BEAM DYNAMICS ISSUES OF SPES-1 LINAC

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Abstract

An Independent Superconducting Cavity Linac able to accelerate 10 mA CW proton beams up to 20 MeV has been studied for the SPES-1 project. This paper presents the results of beam dynamics studies through SPES linac including mapped fields effects on cavities.

INTRODUCTION

The first time step of SPES [1] realization is the creation of a two-way facility able, on one hand, to accelerate a 10 mA protons beam up to 20 MeV for nuclear studies and, on the other hand, to accelerate a 30 mA protons beam up to 5 MeV for cancer therapy and preliminary ADS studies. TRASCO RFQ [2] is used to accelerate beam up to 5 MeV in both cases. Utilization of an accelerator optimized for high current, for relatively low current requires some care [3]. Even if transversal dynamics may be readjusted through beam re-matching at RFQ input, this is not the case for longitudinal one. Separatrix width results larger than necessary and betatron oscillations are too small in number to let good thermalization of longitudinal distribution.

Linac structure has been optimized for this particular distribution in order to guarantee the lowest possible transversal and longitudinal emittance increase, minimum halo formation and complete transmission.

LINAC DESIGN

Linac is structured in two large cryostats (see Fig. 1) with a warm doublet in between that facilitates transversal matching. The linac lattice is based on a doublets structure. The focusing elements are short quadrupoles mounted inside cryostats; the number of cavities between quadrupoles increases with β. The required quadrupole gradient can be reached both by normal conducting and superconducting magnets. Superferric quadrupoles [4], combining a very compact size with a low power dissipation in the cryostat, have been found to be an excellent solution for this linac. A potential drawback is the residual magnetic field of the iron core, which must be shielded below 1 μT during cavity cooldown to prevent performance degradation of the nearby superconducting cavities. To ensure full transmission, cylindrically symmetric (thus dipole free) reentrant cavities [5] are chosen as accelerating elements. Table 1 summarizes beam characteristics at linac input, while Table 2 presents linac configuration used in matching and tracking calculations.

Table 1: Beam characteristics at Linac input

Current	10 mA	
Energy	5 MeV	
Emit. norm. rms	x	0.208 mm-mrad
	y	0.204 mm-mrad
	z	0.240 deg-MeV

Table 2: Main linac parameters

Period Type	**Type 1**	**Type 2**	**Type 3**
No. Periods	6	3	4
No. Cavity / Period	2	3	4
Energy Range (MeV)	5.0→9.5	9.5→13.2	13.2→20.1
Lattice Type	Doublet		
Lattice Period (m)	0.69	0.87→1.13	1.05
Energy Gain / Period (MeV)	0.6→0.8	1.0→1.4	1.1→2.0
RF Phase	-30°		

BEAM DYNAMICS SIMULATIONS

Trace 3D [6], PARMILA [7] and PARMELA [8] codes are used for beam dynamics simulations, while SUPERFISH [9] is used for cavity real fields generation. Few fundamental rules are followed for beam dynamics calculation:

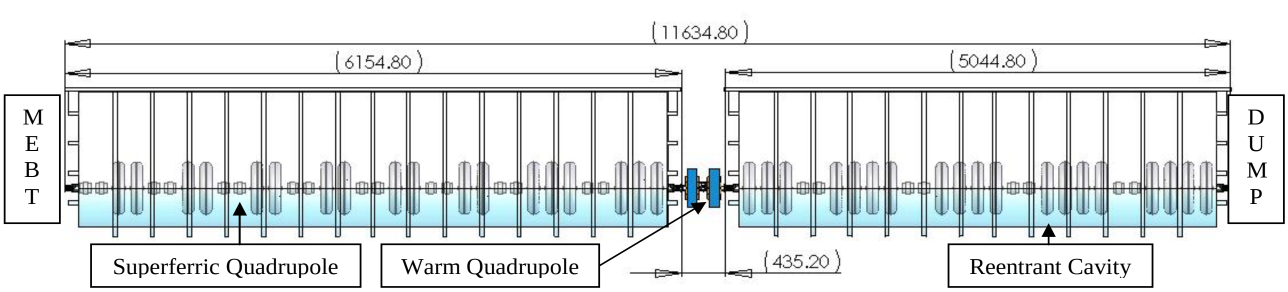

Figure 1: Linac layout. It consists of two large cryostats with a warm section in between.

- Zero current phase advances is less than 90 degrees per period in the entire structure in order to avoid instabilities for every current regime.
- Transversal phase advance is everywhere greater than longitudinal ones except in the matching section where match has precedence.
- Structure is as compact as possible to increase real estate gradient.
- The bore to rms ratio is the greatest as possible to guarantee full transmission.

These constraints, together with cavity choice, fix the number of cavities per period. Beam matching is carried out using the code TRACE 3D. The TRACE 3D code transports a beam ellipse in 6D phase space linearly through a user-defined lattice. Space charge forces are treated linearly using a uniform density model. The initial step in the matching is the calculation of periodic solutions in the first period for each type. Solutions are then matched adjusting quadrupole field gradients and RF amplitudes in few periods before type transition. Match is optimized to maintain continuous phase advances per unit length for both transverse and longitudinal motion across the transitions. Fig. 2 shows phase advances per unit length compared with quadrupoles strength and effective gap voltage (VT) in cavities.

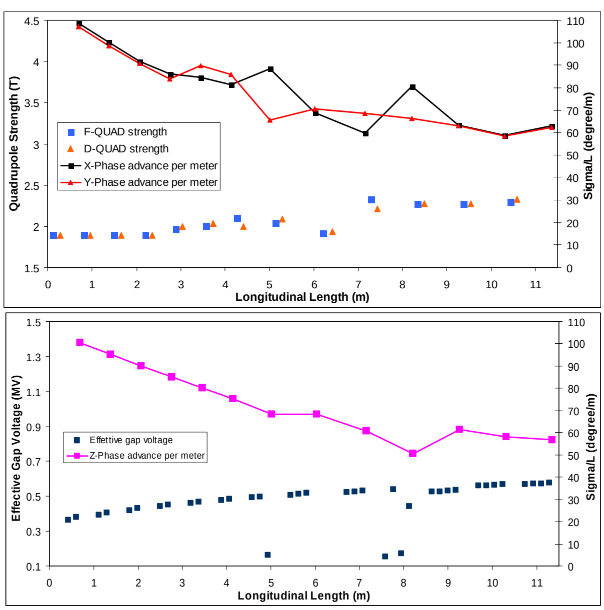

Figure 2: Comparison between phase advance per unit length and quadrupoles (up) and cavities (down) strength.

In order to verify the overall architecture and matching, a more detailed beam dynamics calculation is carried out using PARMILA code with the 3D Picnic space charge routine. Simulations proceed step by step with a feedback procedure that compares rms beam parameters obtained, with rms parameters found with TRACE 3D. At the beginning a uniform distribution of 300000 macroparticle is used as linac input. If results are well-matched uniform distribution is substituted by a 6D waterbag and simulation is repeated. If results are compatible again, input distribution is replaced with the result of beam transport through RFQ and MEBT [10] starting with a 4D waterbag distribution at RFQ input. This simulation is analyzed in more detail not only comparing rms results but also studying emittance, bore to rms ratio and envelope instabilities in relation to phase advances. If results are not satisfactory the procedure is repeated restarting from TRACE 3D and readjusting phase advance. This method guarantees convergence towards good parameters optimization. Final test is simulation of this structure with PARMELA code implementing real cavity fields.

SIMULATIONS WITHOUT ERRORS

Simulations results (see Fig. 3) show that both transverse and longitudinal rms emittance increase remains lower than 10 percent in the whole linac. Oscillation of longitudinal emittance is due to beam redistribution in longitudinal phase space. Phase-energy distribution generated by RFQ at low currents presents a two picked shape with a halo structure. Existence of this structure affects little transversal plane but has serious consequences on longitudinal plane that have to be studied in more detail. A particular of the structure is presented in Fig. 4, while beam distributions at the beginning and at the end of linac are presented in Fig. 5 and Fig. 6.

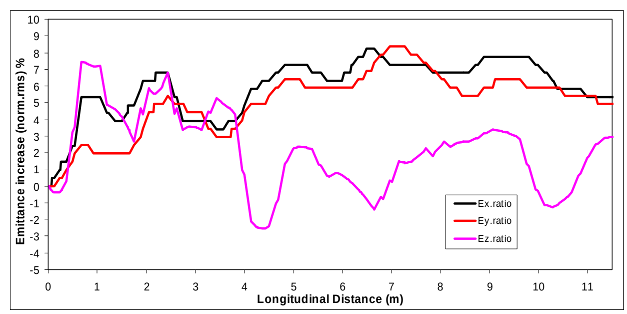

Figure 3: PARMELA calculation of the RMS beam emittances through the matched SC linac.

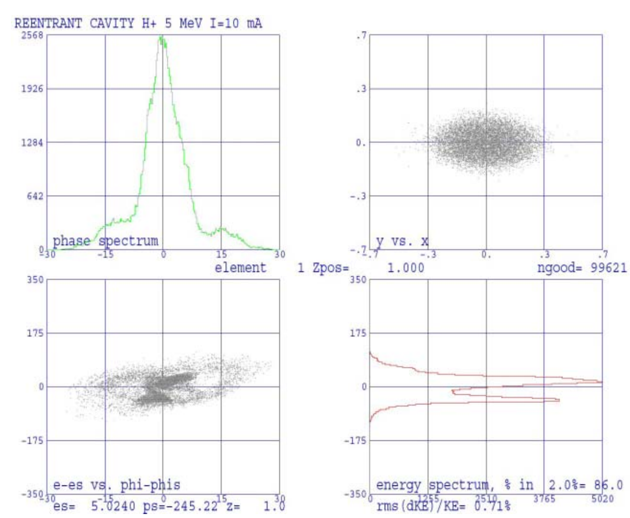

Figure 4: Longitudinal beam distribution at MEBT exit. Beam appears to be double picked in energy spread plane.

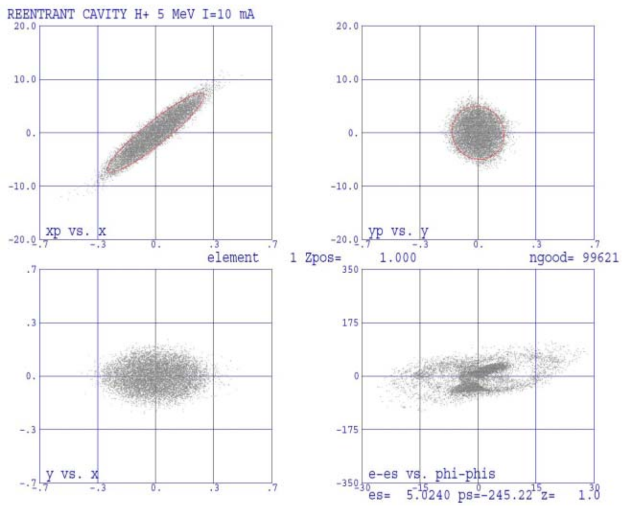

Figure 5: Beam distributions at the beginning of the SC linac at the design energy of 5 MeV.

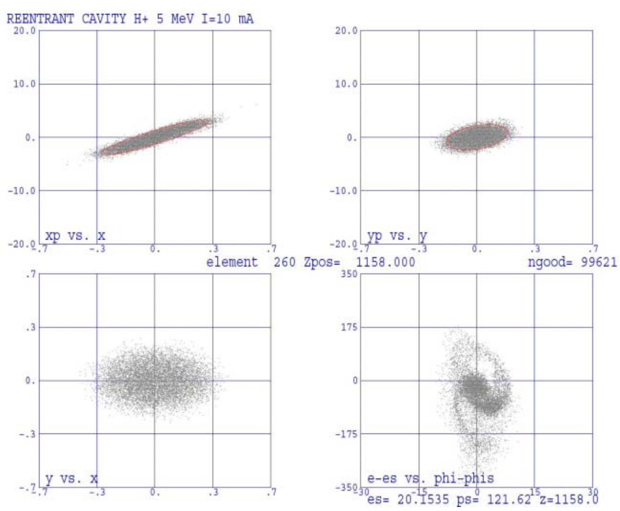

Figure 6: Final beam distributions at the end of the SC linac.

SIMULATIONS WITH ERRORS

A preliminary study on the tolerances of possible errors in the superconducting linac is carried out. Errors in positioning of focusing elements have been considered and are presented in Table 3. Fig. 7 shows the maximum values of beam transverse extent for 200 calculations. Each calculation uses different random number seeds, thus simulating 200 independent linacs with errors. The number of macroparticles used in the simulations is 100000. Full transmission is achieved and the maximum transverse extent of the beam radius is well below bore limits.

Table 3: Values of the error limits of the linac

Quadrupole transverse displacements	0.2 mm
Quadrupole tilt	3.5 mrad
Quadrupole roll	3.5 mrad

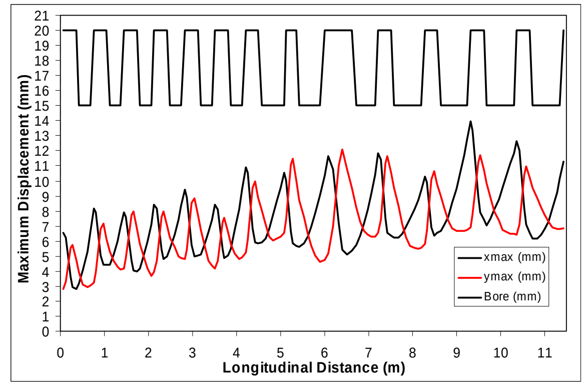

Fig. 7: Maximum transverse extent of the macroparticles in the beam versus longitudinal length for 200 independent runs with about 100000 macroparticles. Each run has been done with different random number seeds for simulating errors.

CONCLUSIONS

The structure presented fulfils the requirements of SPES-1 project. Other studies are being performed to further investigate this architecture: sensitivity to focusing errors and cavities failure. Up to now loss level is below 2 Watt in the whole linac.

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