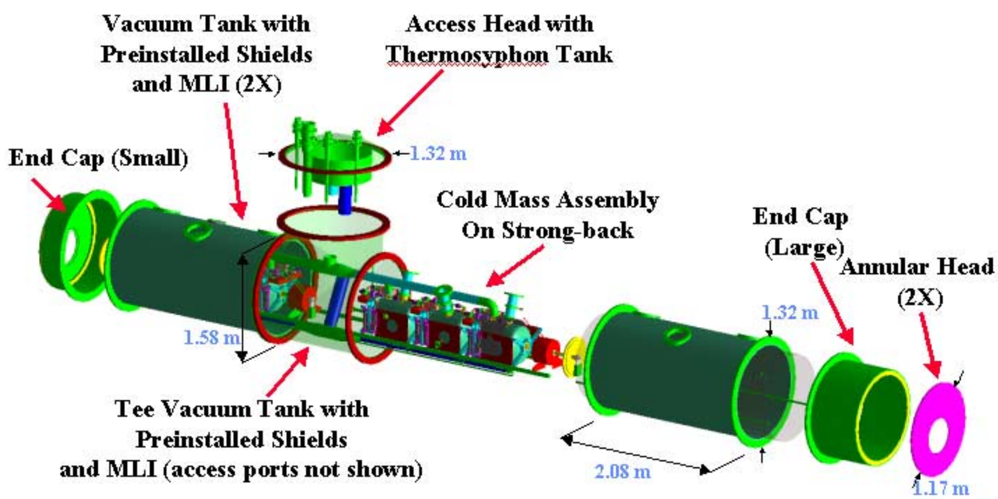

Figure 2: Conceptual Section 2/3 Cryomodule Layout.

The maximum zero-current transverse phase advance per period is chosen to be 82° and is allowed to vary to maintain a nearly constant transverse phase advance per unit length in each section. Since the cryomodules are long, a relatively large transverse phase-advance per period was chosen to provide the strongest possible focusing. Figure 4 shows the transverse and longitudinal phase-advances. The synchronous phase ramps in Sections 1 and 2 have been chosen to reduce the effects of RF defocusing and to more adiabatically capture the beam longitudinally. Additionally, to further aid in reducing the RF defocusing, the energy-gain per cavity (and hence, the peak-field per cavity) has been ramped from 0.08 MeV to 0.353 MeV. In the other sections, the accelerating gradient has been chosen to longitudinally match between sections while not exceeding 5 MV/m. Figure 5 shows the phase and amplitude ramps.

2 SIMULATION RESULTS

Beam dynamics simulations for the SC linac were completed for 0 mA, 13.3 mA, and 100 mA in order to investigate the current-independence of the design and to demonstrate performance at 100 mA for accelerator production of tritium. The 13.3-mA beam current is required for the AAA program. PARMTEQM simulations of the RFQ were run to produce 10,000 macroparticle distributions for each beam current. The LINAC code, modified to model the spoke cavities and solenoid focusing, was used to perform the SC linac simulations. No operational or alignment errors were included in the simulations presented here.

In order to match the RFQ output distributions to the SC linac, each beam distribution was transformed to have the rms-matched Twiss parameters as determined from

TRACE 3-D for each specific beam current. Work to design a matching section is presently in progress.

Figure 6 shows the maximum beam sizes, along with the accelerator apertures, plotted as a function of beam energy along the SC linac for the three beam currents. As can be seen, a large excursion of the beam is seen near 20 MeV for the 100-mA case. Examination of the simulation results showed that particles are falling out of the RF bucket, becoming off-energy, and eventually being lost transversely. At the resolution of these preliminary simulations, 3 x 10^{-4} beam loss was observed in Section 1 for the 100-mA case. No beam losses were observed for 13.3 mA. We have done additional studies that indicate these losses can be eliminated by choosing slightly

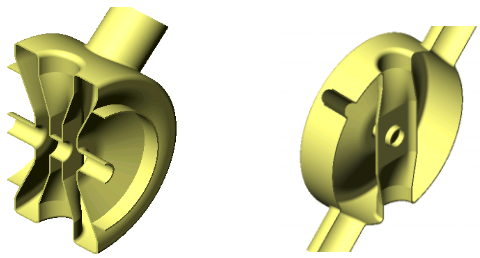

Figure 3: Cutaway of 2-Gap Spoke Resonator.

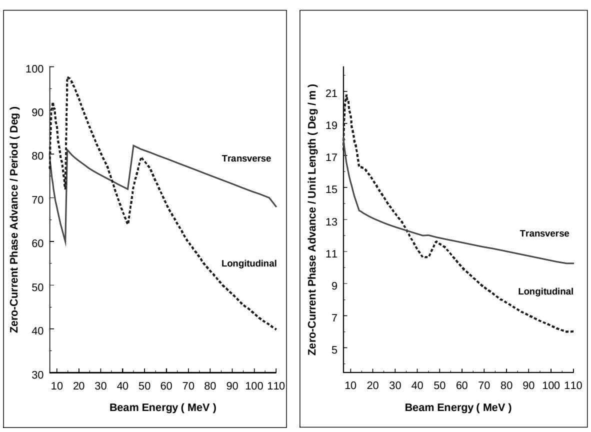

Figure 4: Transverse and longitudinal phase advances.

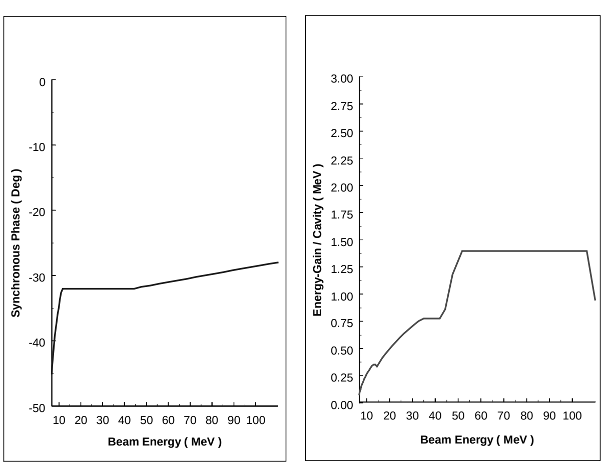

Figure 5: Synchronous phase and energy-gain ramps.

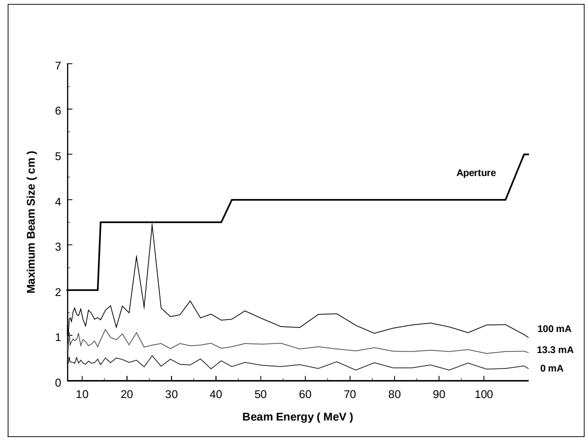

Figure 6: Maximum beam size as a function of beam energy for 0 mA, 13.3 mA, and 100 mA.

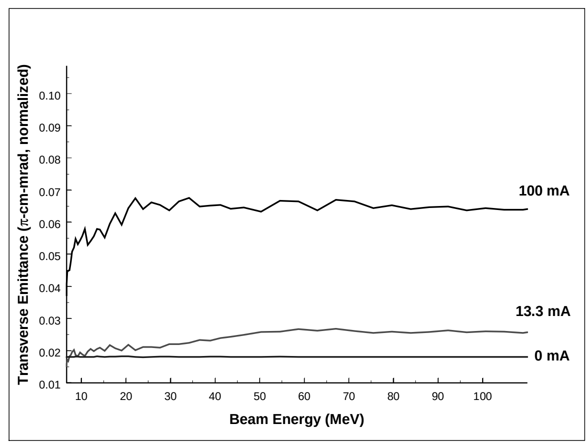

Figure 7: Transverse emittance as a function of beam energy for 0 mA, 13.3 mA, and 100 mA.

different synchronous phase and accelerating gradient ramps. Figure 7 shows the transverse and longitudinal emittances as a function of beam energy for 0 mA, 13.3 mA and 100 mA.

4 REFERENCES

[1] J. R. Delayen, W. L. Kennedy, and C. T. Roche, “Design and Test of a Superconducting Structure for High-Velocity Ions,” Proceedings of the 1992 Linear Accelerator Conference, Ottawa, Ontario, Canada, 24-28 August 1992, AECL Report AECL-10728, p. 695.

[2] F. Krawczyk and R. LaFave, “Design of a Low-β 2-Gap Spoke Resonator for the AAA Project,” these proceedings.