ADVANCES IN TOP LINAC CONSTRUCTION

L. Picardi, C. Ronsivalle, ENEA, Frascati (Roma); S. Frullani, ISS, Roma

Abstract

The TOP LINAC, an innnovative linac for protontherapy in the energy range 65 - 200 MeV is under construction at ENEA in Frascati. The system is intended to be installed in the main Oncologycal Hospital in Rome, Istituto Regina Elena. Up to now funding allowed the construction of a 7 MeV injector and of the first 3 GHz module (up to 13.4 MeV). The injector has been produced by AccSys Company (USA) and is under commissioning at Frascati. The low energy (7 MeV) beam lines for F-18 production and injection in the following accelerating sections are under construction. The first 3 GHz SCDTL module has been completely built. The characteristics of the various accelerator components and the last measurements are presented.

1 GENERAL DESCRIPTION

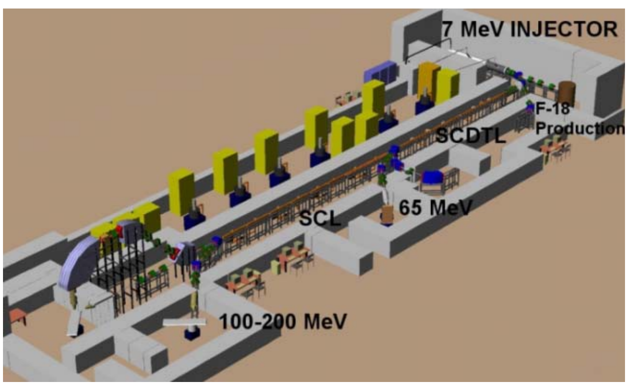

Figure 1: TOP Linac layout

The TOP (Terapia Oncologica con Protoni) Linac [1] is designed to produce several beams (fig. 1):

- a 7 MeV, 700 W beam for 18F radioisotope production;
- 3-65 MeV, 10 nA (average) beams for radiobiology;
- a 65 MeV, 10nA (average) beam for proton eye therapy;
- a 100-200 MeV, 10 nA (average) beam for deep seated tumours proton therapy.

The time structure of the beams is 1-5 μs pulses at 200-300 Hz repetition frequency. The fully 3-D scanning irradiation of deep seated tumours requires a beam whose position, energy and pulse current can be varied on a pulse-to pulse basis, that is energy between 130 and 200 MeV and pulse current between 0.1 and 10 μA (a factor 100).

The TOP Linac is composed of a 7 MeV injector, a first 65 MeV 3 GHz linac booster, named SCDTL from the accelerating structure name, a second 200 MeV 3 GHz linac booster named SCL, and the various beam lines to the application rooms.

The construction was started within a cooperation agreement between ENEA and ISS (National Institute of Health) and installation was agreed to be done in Rome at the Istituto Regina Elena (IRE) Oncologycal Hospital. Up to now unfortunately only a minor part of the funding has been available so that work is carried on at ENEA Frascati laboratories, where a proper temporary site is being set up for the first machine tests.

2 THE INJECTOR LINAC

The injector linac is an AccSys Model PL-7 system modified to meet the TOP requirements [2]. It will be used for three main purposes: Fluorine-18 production (F-Mode), Protontherapy beam injection (P-mode) and Radiobiology experiments (R-Mode) In tab. 1 the typical beam characteristics are reported for each mode.

Table 1: PL-7 injector characteristics

	F- Mode	P-Mode	R-Mode
Energy, MeV	7	7	3-7
Pulse current, mA	8	.001-.03	0.03
Pulse duration, μs	60	7	7
Pulse rep frequency, Hz	60	250	100

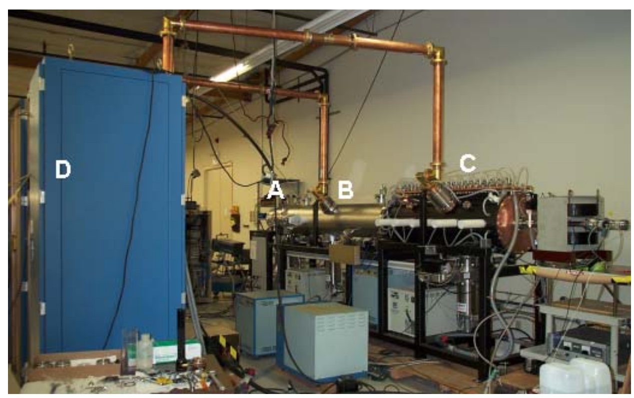

Figure 2: PL-7 injector linac

The injector linac is composed of several sub-systems as showed in fig.2. The proton ion source (A), is a pulsed 30 keV duoplasmatron, followed by a single einzel lens and a water-cooled current limiting aperture that can be inserted by remote control to reduce the linac current by a factor of 100 for operation in the proton therapy mode. The main accelerating system is composed by a 3 MeV RFQ (B), and a 3 to 7 MeV DTL (C). Both work at 425 MHz. The two main RF amplifiers (D), one for RFQ and the other for DTL are based on a parallel arrangement of twelve EIMAC YU176 tubes.

The injector has been tested at factory, but still not installed in Italy. As to the F-mode, numerous radioisotope production tests at 7 MeV with partially enriched O-18 water (4.5%-95%), at average target currents of 25-35 μA and irradiation times between 15 min and 2 hours, produced F-18 yields in the range of 65-80% of the theoretical values due to the irradiation scheme. The final F-18 production test with a 2 hr irradiation achieved an equivalent activity of 0.762 Ci. Current on the target was limited by the temporary beam line, but larger currents and hence, higher production yields will be possible with the final beam transfer line. An analysis of the measured activity compared to the theoretical ^{18}F decay curve, indicated that less than 0.1% of other radionuclides were present.

The injector linac was then tested in Protontherapy Mode. The linac pulse current was decreased from the mA range to the μA range needed for proton therapy, by inserting, by a pneumatic actuator, the water-cooled aperture at the RFQ entrance. The machine showed to work up to 300 Hz (maximum flat top pulse length of 2 μs), and steadily at 250 Hz with flat top of 7 μs.

To vary the current for this operational mode, it is possible to set the ion source output current from 15 mA down to 2 mA using the arc voltage, gas pressure and magnet current. The einzel lens voltage can then be used to rapidly vary the current through the aperture by another factor of 10-20. In fact, the programmable pulsed high voltage power supply for the Einzel lens allows the pulse-to-pulse variation of the beam current through the aperture that is needed for a high quality protontherapy. For a range of 30-23 kV of the Einzel lens voltage a variation range of 25 μA - 1.1 μA was obtained that gives a factor 25. Another factor of 4-5 can be obtained by an appropriate phasing of injection line cavities.

Beam energy spread measurements have been performed both in high current (F) mode and in low current (P) mode using a 22.78° bending magnet followed by a short transfer line with two PMQs and a slit placed in the image plane of the accelerator output beam. Energy spread of ±100 keV at low current and ±130 keV at high current have been measured, in good agreement with the specifications and computed values.

3 BEAM TRANSPORT LINE

The 7 MeV beam transport line (figure 3) is a dual output beam line composed of a straight section for the Radioisotope production line and a 90° section for protontherapy beam injection, in order to avoid bending the proton beam in the high current operating mode. The two lines share the first two quadrupoles.

The protontherapy injection line is composed by an achromatic bend system to preserve the horizontal emittance, and a sequence of two RF cavities and four quadrupoles to adapt the total beam phase space to the SCDTL acceptance. The longitudinal space matching is obtained by allowing the bunch to lengthen to much more than one 2998 MHz RF period, under the velocity spread, and then by using two RF cavities, one working at 425 MHz with a voltage of 65 KV to reduce the beam energy spread and the second, working at 2998 MHz with a voltage of 16 KV to re-bunch at 2998 MHz to increase the beam capture in the SCDTL. An aluminium model of the 425 MHz cavity, a re-entrant cavity designed with a relatively low Q and slanted noses in order to avoid multipactoring, has been built.

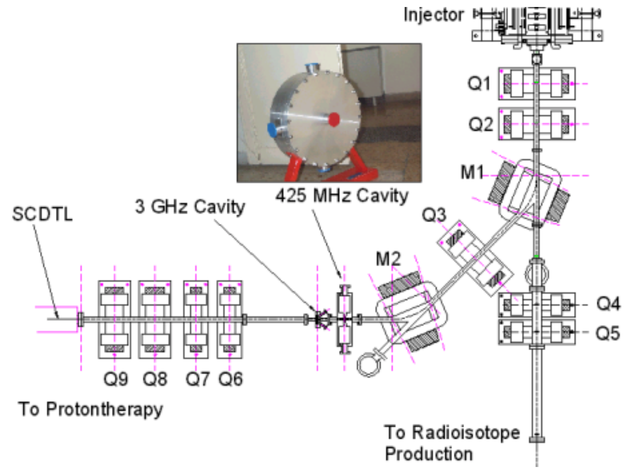

Figure 3: Injector Beam output lines

4 SCDTL 7-65 MEV

The SCDTL structure has been previously described [1,2]. It satisfies the primary requirement of having a larger shunt impedance in the 7-65 MeV energy range than conventional SCL structure. It consists of short DTL tanks coupled together by side cavities. The DTLs are short tanks, each having 5 to 7 cells of βλ length, and the side cavity extends in a space left free on the axis for the accommodation of a very short (3 cm long, 2 cm o.d., 6 mm i.d.) PMQ (Permanent Magnet Quadrupole) for transverse focusing. The SCDTL tanks accelerating the beam to 65 MeV are grouped in seven modules of similar length. The first three boost the energy to 30 MeV and the other four to 65 MeV. The subdivision has been chosen in order to have the possibility to switch already at 30 MeV to the easier structure SCL, tolerating the RF power increase due to the lower shunt impedance of SCL at these energies.

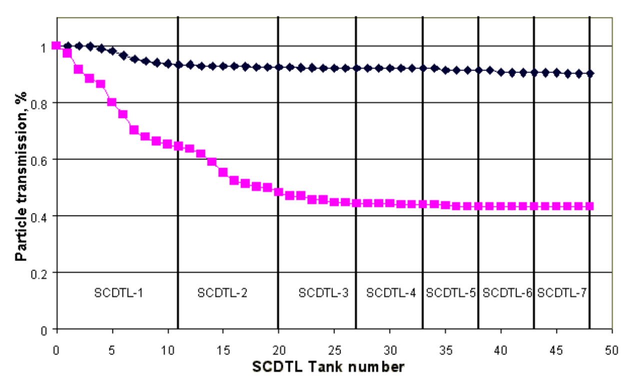

Figure 4: Beam transmission through SCDTL: Upper only transverse dynamics; lower total dynamics

Particles have been tracked from the PL7 output, using the PARMILA output given by AccSys, through the beam transfer line and through the SCDTL up to 65 MeV. In fig. 4 the particle trasmission is plotted vs the SCDTL tank number in the case of only transverse dynamics, and in the real case where also the longitudinal distribution is included. The SCDTL acceptance is smaller than the input beam emittance (5.5 π mm mrad), but as to transverse behaviour the losses are only 10%. However, inclusion of the real longitudinal beam distribution leads to a maximum capture of 40%. The computed normalized beam emittance is 0.7 π mm mrad at 30 MeV and 0.8 π mm mrad at 65 MeV.

The first module (7-13.4 MeV, 1.32 m long, 11 DTL tanks, 5 cells per tank) has been built but for the final braze, and measured on RF bench (figure 5).

Figure 5: SCDTL first module

The properties of this structure were also investigated by analytical and numerical calculations [4]. In fig.6 the electric field on the axis is shown as measured by the bead pull method. Beam dynamics requires the electric field uniformity to be within ±2% among the 11 average tank fields and ±5% among the 55 cells fields.

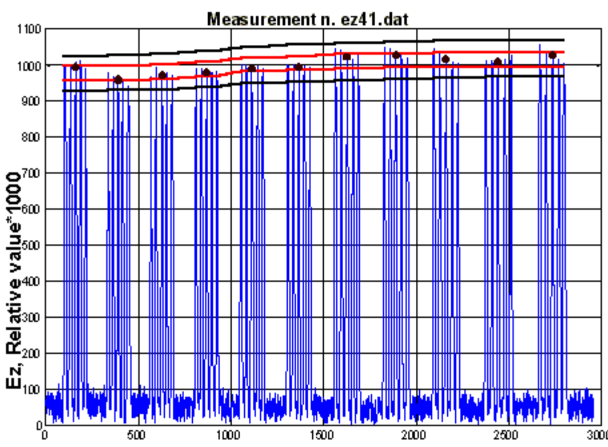

Figure 6: Axial electric field distribution

To get this result, being the tanks all different, it was necessary to tune independently each half of each coupling cavities by appropriate tuning screws (figure 7). Indeed a simulation was done of the first module structure in which any of the 55 accelerating cells is treated independently and the 10 coupling cavities are each split in two cells. The result is that even in the case of no frequency errors, the field do not distribute within the tolerance limits. However, unbalancing the half-coupling cavities frequency in a way to keep the overall coupling cavity frequency unchanged, tunes the relative axial field distribution at the coupling cavity sides while keeping the overall structure frequency distribution unaffected.

The structure is now under final testing and to some mechanical modifications before undergoing last braze.

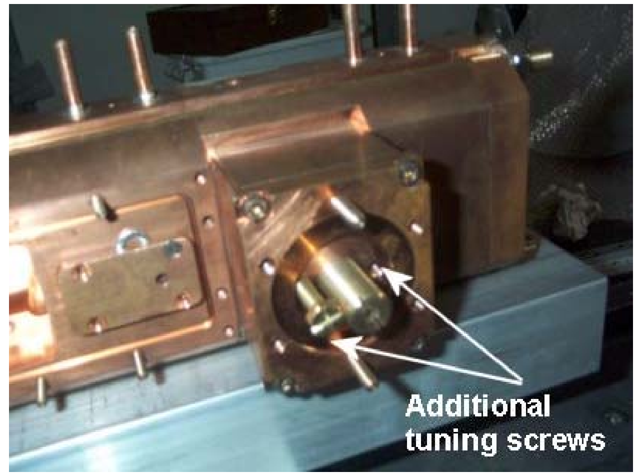

Figure 7:First SCDTL module on RF bench

5 SCL 65-200 MEV

The SCL development for the TOP Project has been left to a second priority, also given the uncertainties of the total project funding. However, very good results were obtained by TERA with a LIBO (LInac BOoster) Module, a 3 GHz SCL 1.3 m structure that was tested in March with the 62 MeV proton beam from Catania SC cyclotron [5] accelerating it to 75 MeV. The design of the 65-200 MeV sections will be therefore carried out in close collaboration with TERA.

6 PROJECT STATUS

As the temporary site (a 20 m long bunker) in ENEA Frascati Laboratory is available, the injector and the first SCDTL module will be mounted and tested. All future development are subjected to the definitive funding of the total project.

7 REFERENCES

[1] L. Picardi et al. “The TOP Project status”, Proc. PAC2001, Chicago, USA, p.2491

[2] L. Picardi, C. Ronsivalle, R. Hamm “Beam injection study of the TOP linac using an AccSys Model PL-7 linac”, EPAC2000 Proc., p. 1675.

[3] L. Picardi, C. Ronsivalle, A. Vignati “Progetto del TOP Linac”, in Italian, ENEA Technical Report RT/INN/97/17, 1997.

[4] L. Picardi, C. Ronsivalle, B. Spataro “The first module of the 3 GHz Side Coupled Drift Tube Linac (SCDTL): numerical studies of RF properties and cold tests results”, EPAC2000 Proc., p. 1999.

[5] C. De Martinis et al. “Beam tests for a proton linac booster for hadrontherapy”, these Proceedings