STUDY OF A SUPERCONDUCTING 100 MEV LINEAR ACCELERATOR FOR EXOTIC BEAM PRODUCTION

A. Pisent, G. Bisoffi, M. Comunian, A. Facco, E. Fagotti INFN-LNL, Legnaro, Italy

Abstract

An ISCL (Independent Superconducting Cavity Linac) able to accelerate a 5 mA CW proton beam up to 100 MeV has been studied at LNL. Such a linac can be used as the first stage of a high energy proton linac or as a stand alone machine. The first application is considered for the 1 GeV primary linac of a European facility for the production of exotic beams (EURISOL project), while as stand alone machine it can be used for a smaller facility, for example at LNL. The main advantages of this linac (respect to a normal conducting accelerator) are the low power consumption, the large bore hole and the possibility to accelerate ions with different M/q (up to 3-4) with almost the same final energy per charge.

1 INTRODUCTION

The base-line driver for EURISOL [1] is a CW superconducting proton linac able to accelerate 5 mA beam current up to 1 GeV (with a possible upgrade to 2 GeV) [2]. For the intermediate range of energy (5–85 MeV), due to the RF time structure and to the relatively low beam current, the use of an ISCL (Independently phased Superconducting Cavity Linac) is a very convenient choice. Comparing the normal conducting DTL and the ISCL option, the investment cost and the overall length for both solutions seems to be of the same order (20–25 M€, 60–80 m). On the other hand, the AC power difference between the two options is very large (about 7 MW) and makes a huge difference in favour of the ISCL in the operating cost, in the order of 2 M€/year.

A preliminary study for the ISCL, based on four gap Ladder and two gap Half Wave resonators, is presented in this paper. In Tab. I we list the main specifications and the beam characteristics from the TRASCO RFQ [3]. In the last two rows we specify the two main constraints of the independently phased resonators: the surface magnetic and electric field.

Similar parameters are required for other applications, as for the first part of an ADS demonstrator. Moreover this linac can be used as a stand alone machine, as proposed for the SPES project at LNL: 2 10^{13} fissions/s can be generated in a depleted U target using a 1 mA 100 MeV p beam and a Be converter. Respect to the ISCL proposed for TRASCO (30 mA) [4] [5] [6] the beam current is lower and the availability requirement is not so crucial; this allows to simplify the structure and to reduce the number of cavities (more than a factor two). On the other hand many ideas and components used here were developed within TRASCO program.

Table I Main specifications of the linac.

Particle species		p	
Input energy		5	MeV
Output energy		85	MeV
Beam Current		5	mA
Duty cycle		100%	
Input	Trans (norm)	0.2	mmmrad
RMS Emittance	Long.	0.2	MeVdeg
Frequency		352	MHz
B surface field		<65	mT
E surface field		<25	MV/m

2 CAVITY CHOICE

The four families of cavities used in the design are described in Table II.

The Half Wave Resonators (HWR) are an almost straightforward extension of the design and construction experience developed in these years at LNL for bulk Nb QWR [7]. For this application HWR are preferred to QWR, because the accelerating field is symmetric (electric and magnetic dipole free), while at this frequency the dimensions are in any case small. Respect to a two gap Spoke cavity the HWR is more compact on beam line at the price of a lightly lower shunt impedance.

The Ladder is a novel structure [8], with three parallel half wave stems that allow the use of four accelerating gaps at low energy. The main advantages are the very small longitudinal space required and the possibility to have in a low magnetic field region an opening flange for inspection and high pressure rinsing.

The four kinds of cavities can operate at the same accelerating field and similar beam loading per cavity (Fig 1). The use of RF solid state amplifiers is foreseen. A high efficiency 2.5 kW prototype unit has been built at LNL [9]. The amplifier construction is modular and units of 2.5, 5, 7.5 and 10 kW can be built with low cost and compact size.

The superconducting quadrupole used in this design has been prototyped at MSU for application in TRASCO ISCL [10].

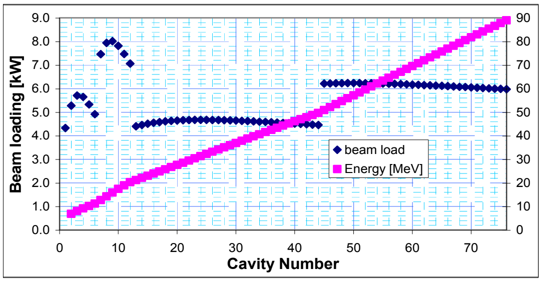

Figure 2 Beam loading per cavity and synchronous energy as function of cavity

Table II Main cavity characteristics.

Cavity type	Lad.	Lad.	HWR	HWR	Units
β_0	0.124	0.17	0.25	0.33	
n. of gaps	4	4	2	2	
E_p/E_a	~3	~3	~4	~4	
H_p/E_a	102	100	95	106	Gauss/(MV/m)
$R_s \times Q$	89	-	54	66	Ω
U/E_a^2	0.2	-	0.057	0.084	$J/(MV/m)^2$
Eff. length	0.2	0.29	0.18	0.215	m
Bore Ø	25	25	30	30	mm
Design E_a	6	6	6	6	MV/m
Cryo. power allowed	10	10	10	10	W
n. required	6	6	32	32	

3 LINAC STRUCTURE

The linac structure is schematically shown in Fig. 2 and the main parameters are listed in Table III; 76 cavities and the 54 superconducting quadrupoles are housed in 10 cryostats, for a total length of approximately 45 meters. There are four kinds of cryostats (one for each cavity family).

The basic focusing structure is a FODO, with a constant period length in each cryostat. The period length increases changing the cryostat kind, because the cavities themselves become longer. A diagnostics box is located in each warm transition, for a total of 9 measuring positions.

The beam matching has to cope with these changes, in presence of space charge effect and possible single particle and envelope resonances.

Particularly dangerous in this linac, with a strong acceleration at a relatively low velocity, is the parametric resonance, occurring when the longitudinal oscillation frequency is about twice the transverse one.

The parametric resonance has a fast exponential growth that rapidly spoils the transverse emittance; to avoid this effect a strong transverse focusing has been implemented in the first cells (about 100^0 per FODO period).

Beam envelopes and beam rms dimensions corresponding to 5 mA current are plotted in fig 3. This preliminary simulation is performed with PARMILA using 100000 macro-particles and a thin gap representation of each cavity. The residual mismatch due to the transitions can be seen, but the maximum beam dimensions are well below the bore radius. The emittance increase is negligible. In fig. 4 the bore to rms radius, well above 7 times, is plotted all along the linac. This figure, showing one of the main advantages of ISCL respect to DTL, takes into account the different bore radius in cavities and quadrupoles. The ratio is in general smaller in the quadrupoles, where we prefer to have possible losses.

The space charge effect is not dominant (initial transverse tune depression is about 10%) and the same beam matching can be used to transport up to about 50 mA of beam current with full transmission. In fig 4 the results of various runs with different beam intensities are shown. The plot shows that this linac, optimized for 5 mA where the emittance growth is practically zero, maintain, with the same setting, an acceptable emittance growth up to 10 mA (about 20%). Lower emittance can be obtained with new beam matching.

This opens a wide range of future applications and suggests that for this linac the limitation to 5 mA beam current is due to the available RF power and not to the beam dynamics.

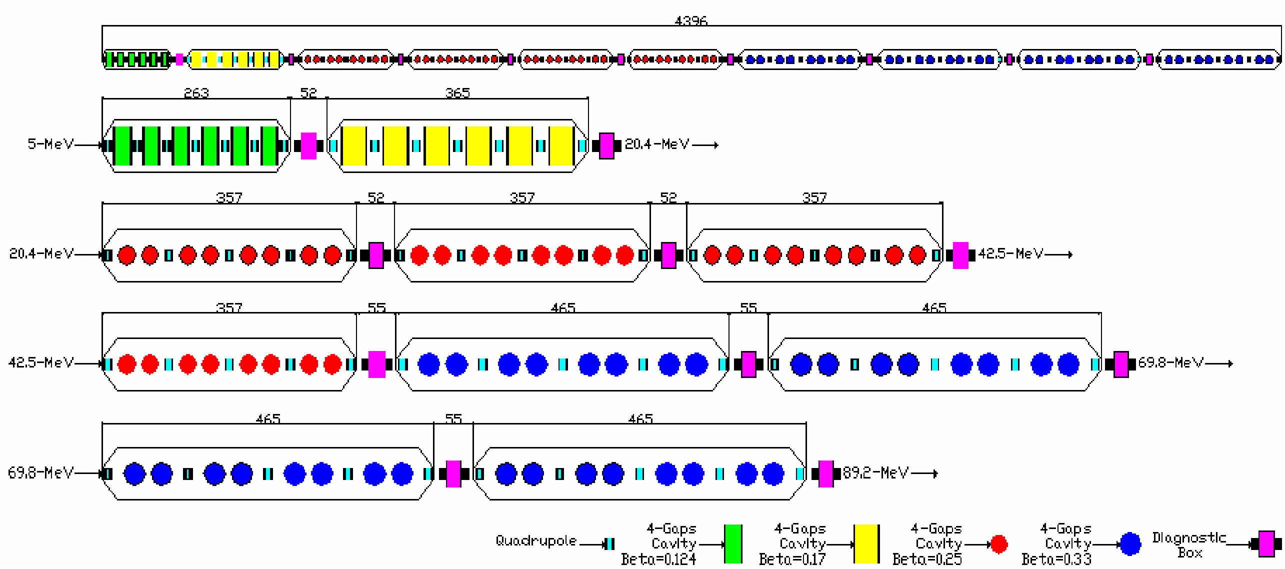

Figure 1 *Linac layout*

To guarantee the operation of the linac with losses below 1 W/m, a value which is needed for hands-on maintenance, deeper studies are needed. The use of a larger number of particles, a better modeling of the RF field, a systematic study of alignment errors, a fully 3D space charge routine, are all elements needed for the final simulations.

As mentioned in the introduction the power consumption of this linac is relatively low. To the value listed in table III the power consumption for the quadrupole power supplies, vacuum equipment and all the ancillaries hare to be added, but the final efficiency remains competitive.

A specific characteristic of the ISCL is to be an "open structure", since ions with different A/q can be accelerated thanks to the impendent cavity phase control. In Fig. 6 we show for example how a beam with A/q=3, and an initial energy of 6.8 MeV/u is accelerated up to 87 MeV/q, with a beam loading per cavity consistent with the installed RF.

TableIII: ISCL Parameters (5 mA)

Total length	44	m
Synchronous phase min/max	-35/-25	deg
Average acceleration	1.8	MeV/m
Number of cavities	76	
Number of Quadrupoles	54	
Max. Quadrupole gradient	40	T/m
Quad aperture/length	2/5	cm
Current limit (losses<10^{-5})	>50	mA
RF dissipation	760	W(@4.5K)
Beam loading	420	kW
RF sys. pwr. cons. (η_{RF}=50%)	840	kW
Static cryo. losses (10 W/m)	440	W
Cryo. sys. cons. (η_{cryo}=1/500)	650	kW
Mains power	1.5	MW
Power conversion efficiency	28%	

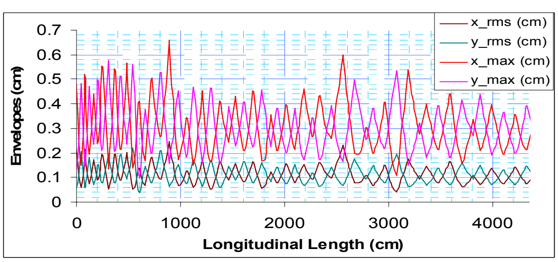

Figure 3 Beam amplitude rms and max along the linac.

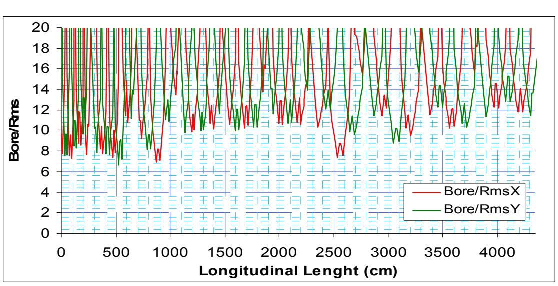

Figure 4 Cavity and quadrupole bore to rms beam size ratio.

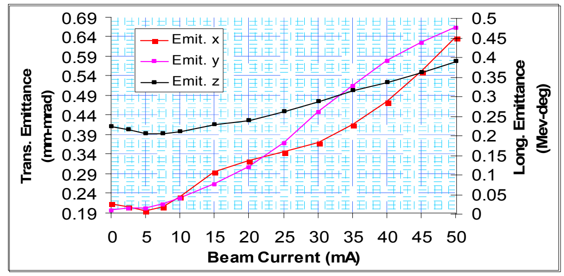

Figure 5 Output Emittance vs. beam current.

4 CONCLUSION

We have designed a 352 MHz superconducting linac, able to accelerate a 5 mA CW beam up to 85 MeV. The cavity choice allows the acceleration of different beams, keeping a convenient number of cavities and an RF amplifier size compatible with the solid state units prototyped.

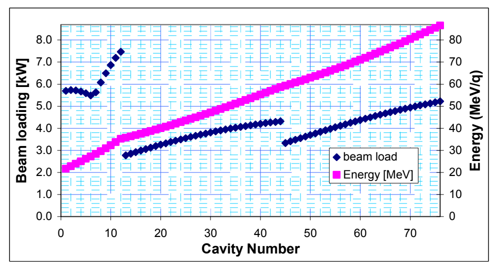

Figure 6 Beam Loading and synchronous Energy in the case of q/A=1/3.

REFERENCES

[1] http://www.ganil.fr/eurisol
[2] J-L. Biarrotte et al. " High intensity driver accelerators for EURISOL", this conference.
[3] A. Pisent et al "TRASCO RFQ" proceedings of of Linac 2000 Conference, Monterey, California.
[4] M. Comunian, A. Facco, A. Pisent "A 100 MeV Superconducting Proton Linac: Beam Dynamics Issues." Linac 1998 Proceedings pp. 64-66.
[5] A. Facco et al. "RF Testing of the TRASCO Superconducting Reentrant Cavity for High Intensity Proton Beams ", this conference.
[6] M. Napolitano et al. "Status of the high current proton accelerator for the TRASCO Program", this conference.
[7] A. Facco, V.Zviagintsev "Completion of LNL Bulk Niobium Quarter Wave Resonators", Workshop on RF superconductivity, Santa Fe, 1999.
[8] V. Andreev et al. "Study of a Novel Superconducting Structure for the Very Low Beta Part of High Current Linacs", this conference.
[9] F. Scarpa et al. "A 2.5 kW, Low Cost 352 MHz Solid State Rf Amplifier for Cw and Pulsed Operation", this conference.
[10] A. F. Zeller et al. "A Superferric Quadrupole for use in an SRF Cryomodule" LNL Annual Report 2001, INFN-LNL 181/02.