DESIGN OF THE HIGH CURRENT LINAC OF SPES PROJECT

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Abstract

The proposed driver, composed by a four vanes RFQ and an Alvarez DTL, generates a high intensity beam, for an average current of 1.5 mA and an energy of 43 MeV, upgradable to 95 MeV. The high rep rate (50 Hz) is necessary for the correct mechanical behavior of the target. The accelerator is composed by the source TRIPS, built at LNS and now in operation at LNL, by the RFQ of TRASCO research program (5 MeV 30 mA), very advanced in the construction, and by a normal conducting Drift Tube Linac (DTL). This last accelerating structure is the same proposed for LINAC4 at CERN. A prototype of this structure, of interest for both projects, is in construction in Italy with the joint effort of CERN and LNL. The RFQ and the two tanks of the DTL are fed by 3 klystrons; the first one, with a power of 1.3 MW, is already at LNL, while the other two with a power of 2.5 MW each are the same adopted for LINAC4. The power supply of the RF system (50 Hz 0.6 ms) has been evaluated in details on the bases of the system in operation for the Japanese project JPARC. This paper illustrates the physical design and beam dynamics studies of this linac.

INTRODUCTION

The project SPES (Selective Production of Exotic Species) foresees the construction at LNL of a ISOL facility for the production of radioactive nuclear beams (RNB) neutron reach by means of proton induced fission on depleted uranium, under uranium carbide form. The nominal fission rate is $10^{13}s^{-1}$; the RNB will be accelerated up to about 10 MeV/u by the superconducting linac ALPI.

The driver proposed in the recent SPES TDR[1] generates a low emittance and high intensity beam, for an average current of 1.5 mA and an energy of 43 MeV, upgradable to 95 MeV, for an optimal illumination of the uranium carbide target, keeping the operative margins necessary for future developments. The main linac parameters are:

- Beam energy: ~43 MeV
- Average beam current : up to 1.5 mA
- Beam pulse length up to 600 μs
- Repetition rate 50 Hz
- RF frequency: 352.2 MHz
- Possible upgrade to 95 MeV

The layout of the LINAC is presented in Fig.1; the main elements are the off resonance ECR source (TRIPS), the Low Energy Beam Transport (LEBT), the radio frequency quadrupole (RFQ), the Medium Energy Beam Transport (MEBT) and the Drift Tube Linac (DTL). The main parameters of the RF structures are summarized in Tab. 1.

After the linac a High Energy Beam Transport (HEBT) line will deliver the beam to two different RIB production target and possibly to other lines for different operations like neutron production. The pulsed structure of the beam allows the distribution of the beam between the various users switching a dipole magnet from pulse to pulse (20 ms). It is for example possible in this way to operate simultaneously two RIB production targets at 0.25 mA and 25 Hz .

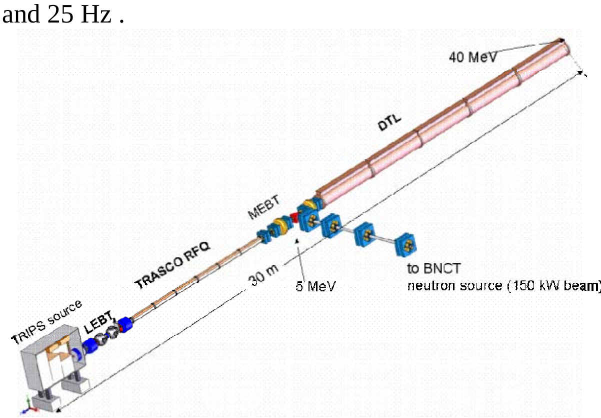

Figure 1:Lay out of SPES linac.

Table 1: RFQ and DTL main parameters

	RFQ	DTL	DTL upgrades		
Energy	5	43	60.8	95.5	MeV
Ave. Acceleration	0.7	2.5	2.3	2.1	MeV/m
Max Field	1.8	1.6	1.3	1.3	Ekp
RF Power	0.8	4.03	2	4.1	MW
Nb. of Klystrons	1	2	1	2	
Length	7.13	15.2	7.6	16.3	m

The linac pulsing is necessary to decrease the power dissipation in the copper of the structure, keeping a conservative peak current of 50 mA. A specific requirement for SPES rises from the thermal behavior of the production target, that is heated up to more than 2200 deg to enhance the release of fission fragments and has to withstand the beam power deposition of about 10 kW. The linac pulsing adds a time dependent transient to the target temperature distribution that could increase the stresses on the disks; indeed with a linac repetition rate >10 Hz this effect is negligible (Fig. 2). At the nominal rep rate of 50 Hz the transient temperature ripple is much lower than the maximum temperature non-homogeneity in the target and would not influence the target performances and lifetime.

In this configuration the linac uses the same injector (up to 5 MeV) both as neutron source (BNCT) and for the production of RNB.

The proposed linac, partially already in construction phase, represents therefore an accelerator at the technological frontier. On the other hand for all the components the performances required have already been demonstrated. It is therefore an accelerator that makes full use of the experience matured at LNL and of what has already been built, of the possible synergy with CERN and with other international laboratories. The DTL engineering made in common with CERN allows being competitive in costs and realization schedule with more conventional commercial accelerators.

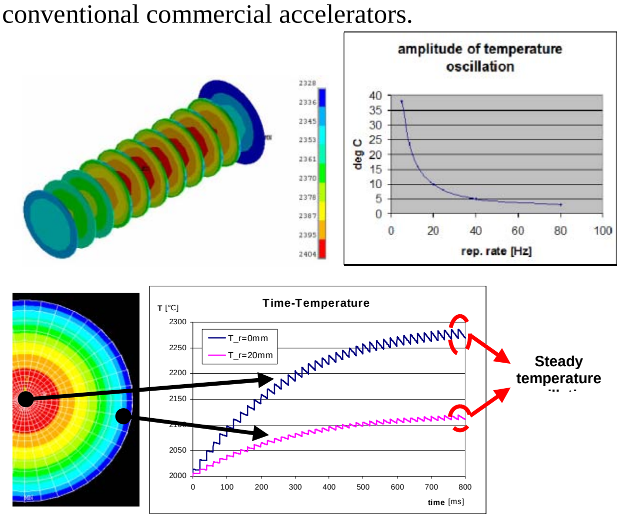

Figure 2: Temperature distribution in the steady state and temperature ripple amplitude as function of puling frequency; simulation of the approaching to the steady state at 50 Hz.

THE SOURCE AND THE RFQ

The front end of the linac has to deliver two very different beams, a 2.5 kW pulsed beam for the DTL and the RIB production, and a 150 kW cw beam for the 5 MeV neutron source.

The cw mode requirements are fulfilled by the TRIPS source and the RFQ which were developed in the framework of the TRASCO project. The source is a high current microwave discharge ion source. Its goal is the injection of a minimum proton current of 35 mA for an operating voltage of 80 kV in the following RFQ, with a rms normalized emittance lower than 0.2 π-mm-mrad and with a reliability close to 100 % (few failures per year). Concerning TRASCO RFQ construction, it is almost completed. Three of the six modules (Fig.3) are fully machined and brazed, for the other three the high precision machining is completed and they are waiting for the brazing to be done at CERN. The main components of the RF system, part of the former LEP RF system, are already stored at LNL.

The pulsed mode requirements may be fulfilled by pulsing source RF generator and adding a chopper in the LEBT. The performances of this system, that has unknowns related to the source behaviour and beam neutralization in the LEBT during the transient, are part of the experimental test program at LNL test bench.

The second application corresponds exactly to the beam requirements originally given for research program TRASCO where the main components of the injector of a high intensity linac for Nuclear Waste Transmutation were studied and prototyped. The ion source, built and commissioned with beam at LNS, has been now installed at LNL.

The pulsed mode beam is prepared by pulsing the source RF generator; a sharper beam pulse rise time, for a further reduction of beam losses, can be reached with a relatively slow beam chopper in the LEBT (about 1 μs rise time).

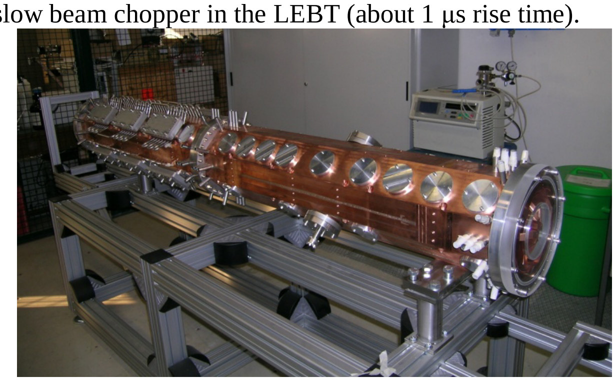

Figure 3: The first 2 TRASCO RFQ structures.

THE DRIFT TUBE LINAC

The beam focusing in SPES DTL is guaranteed by permanent quadrupole magnets with alternated polarity (FFDD scheme) hosted in the accelerating tubes. The beam dynamics design was aimed at keeping the transverse and longitudinal phase advances continuous.

The nominal simulation case performed with TraceWin show no losses and no emittance growth (Fig. 4) with Gaussian input beam distribution, the bore over rms beam size ratio is 7.5 at minimum.

The cooling system of the resonator is dimensioned for a duty cycle of 10%, so to leave open the development toward a higher power linac. The cooling water temperature is used for the tuning of the resonant frequency.

The main parameters of the first five tanks are listed in Table 2. This linac fulfils the requirement of the direct target, with a large margin in beam current. Moreover in the third and forth column the possible upgrade of the linac in energy (up to 95 MeV) are considered; in this way the original SPES linac requirements (>100 kW for neutron converter operation) can be met.

The design of the cavity takes advantage from the experience and the studies done at CERN in the last years for LINAC4[2]. Indeed the main requirements of this linac (like the operating frequency, the duty cycle) are in common with LINAC4; the different input energy (3 MeV for CERN and 5 MeV for LNL) allows avoiding the most demanding part for focusing strength and peak electric field. Therefore, except for the details in the dimensions and position of drift tube, the cavity design can be the same for CERN and LNL.

Table 2: Parameters of the DTL Tanks up to 61 MeV.

	Tank 1	Tank 2	Tank 3
Output energy [MeV]	23.82	43	60.76
Gradient E_0 [MV/m]	3.10	3.10	3.10
Synchronous phase [deg]	-35/-20	-20	-20
Lattice	FFDD		
Aperture radius [mm]	10		
Tank diameter [m]	0.52		
Drift tube diameter [mm]	90		
Length [m]	7.53	7.68	7.59
Max surface field [kilp.]	1.6	1.23	1.15
Peak RF power [MW]	2	2	2
N. of klystrons	1	1	1
Quadrupole length [mm]	45		
N. of gaps	55	35	28
Stem diameter [mm]	28		
N. of post-couplers	27	17	14
Post coupler diameter [mm]	20		
Frequency tuning	Water temperature		
Fixed tuner diameter [mm]	90		
N. of fixed tuners	10	10	10

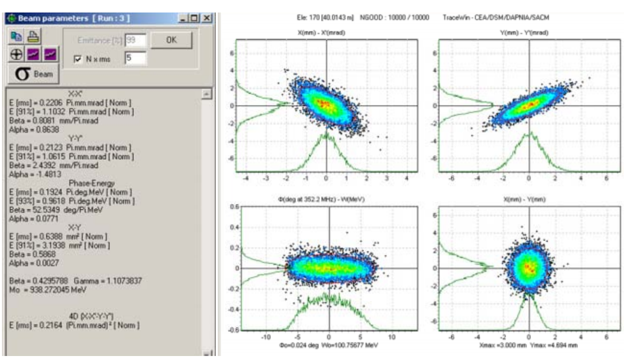

Figure 4: Output beam from DTL.

Concerning the mechanical design we have investigated the possibility of an industrial production in EU on the bases of SNS design. More recently in the frame of the R&D programme for the Linac4 project, a novel mechanical design for a Drift Tube Linac (DTL) at 352 MHz has been developed. The advantages of this new design are simpler assembling, better long term stability and lower cost as compared with other DTL designs.

LNL participates directly to this R&D effort end the results of this prototype will be available for both projects.

RF SYSTEM

The power budget of the RF system for the pulsed case has to take into account the peak power requirements for the RFQ and the DTL as well as the pulse duration. As for the RFQ, it has to be considered that the beam current for injection in the DTL is equal to 50 mA. Therefore peak RF power requirement for the RFQ becomes equal to 1.015 MW and to 4.836 MW for the DTL. The parameters of the system were rated for maximum flat-top pulse duration of 600 µs, corresponding to an average beam current of 1.5 mA. The availability of 2.5 MW pulsed klystrons permits to simplify the RF distribution scheme to the DTL. The two klystrons, are an adaptation of the one developed by TOSHIBA being used for the 324 MHz J-PARC linac (type E3740A OP 352), where 23 klystron were tested and put into operation, reaching the specifications[3]

In order to feed each klystron of the DTL, an unique 110 kV-90 A High Voltage Power Supply (HVPS) can be used, with separated modulating anode pulsed modulators. It consists of a step-down transformer (20 kV-1 kV), the thyristor unit, the step up transformer (1 kV-110 kV), the rectifier, the ripple filter and a crowbar circuit against overcurrents. The power supply feeds the same voltage to each klystron cathode and the pulsed modulators, derived from the cathode DC line, generate the voltage pulse. This approach corresponds to the one employed at the J-PARC facility, where this kind of HVPS underwent a long-run test [4], but in the case of the SPES linac, due to the lower power ratings required, some parameters can be relaxed. A simplified scheme of the RF system is shown in Fig.5

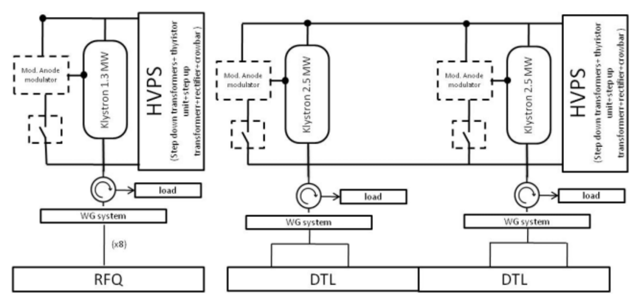

Figure 5: Simplified scheme of the RF system.

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