THE TOP PROJECT STATUS

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Abstract

ENEA, in collaboration with ISS (Italian National Institute of Health), is developing a dedicated proton medical accelerator. The TOP (Oncological Therapy with Protons) Linac is to be installed at the IFO Oncological Hospital in Rome. It will be a sequence of three pulsed (5 μsec, 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 7 MeV injector output will also be used in high current mode for F-18 radioisotope production. The SCDTL output will be used for proton treatment of ocular melanoma and for radiobiology studies, with the SCL output dedicated to proton treatment of deep seated tumours. The 7 MeV injector has been completed by AccSys and shipped to ENEA in Frascati and the first SCDTL module (to boost the beam from 7 to 13.4 MeV) has been constructed. The low energy (7 MeV) beam lines for F-18 production and injection in the SCDTL are under construction. The characteristics of the various accelerator components and the status of the project are presented.

1 THE INJECTOR LINAC

The injector linac is an AccSys Model PL-7 system modified to meet the TOP requirements. It will be used in two operating modes:

- **PROTON THERAPY MODE -** injecting protons (2.5 – 30 μA, 7 μs, 30 – 300 Hz) into the TOP Linac accelerating sections;
- **RADIOISOTOPE MODE -** generating an intense proton beam (8 – 10 mA, 50 – 100 μs, 30 – 100 Hz) to produce the positron-emitting radionuclide ^{18}F for PET analyses.

The injector linac is composed of the sub-systems (fig.1):

A. A pulsed 30 keV duoplasmatron proton ion source 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.
B. A 3 MeV RFQ (Radiofrequency Quadrupole).
C. A 3 to 7 MeV DTL (Drift Tube Linac).
D. Three cabinets containing the control electronics, the ion source power supplies and the vacuum system controls, and the RFQ and DTL RF power systems.
E. A computer with a LabView-based control system.

The Model PL-7 injector linac is being tested at ENEA-Frascati before final transfer to the IFO Oncological Hospital in Rome.

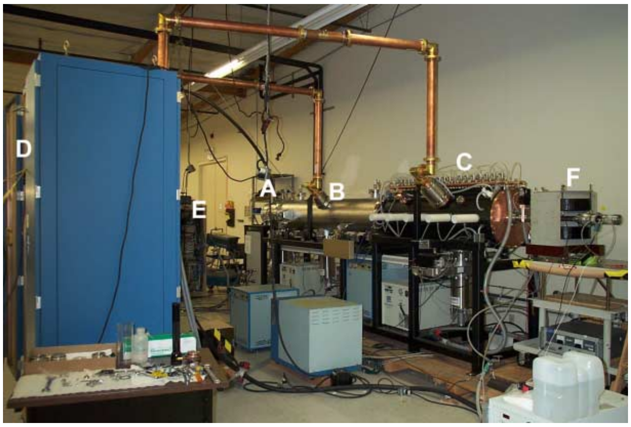

Figure 1: PL-7 injector linac

1.1 Radioisotope mode and ^{18}F production tests

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. The final F-18 production test with a 2 hr irradiation achieved an equivalent activity of 0.762 Ci, 76% of the theoretical value. Current on the target was limited by the temporary beam line. Larger currents and hence, higher production yields will be possible with the final beam transfer line. Figure 2 shows the measured activity compared to the theoretical ^{18}F decay curve, indicating that less than 0.1% of other radionuclides are present.

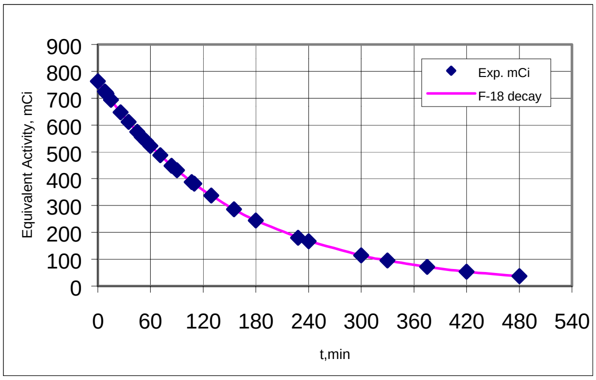

Figure 2: Equivalent activity of the radioactive product

1.2 Proton therapy mode

The injector linac has also undergone testing for Proton Therapy Mode, with cycles of Beam ON-Beam OFF typical of proton radiotherapy operation for a total period of 1 h, in which no serious faults occurred. Duty cycle tests were completed, with 300 Hz operation having been verified with short pulses. At this repetition frequency the maximum flat top pulse length is 2 µs, while below 250 Hz a flat top of 7 µs can be achieved (fig.3).

In order to decrease the linac pulse current from the mA range to the µA range needed for proton therapy, the water-cooled aperture at the RFQ entrance is inserted by a pneumatic actuator. Also, to vary the current for this operational mode, it is possible to change 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 pulse-to-pulse variation of the beam current through the aperture. A variation range of 25 µA - 1.1 µA was obtained for a voltage range of 30-23 kV of the Einzel lens voltage (fig.4).

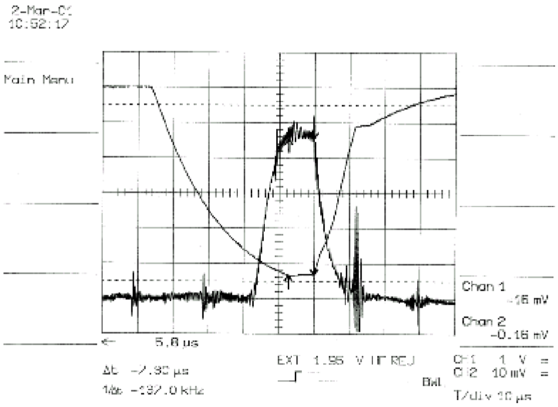

Figure 3: Beam current (26 µA) and DTL cavity for P-mode, 200 Hz.

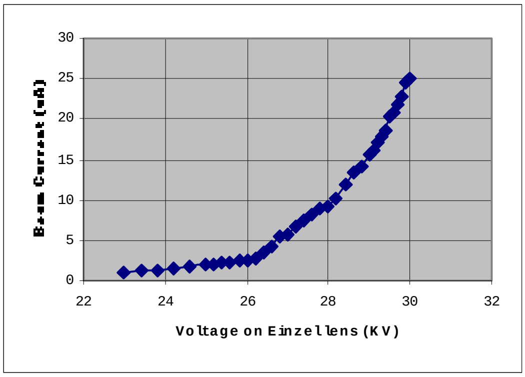

Figure 4: Beam current vs Einzel lens voltage

1.3 Energy Measurements

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 (fig.5) and a slit placed in the image plane of the accelerator output beam. This system minimises the increase of the spot size in the second slit plane due to the beam angular spread. The analysis system has been optimised with TRACE and simulated with PARMELA using the computed beam distribution from the PL-7 linac, and results compared with measurements (fig.6). An energy spread of ±100 keV at low current and ±130 keV at high current has been measured, which agrees well with the specifications and computed values.

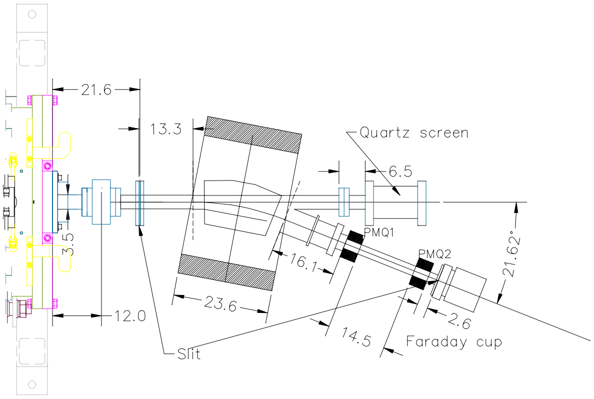

Figure 5: Energy measurement setup

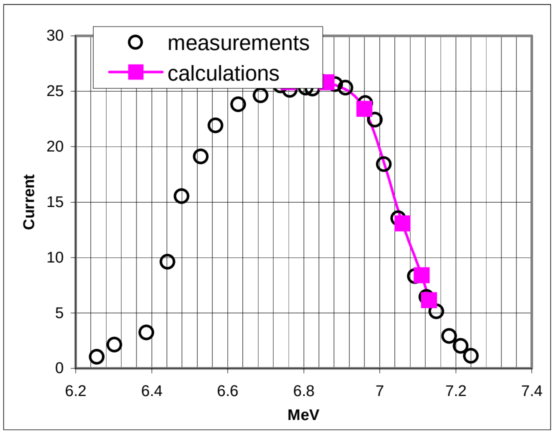

Figure 6: Collected current after the slit vs energy

2 BEAM TRANSPORT LINE

A dual output beam transport line composed of a straight section and a 90 degree bending section has been designed (fig. 7). The design criteria of the injection line for the SCDTL were described earlier [1]. In this new design, in order to simplify the line and avoid bending the proton beam in the high current operating mode, the radioisotope production area will be installed after the straight section and the SCDTL module will be placed after the 90 degree bend section. The straight line shares the first two quadrupoles with the injection line of the SCDTL. The latter includes an achromatic bend system to preserve the horizontal emittance, and a sequence of six elements - four quadrupoles and two RF cavities - to match the total beam phase space to the SCDTL acceptance. In particular the longitudinal space matching is obtained by allowing the bunch to lengthen to much more than one 2998-MHz RF period due to the velocity spread, and then by using two RF cavities, one working at 425 MHz with a voltage of 65 KV and the second working at 2998 MHz and with 16 KV. The first cavity reduces the beam energy spread and the second cavity works as a prebuncher, receiving practically a continuous beam (that is a bunch much longer than one wavelength) which is re-bunched 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, is in construction.

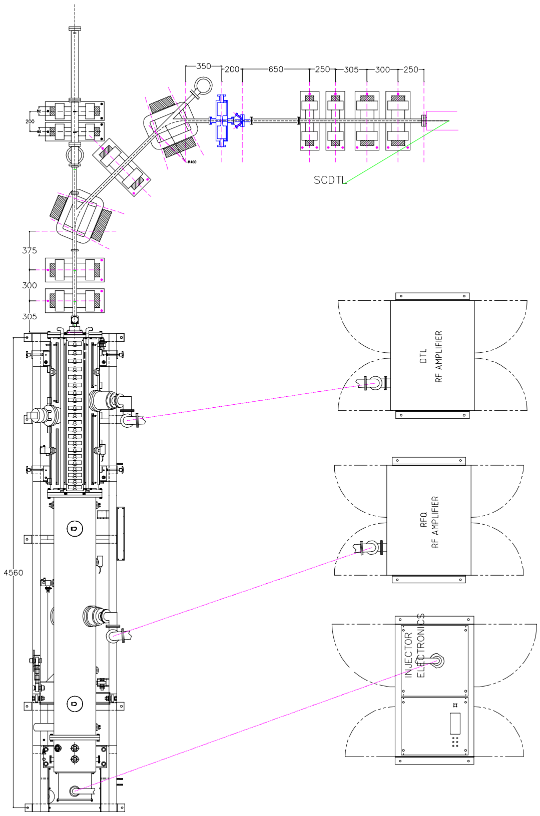

Figure 7: Beam transport lines from PL-7

3 SCDTL

The SCDTL structure has been previously described [2,3] and has been chosen to satisfy the primary requirement of having a large shunt impedance in the 7-65 MeV energy range. It consists of short DTL tanks coupled together by a side cavity in an arrangement like a Side Coupled structure. The main differences between a standard SCL (Side Coupled Cavity Linac) and the SCDTL are that the single cavities are replaced by short Alvarez tanks, each having 5 to 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. The coupled tanks of the SCDTL are grouped in eight modules of similar length. The properties of this structure were well investigated by analytical and numerical calculations and RF measurements on prototypes. The first module (7-13.4 MeV, 1.4 m long) has been built and RF bench measured (fig.8). It was found that in order to obtain the required electric field uniformity, different coupling coefficients are necessary along the structure. In the first prototype, not yet brazed, this was achieved by setting an asymmetry of a few tenths of a millimetre in the coupling cavities nose lengths. From the equivalent circuit model of the structure, this corresponds to a change in the resonant frequencies of the two half cavities that make up the coupling cavity. In order to simplify this tuning procedure the design of the coupling cavities was modified to have noses of equal length and to use two symmetric variable length posts. The dimension and the excursion of the posts were derived from 3D MAFIA calculations. The final structure for the first module is undergoing final brazing.

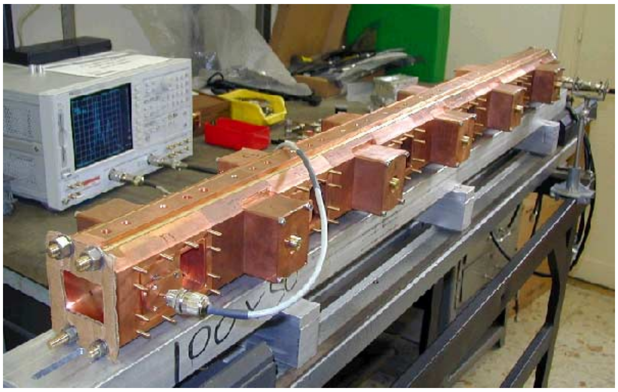

Figure 8:First SCDTL module on RF bench

4 FUTURE PROJECT DEVELOPMENT

The next steps in the project will be the construction of the beam lines and proton acceleration tests of the first SCDTL module, which will take eighteen months. The final design of the modules up to 65 MeV is underway. The design of the 65-200 MeV sections will be carried out in close collaboration with TERA, which is developing the LIBO 3 GHz modules to boost protons from 65 MeV to 200 MeV. In addition, beam monitoring of a single proton pulse is under development. The goal is to measure the beam charge pulse by pulse over the wide dynamical range (four order of magnitude) required by the treatment planning of a proton beam with active scanning.

5 REFERENCES

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

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

[3] 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.