A COMPACT LINAC DESIGN FOR AN ACCELERATOR DRIVEN SYSTEM*

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Abstract

A compact linac design has been developed for an Accelerator Driven System (ADS). The linac is about 150 meters in length and comprises a radio-frequency quadrupole (RFQ) and 20 superconducting modules. Three types of half-wave cavities and two types of elliptical cavities have been designed and optimized for high performance at frequencies of 162.5, 325 and 650 MHz. The lattice was designed and optimized for operation with a peak power of 25 MW for a 25 mA – 1 GeV proton beam. The cavities RF design as well as the linac lattice will be presented along with end-to-end beam dynamics simulations for beam currents ranging from 0 to 25 mA.

COMPACT LINAC LAYOUT

Figure 1 shows a schematic layout of the proposed linac with its different sections. The linac is only 150 m in length taking advantage of the latest and successful normal conducting and superconducting RF developments at Argonne [1], especially developments of high cavity accelerating voltages [2] and compact cryomodule design [3]. For comparison, the proposed linac has half the length of the SNS linac [4] with the same 1 GeV output energy and a 25 mA CW proton beam. The key factors for a compact linac design are:

- Optimized superconducting cavity design for high voltage and low cryogenic losses.
- Superconducting solenoid focusing inside cryomodules to minimize warm transitions and consequently the number of required cryomodules.
- Cold BPMs attached to SC cavities inside the cryomodule to reduce the number of diagnostics required between cryomodules
- Horizontal and vertical steering correctors are built into the solenoids requiring no additional space for correctors along the beam-line.

With these considerations, the drift space between cryomodules is reduced, benefiting the beam dynamics from a more periodic focusing and acceleration sequence.

RF CAVITIES DESIGN

The base linac frequency is 162.5 MHz, it was mainly chosen because the CW RFQ requires less power and is more reliable in operation than at 325 MHz for example. At this frequency, half-wave (HWR) and single-spoke (SSR) resonators are more efficient for beta < 0.6 than other resonators. HWRs were chosen because of the mature fabrication and processing technologies available at Argonne. Figure 2 shows three types of half-wave resonators and two types of elliptical resonators. The cavity design frequencies are 162.5, 325 and 650 MHz. The low-β HWR is very similar to the one being constructed for the PXIE project [5] and could actually be used as is. Table 1 lists the RF performance parameters for the different cavity types and figure 3 shows the electric and magnetic field distribution in the HWR-2 and ELL-2 cavities. We can clearly distinguish between the electric and magnetic field regions. Making sure the surface fields are evenly distributed reduces their peak values.

LINAC LATTICE DESIGN

The lattice design is a very important step for any accelerator, it defines the acceleration and focusing profiles for the machine. The transition from one cavity type to the next has to be optimized based on the voltage a cavity can provide as function of the beam velocity or transit time factor. Figure 4 shows the voltage profile for the different cavities as a function of β, it also shows the transitions between cavity types. It is important to slowly ramp up the voltage for the lowest-β cavity to avoid rapid acceleration and beam blow-up. It is also important to provide sufficient and more frequent focusing in the first cryomodule to better control the space charge forces in the low-energy region, especially below 10 MeV. Table 2 gives the details of the lattice design, including cavity voltages and synchronous phases, the focusing period per section as well as the cavity, solenoid and cryomodule counts for each linac section.

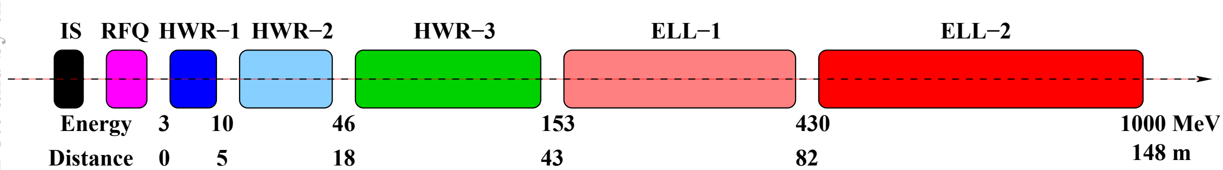

Figure 1: Layout of the proposed compact ADS linac showing the energies and dimensions of every section.

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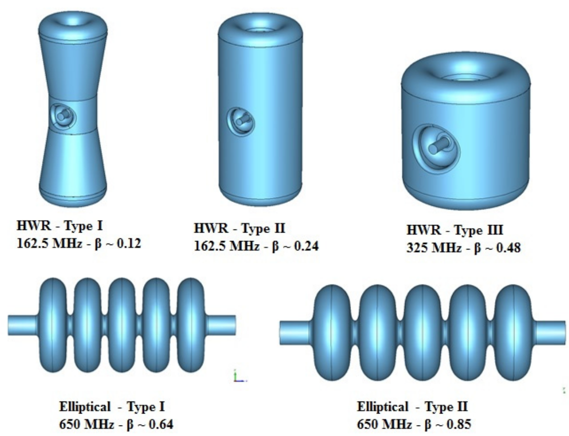

Figure 2: Types of cavities designed for the ADS linac at different β values and frequencies.

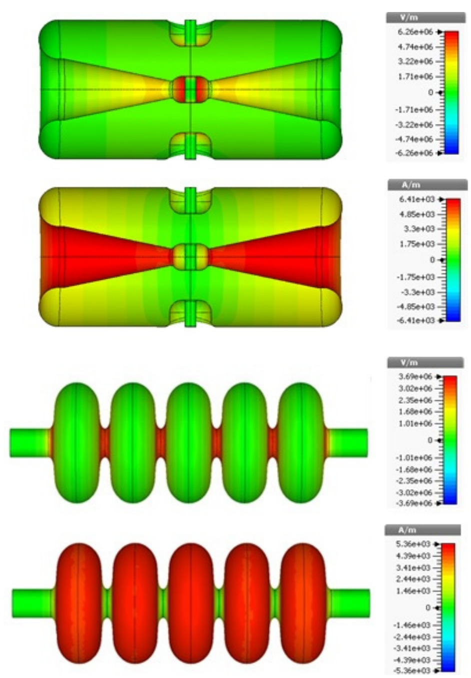

Figure 3: 3D electric and magnetic field distributions. The top two plots are for the HWR-2 cavity and the bottom two are for the ELL-2 cavity.

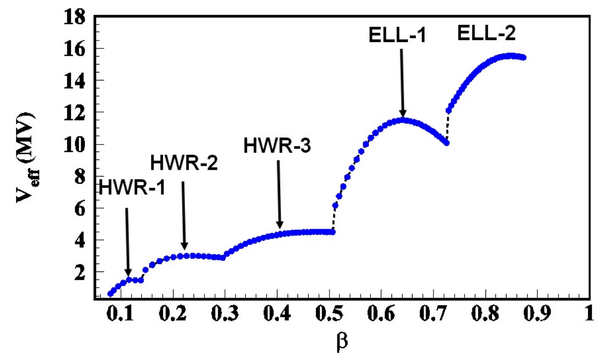

Figure 4: Voltage profile and transitions between cavity types as function of β.

PRELIMINARY BEAM DYNAMICS

Following the lattice design, beam simulations are required to check the longitudinal and transverse dynamics, especially the focusing and the matching between the different sections of the linac. Figure 5 shows the end-to-end TRACK simulation for a 0 mA proton beam, while figure 6 shows the longitudinal and transverse phase advances along the linac. The wave number, which is the phase advance normalized by the period length, displays the expected smooth damping especially in the transverse plane. Although satisfactory, the longitudinal wave number may benefit from better matching between the different linac sections.

Running a 25 mA beam through the same lattice and linac tune as for the 0 mA beam, we noticed significant longitudinal and transverse rms emittance growth. A simple optimization of the lattice and the tune reduced the longitudinal emittance growth from ~ 100% to ~ 33% as shown on figure 7. The remaining emittance growth is mainly due to space charge forces in the low-energy section of the linac and may not be avoidable.

Table 1: Cavities RF Design Parameters

Cavity type	HWR-1	HWR-2	HWR-3	ELL-1	ELL-2
Frequency, MHz	162.5	162.5	325	650	650
Optimum β	0.12	0.24	0.5	0.65	0.85
Effective length, cm	22.1	44.6	46.1	74.5	98.1
Epk/Eacc	5.0	4.8	4.1	2.5	2.4
Bpk/Eacc, mT/(MV/m)	5.9	6.2	7.9	4.6	4.4
R/Q ratio, Ω	293	332	292	377	551
G factor, Ω	50	73	117	192	236
Voltage at Epk=40 MV/m, MV	1.8	3.7	4.5	11.9	16.2
Voltage at Bpk=70 mT, MV	2.6	5.0	4.1	11.2	15.5

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Table 2: Linac Lattice and Sections Design. In the Cryostat Arrangement Line, (c) is for Cavity and (s) is for Solenoid.

Section	HWR-1	HWR-2	HWR-3	ELL-1	ELL-2	Total
Frequency, MHz	162.5	162.5	325	650	650	
Input energy, MeV	3	10	46	153	430	
Output energy, MeV	10	46	153	430	1001	
Voltage per cavity, MV	1.5	3.0	4.5	11.5	15.7	
Synchronous phase, deg	-30	-25	-25	-25	-25	
Cavities per cryostat	7	7	7	6	6	
Cryostat arrangement	7(sc)	3(s2c)sc	3(s2c)sc	2(s3c)	2(s3c)	
Number of cryostats	1	2	4	5	7	19
Number of cavities	7	14	28	30	42	121
Number of solenoids	7	8	16	10	14	55

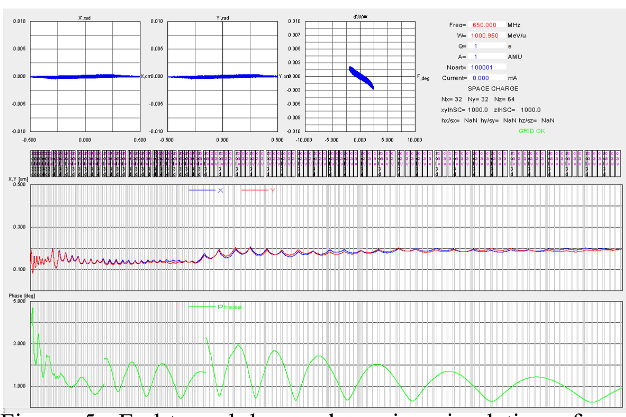

Figure 5: End-to-end beam dynamics simulations for a 0 mA proton beam from the input energy of 3 MeV to the full output energy of 1 GeV.

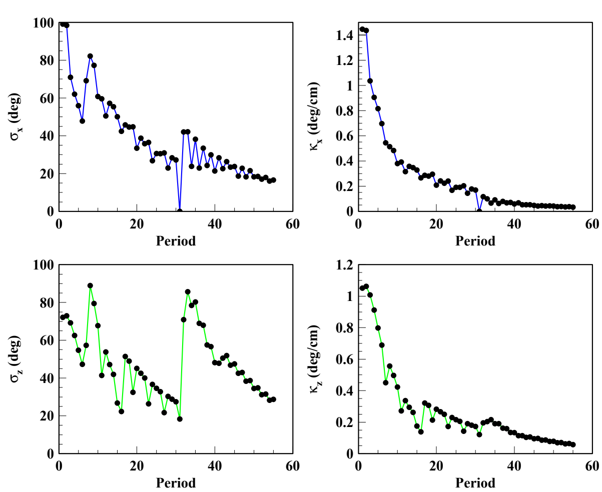

Figure 6: Transverse (top plots) and Longitudinal (bottom plots) phase advances and wave numbers per period along the linac.

The simple longitudinal optimization that helped reducing the emittance growth consisted of:

- lowering the voltage for HWR-2 cavities from 3 MV to 2.5 MV and ramping their phases from -30 to -25 degrees
- ramping the voltage in the first 3 cryomodules of the ELL-1 section from 9.5 MV to 11.5 MV and their phases from -25 to 20 degrees
- adding three ELL-2 cavities at the end of the linac to make up for the lost energy

Although simple, this optimization has led to a significant improvement in the longitudinal dynamics of the 25 mA beam. More detailed optimizations are underway for the low-energy section and the transverse beam dynamics. In order to test the robustness of the design, we are planning large scale error simulations and eventual beam loss analysis.

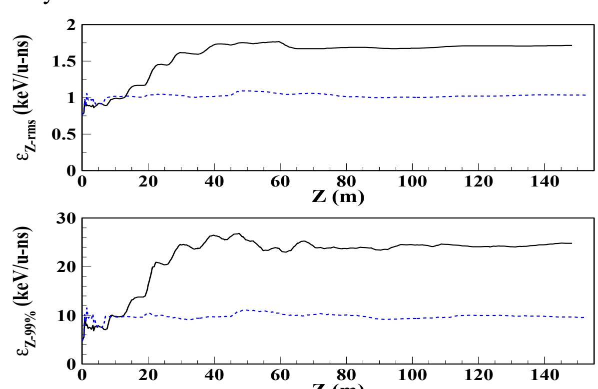

Figure 7: RMS and 99% longitudinal emittance along the linac before (black) and after (blue) the simple optimization of the linac tune for a 25 mA proton beam.

REFERENCES

[1] P.N. Ostroumov et al, "R&D towards CW Ion Linacs at ANL", Proceedings of Linac 2012, Tel Aviv, Israel, p 579.

[2] Z.A. Conway et al, "Reduced-beta Cavities for High-Intensity Compact Accelerators", Proceedings of Linac 2012, Tel Aviv, Israel, p 621.

[3] Z.A. Conway et al, "Cryomodule Designs for Superconducting Half-Wave Resonators", Proceedings of Linac 2012, Tel Aviv, Israel, p 627.

[4] N. Holtkamp, "Status of the SNS Linac", Proceedings of Linac 2004, Lubeck, IL, USA

[5] Z. Conway et al, "First Experimental Results for the Superconducting Half-Wave Resonators for PXIE," MOPP001, These Proceedings, LINAC 2014, Geneva, Switzerland.