Status of the TOP Linac project
Cesidio Cianfarania, Evaristo Cisbanib, Gianluca Orlandia, Salvatore Frullani, Luigi Picardia, Concetta Ronsivallea

Abstract
The TOP Linac (Oncological Therapy with Protons), under development by ENEA and ISS is a sequence of three pulsed (5 µs 300 Hz) linear accelerators: a 7 MeV, 425 MHz RFQ+DTL (AccSys Model PL-7), a 7–65 MeV, 2998 MHz Side Coupled Drift Tube Linac (SCDTL) and a 65–200 MeV, variable energy 2998 MHz Side Coupled Linac (SCL). The status of the project will be presented. The 7 MeV injector is installed at ENEA-Frascati laboratories. The first SCDTL module structure, composed by nine DTL tanks coupled by eight side cavities, has been built and tested on RF bench, so that it is ready for proton acceleration. The results of the measurements done will be also shown.

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1. The TOP Linac
The TOP Linac is a proton medical linac facility under design and development by Italian National Institute of Health (ISS) and ENEA to be used in a medium-large size hospital for proton therapy and radioisotope production. TOP is the acronym of the Italian translation of “Oncological Therapy with Protons”. The facility is designed to use a linear accelerator to accelerate the proton beam. Proton therapy is indeed a reality in oncological radiotherapy. Several types of cyclotrons and synchrotrons have been and are being developed worldwide for this application.

The reasons for this unusual choice are: (a) the modularity of the construction, as this linac is composed of at least three sub-systems, each of them able to be operated for a specific task, (b) the compactness, as the linac extends in the area used by beam transport lines in other types of machine, and the (c) flexibility, as a fully 3D scanning irradiation with energy, current and position variable on a pulse-to-pulse basis is possible (d) the use of 3 GHz accelerating structures in a large part of the machine that makes the use of the facility closer to the electron conventional radiotherapy accelerators as to time structure, maintenance and dosimetry.

A 3D draw of the TOP Linac is shown in Fig. 1. It is designed to produce at least the following beams:

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

The linac is composed of a 7 MeV 425 MHz injector, a 7–65 MeV 3 GHz linac booster, named SCDTL (Side Coupled Drift Tube Linac) from the accelerating structure name, a second 65–200 MeV, 3 GHz linac booster named SCL, and the various beam lines to the application rooms. The beam time structure depends on the application. The design foresees for proton therapy the generation of a beam whose position, energy and pulse charge can be varied on a pulse-to-pulse basis for a fully 3D scanning irradiation of deep seated tumours. Energy can be varied between 130
and 200 MeV, pulse current between 0.1 and \( \sim 10 \mu \text{A} \) (a factor 100 and possibly 1000) and pulse duration between 1 and 5 \( \mu \text{s} \) pulses at 100–250 Hz repetition rate.

The original linac design [2] was developed by ENEA in collaboration with CERN, INFN and TERA and it was approved by ISS (National Institute of Health) and funded in 1997 with about 2.5 M\( \text{€} \) although 22 M\( \text{€} \) are estimated for the high technology devices of the facility. However, construction started within a cooperation agreement between ENEA and ISS and installation was agreed to be done in Rome in a large Oncological Hospital, that would immediately benefit of the F-18 production by the injector. At the moment, with no additional funding, a temporary site has been setup at ENEA Frascati laboratories, where the injector tests are currently being done.

2. Injector and LEBT

The injector linac has been built by AccSys Inc., USA. It is a PL-7 model modified to meet the TOP requirements. It is actually installed in a test bunker at Frascati and has been put in operation since some months. It will be used for three main purposes: test of F-18 production (F-Mode, high current), test of transport and injection in the SCDTL section in the beam conditions for radiotherapy and radiobiology, test of acceleration with SCDTL structure (for the last two series of tests the injector will be operated in P-mode, low current). In the high-current mode the pulse current is 8 mA for 60 \( \mu \text{s} \) and 60–100 Hz repetition rate. In the low-current mode the pulse current can be variable between 1 and 30 \( \mu \text{A} \) for 7 \( \mu \text{s} \) and up to 250 Hz repetition rate.

The injector linac and its application in radioisotope production are described in another paper of this conference [3].

In the reference layout of the TOP linac (Fig. 2), after the 7 MeV injector two quadrupoles are placed, and then the high current beam can go straight to the radioisotope production while the low current beam is transferred, through a LEBT to the following accelerating sections. The LEBT is composed by a 90° 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 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, the first (425 MHz, 65 KV) reducing the beam energy spread and the second (2998 MHz, 16 KV) for re-bunching at 2998 MHz to increase the beam capture in the SCDTL. The 425 MHz cavity and the 3 GHz prebuncher have already been built. The last one is a three-gap cavity with slanted noses drift tubes each supported by a couple of 4 mm diameter stems. It has been tested at 750 W of RF power to have 20 kV total across the gaps with no evidence of multipactoring.

3. SCDTL 7–65 MeV

The TOP Linac intermediate energy (7–65 MeV) accelerating section is a 3 GHz linac booster based on the SCDTL accelerating structure that was developed to satisfy the requirement of a high shunt impedance in the low-beta part of the TOP Linac. The SCDTL tanks are grouped in seven modules of around 1.4 m each: the first three boost the energy to 30 MeV and the other four to 65 MeV. A total RF power of 7.5 MW is required.

SCDTL structure [4] consists of short DTL tanks coupled together by side cavities. The DTLs are short tanks, each having 5–7 cells of \( \beta \lambda \) 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.

A reduced length (1 m) prototype of the first module has been built by a local workshop and it stays under vacuum (Fig. 3). With respect to previous descriptions [1] the number of its tanks was reduced from 11 to 9, coupled by 8 coupling cavities. Structurally it is divided in two halves with 5 and 4 tanks, respectively, that have been brazed and
then coupled by bolts in correspondence to the fifth coupling cavity, that is split in the middle. This arrangement was needed because of the limited length of the brazing furnace. Actually many viton gaskets are used to vacuum seal the structure. They are used in the middle, between the two halves and for the 16 flanges that cover the insertion of the PMQs and of the tuning posts, both in the tanks and in the coupling cells. All these gaskets will be replaced with aluminum gaskets, when the structure will undergo RF power tests.

The tanks are composed of a 60.5 mm i.d. cavity with four drift tubes supported each by two rectangular stems 180° apart. Each arrangement of stems and drift tube is machined from a solid piece and two parallel 1.5 mm diameter holes are drilled through the 60 mm long rectangular stem with smoothed edges, for the coolant flow. Each stem is then TIG welded to the tank outer surface to provide for vacuum/coolant tightness, while thin channels are drilled at the inner surface of the tank body and filled with brazing alloy that will melt during final braze and will provide the correct electric contact between surfaces.

The coupling cavities are simple re-entrant cavities that are coupled to the tanks by elliptic holes, with a longitudinal interference of 1 mm. This guarantees a coupling coefficient of about 3%, depending on the specific relative cavity volumes.

With the structure correctly tuned at 2997.9 MHz the electric field was adjusted with tuning screws in the coupling cells to get the axial distribution uniform (Fig. 4) to the specified value. The construction of the final version of first module will be carried on in next year, after the test with the proton beam.

4. SCL 65–200 MeV

The development of the final part of the TOP Linac has been left to a second priority. It will be based on conventional SCL structures at 3 GHz, suitably graded to follow the particle velocity. A prototype of a similar structure was built in 2002 by other groups [5]. Beam delivery systems will be taken into account as a real funding of the machine is available.

5. Conclusions

The TOP Linac construction is slowly going on despite lack of complete funding. The injector is operating in a temporary site in ENEA Frascati Laboratory and many
LEBT components as well as a prototype of the first module of the SCDTL structure are completed. Tests of radioisotope production and acceleration in SCDTL cavity are in progress.

References


