TRASCO 100 MeV High Intensity Proton Linac

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Abstract

The Italian project TRASCO foresees the feasibility study of a 1.6 GeV 30 mA proton linac, based on superconducting elliptical cavities in its main part, to be used as a driver for a ADS. The linac up to 100 MeV consists of a microwave discharge ion source, a normal conducting CW RFQ up to 5 MeV and a superconducting linac with independent single gap cavities up to the final energy. The design and the status of the R&D for the various parts are illustrated in this paper; in particular the construction of the source, of the first third of the RFQ and of a superconducting cavity. The first part of this linac has been proposed for the future development of LNL within SPES project.

1 INTRODUCTION

The Italian research program TRASCO [1] foresees the feasibility study of an ADS plant, for nuclear waste transmutation or energy production by means of a sub-critical reactor. In particular, INFN is studying a 30 mA proton linac based on superconducting elliptical cavities above 100 MeV.

The program includes the design study of the facility and the prototyping of some critical parts. In this paper we shall discuss the design of the low energy linac (up to 100 MeV), developed at LNL and LNS, and the status of the prototype construction. A schematic lay-out of the linac is shown in Fig. 1, while a list of the main parameters is shown in Tab.1.

The low energy linac is composed by a microwave discharge ion source, an RFQ and a superconducting linac (ISCL); at low energy the beam is more sensitive to space charge and in general to perturbations, so that the design and construction of this part of the linac is particularly demanding. Our design choice has been driven by the requirements of reliability (continuity in beam delivery to the reactor), power conversion efficiency and compactness. The prototypes under construction are the source, at LNS, the first third of the RFQ and one of the superconducting cavities at LNL.

The construction of the first part of TRASCO linac at LNL is foreseen by INFN three-years plan; it will be the driving linac for SPES neutron facility[2].

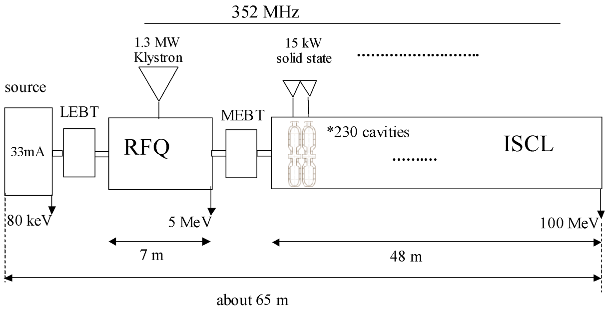

Figure 1: Block diagram of the linac.

2 THE SOURCE AND THE LEBT

The requirement of intense proton beams for the TRASCO project can be fulfilled by many different type of sources, operated by means of an electron discharge, RF discharge or a microwave discharge, but only the latter method can guarantee the expected performances in terms of proton fraction, emittance, stability, reproducibility and reliability.

In particular, the reproducibility and the long term stability are the well-known features that makes the microwave discharge source the preferred type of source for this application. With respect to the others. it has not parts subject to consumption and it can work for weeks without any maintenance and with stable currents, provided that a constant gas flow is maintained.

Moreover, not only a large current of proton is requested for the injection into the following RFQ but also the proton fraction must be maximized, to avoid that a large fraction of the beam is lost inside the RFQ.

The emittance should match with the RFQ acceptance and the rule of thumb is “the lower the emittance, the better is the coupling”: a good compromise suggested to fix a goal around 0.2 mm mrad (product of the two semi axis for an upright ellipsis). In order to get this result, a long series of experiments have been performed at the test bench of CEA Saclay with the source SILHI and the results exceeded the expectations. The reliability was also optimized and the collaboration CEA-INFN demonstrated that this kind of source is able to produce the requested currents with reliability close to 100% [3]. The design of TRIPS (Trasco Intense Proton Source) source is an outcome of these experiments and its design was finished in 1999. The source has been completed recently and installed at LNS on a 100 kV high voltage platform; its commissioning is under progress [4].

The source is fed by a 2.45 GHz - 2 kW magnetron, the magnetic field is produced by two on-line movable coils independently energized. The five-electrode extraction system has been computed with the AXCEL code and the results have been cross-checked with the IGUN code [3]. A simple LEBT line has been designed to characterize the extracted beam. It consists of a solenoid for the beam focusing, followed by a four sector ring, a direct current transformer to measure the beam current and a 10 kW beam stop that closes the LEBT. The matching line to the RFQ will be defined in the coming months.

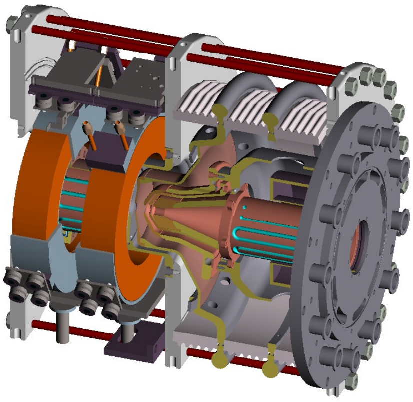

Figure 2: A 3D view of TRIPS.

3 THE RFQ

The RFQ modulation has been designed so to accelerate the relatively high current with low beam losses [5]. The main technological constraints are the maximum surface electric field (33 MV/m=1.8 Kilpatrick) and the available RF power, using a single klystron with 1.3 MW nominal power (LEP kind). The beam transmission from beam simulations is more than 96%, with losses mainly located below 2 MeV, so to minimize the activation problems of the copper structure.

The resonator of four vanes kind, will consist in six sections, built in copper OFE and flanged together (fig. 2). Each section is a sandwich of four parts, brazed together in a vacuum furnace. The vane tips are modulated with a high precision milling machine before brazing. The tolerances required for the brazed structure are of the order of 20 µm. The RF power dissipated is of the order of 0.8 kW/cm, and requires twenty cooling channels, drilled in the structure.

The RFQ is being developed in collaboration with Italian industry (CINEL s.r.l.). The construction of a technological model, corresponding to the first third of the structure, will begin in autumn. RF power tests are foreseen during 2001.

The structure will be fed throw four 250 kW RF loops, based on LEP normal conducting cavity design.

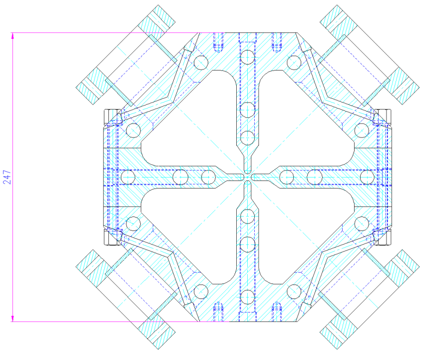

Figure 3: RFQ cross section; the cooling channels and the vacuum ports, with cooled grids, can be recognized.

4 THE ISCL

The interest for a superconducting proton linac covering the traditional DTL energy range has recently grown, in connection with various high intensity linac studies. The extension of the superconducting linac technology to lower energy has obvious advantages for a CW, moderate current machine, but implies complications. We considered an Independently phased Superconducting Cavity Linac (ISCL) similar to those used for low energy heavy ions in many nuclear physics laboratories like ours, but at much higher beam intensity, and in a wider beta range[6]. We checked various kind of cavities and we selected the so-called “reentrant cavities”, that are modified pillbox, cylindrically symmetric and therefore theoretically dipole free [7].

One of the advantages of this kind of linac is its remarkable flexibility, that allows using it CW at lower current or even with different kind of particles, like deuterons. In Tab. I we list the main specifications and machine characteristics. In particular we specified the two main constraints of the independently phased resonators: the surface field and the beam loading per cavity. The second constraint is specific of high current machines: in our case we want to feed each cavity with a single solid state amplifier and the limitation to 15 kW is consistent with the present technology.

An additional constraint is given by the reliability requirements typical of an ADS, where the operation with a sub critical reactor is spoilt even by beam shut down of a second. To meet these requirements we have chosen an architecture with reliable solid state amplifiers. Even in the presence of a large number of such RF systems with finite reliability, we required that the beam could be transmitted in case of failure of a cavity. This is connected to the requirement that the acceleration per cavity plus the energy spread is smaller than the separatrix energy width. If the beam survives the failure of a single amplifier, and the amplifier is replaced on line, the resulting availability of the linac is highly improved.

We have chosen a FODO focusing structure with period $8\beta\lambda$. As the period becomes longer, a larger number of cavities can be installed between the quadrupoles (Fig.4).

The required gradient can be reached both by normal conducting and superconducting quads. Nevertheless, due to the lack of space, it is necessary to use superconducting quadrupoles installed inside the same cavity cryostat.

The linac has been simulated with PARMILA using 10000 macro particles. Each cavity is represented by an accelerating gap. We have simulated currents up to 50 mA, and we did not see losses (100000 macro particles). Smaller losses must be investigated by other means.

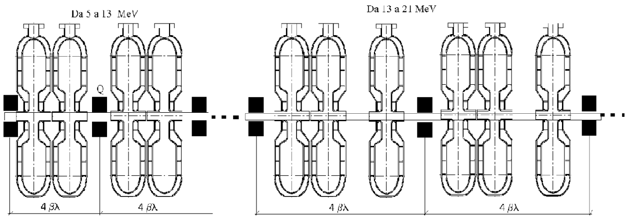

Figure 4: ISCL layout: reentrant cavities and quadrupoles in the cyrostat.

CONCLUSIONS

The high intensity proton source is already installed at LNS and its commissioning is under way. The construction of one third of the RFQ and of the first reentrant cavity will begin in Autumn.

REFERENCES

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[6] M. Comunian, A. Facco, A. Pisent "A 100 MeV Superconducting Proton Linac: Beam Dynamics Issues." Linac 1998 Proceedings.

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Table 1 TRASCO 100 MeV linac nominal design

General parameters			
Particle species		p	
Input energy		5	MeV
Output energy		100	MeV
Beam Current		30	mA
Duty cycle		100	%
Radiofrequency		352.2	MHz
Source parameters			
Beam energy		80	keV
Beam current		35	mA
Emittance rms normalized		0.2	mm mrad
Discharge power		2 kW at 2.45 GHz	
RFQ parameters			
Maximum surface field		33	MV/m (1.8 Kilp.)
Energy range		0.08-5	MeV
Emittance T RMS in/out		0.2/0.2	mm mrad norm.
Emittance L RMS		0.18	MeV deg
RFQ length		7.13	m (8.4 λ)
Intervane Voltage		68	KV
Transmission		96	%
Modulation		1-1.94	
Average aperture		0.29-0.32	cm
Synchronous phase		-90÷-29	deg
Dissipated power SF*1.2		0.579	MW
Beam loading		0.1476	MW
RF power		0.726	MW
ISCL parameters			
Energy range		5-100	MeV
Total length		48	m
Synchronous phase		-40	deg
Average acceleration		1.82	MeV/m
Number of cavities		230	
Cavity bore radius		1.5	cm
Quadrupole gradient		31	T/m
Quad aperture/length		2/5	cm
Output RMS Emittance	Trans. (nor)	0.42	mm mrad
	Long.	0.2	MeV deg
Current limit (losses$<10^{-4}$)		>50	mA
RF dissipation (R_s=100nΩ)*		1204	W(@4.5 K)
Beam loading		2.85	MW
RF sys. pwr. cons. (η_{RF}=50%)		5.7	MW
Static cryo. losses (10 W/m)		480	W
Cryo. sys. cons. (η_{cryo}=1/500)		0.84	MW
Quadrupoles and ancillaries		0.5	MW
Mains power		7.04	MW
Power conversion efficiency		40%	

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* The BCS resistance is 58 nΩ.