

EXPERIMENTAL RESULTS ON SCDTL STRUCTURES FOR PROTONS

L. Picardi, A. Ampollini, G. Bazzano, P. Nenzi, C. Ronsivalle, V. Surrenti, M. Vadrucci,
 ENEA, Frascati, Italy
 F. Ambrosini, La Sapienza University, Roma, Italy

Abstract

The medium-energy section of the proton linear accelerator for radiotherapy under realization in the framework of the TOP-IMPLART Project consists in a high frequency 7-35 MeV SCDTL (Side Coupled Drift Tube Linac) structure. The structure, made of 4 modules supplied by one klystron, has been completely designed. The first module up to 11.6 MeV has been built and is under commissioning at ENEA-Frascati and the second and third modules are under realization. The paper describes the system and presents the main results of the experimental activity on this part of the accelerator.

THE TOP-IMPLART ACCELERATOR

A RF proton linear accelerator is under realization in the framework of the TOP-IMPLART (Intensity Modulated Proton Linear Accelerator for RadioTherapy) Project led by ENEA in collaboration with the Italian Institute of Health (ISS) and Regina Elena National Cancer Institute IFO-Rome [1]. The project is devoted to the realization of a protontherapy centre to be sited at IFO based on a 230 MeV accelerator.

The first segment up to 150 MeV has been funded by Regione Lazio and is under realization and test at ENEA-Frascati. It is composed by a low frequency (425 MHz) injector (ACCSYS-HITACHI PL7 model, RFQ+DTL) and a high frequency (2997.92 MHz) booster (SCDTL up to 35 MeV and CCL up to the final energy).

The medium energy section

Unlike circular accelerators (cyclotron and synchrotrons) typically used for protontherapy, the modularity of a full linear scheme allows to assembly, test and use the different parts of the machine following the increase of energy. Figure 1 shows the accelerator scheme up to end of the medium energy section of the accelerator.

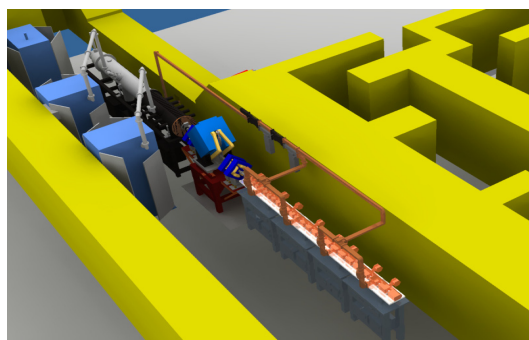


Figure 1: TOP-IMPLART scheme up to 35 MeV.

It consists of four SCDTL (Side Coupled DTL) modules accelerating the beam from 7 to 35 MeV whose main parameters are summarized in table 1.

Table 1: TOP-IMPLART SCDTL parameters

	Module 1	Module 2	Module 3	Module 4
Tanks	9	7	7	5
Gaps/tank	4	5	6	6
Bore hole dia., mm	4	4	5	5
Distance between tanks / $\beta\lambda$	5.5	4.5	3.5	3.5
Energy out, MeV	11.6	18	27	35
Power, MW	1.3	1.6	2.2	2
Length, m	1.109	1.082	1.353	1.105

Actually the segment composed by the 7 MeV injector, a LEBT (Low Energy Beam Transport) magnetic line and the first SCDTL module has been assembled and aligned (fig.2).

The injector is in operation and the low energy beam is used for several applications [2]; the first SCDTL module designed to accelerate protons from 7 to 11.6 MeV is under commissioning.

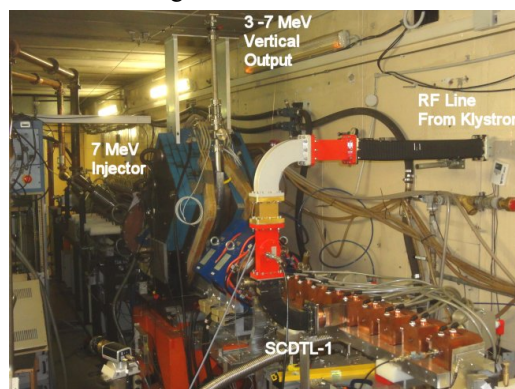


Figure 2: TOP-IMPLART accelerator at ENEA.

THE FIRST SCDTL MODULE

The SCDTL (Side Coupled Drift tube Linac) structure has been described in different papers (see Ref.1 and references included). It has been invented to accelerate

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with high efficiency low energy protons by using a high RF frequency and consists in short DTL tanks composed by few $\beta\lambda$ long cells coupled by a side coupling cavity, with high gradient (around 200 T/m), short (3 cm long) PMQs placed in the inter-tank space for the beam focusing [3]. From the initial proposal of this innovative structure different pre-prototypes of SCDTL tanks have been built and tested in order to simplify the realization. Now the procedure is assessed and can be briefly described as following. The tanks are composed of three main pieces: the central body and two half coupling cavities on each side. These pieces are brazed forming the tank after brazing the CF16 flanges used to connect the inter-tanks beam pipes. After the tuning, stems are TIG welded and so also the various tanks to complete the structure realization. This means that after the brazing of the bodies the procedure does not require the use of the vacuum oven. The operating frequency is 2997.920 MHz. The tuning procedure is done in air at about 23°C: passing from ambient to vacuum the increase of frequency is almost completely recovered working at around 40° (settable within $\pm 5^\circ$ and stable within $\pm 0.2^\circ\text{C}$) so that at bench structures are tuned at 2997.920 MHz ± 100 kHz. The first SCDTL module (7-11.6 MeV) for the TOP-IMPLART accelerator has been manufactured by CECOM (Guidonia, Italy) and TSC (Fiumicino, Italy) companies on ENEA design. It has been mounted at the end of the LEBT following the injector and is under commissioning.

RF cold tests

The structure has been tuned and completely characterized on RF bench with the measurement of dispersion curve (fig.3), $\pi/2$ mode frequency, Q factor and coupling with the waveguide (fig.4).

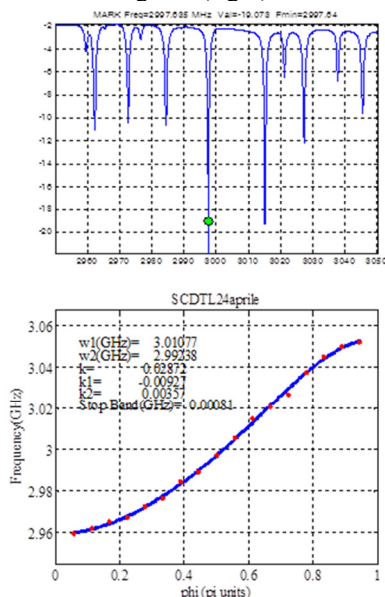


Figure 3: (top) Resonant modes measured in reflection, from the central tanks; (bottom) the measured modes dispersion curve.

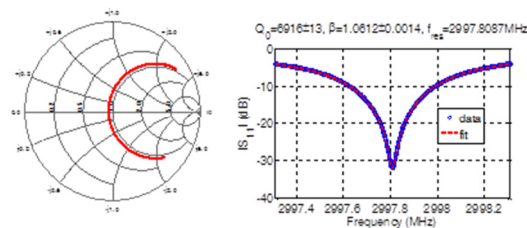


Figure 4: Smith chart showing the coupling of the $\pi/2$ mode (left) and Q reflection measurement (right).

With the structure correctly tuned at the proper frequency the electric field has been adjusted with tuning screws in the coupling cells to obtain the axial distribution uniform within $\pm 2\%$ among the 9 average tank fields and $\pm 5\%$ among the 36 cells fields (fig.5).

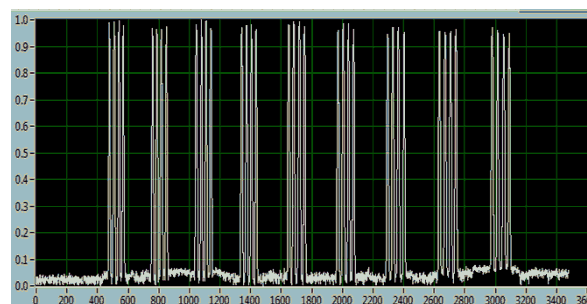


Figure 5: Bead pull measurement: Squared electric field along the axis on the SCDTL structure.

Proton beam transport with RF off

In order to check the transverse matching between the injector beam and the SCDTL structure and the alignment of the total beamline from the injector exit to the output of SCDTL-1 the proton beam has been transported up to the exit of the structure without powering it. In fact beam dynamic simulations show that also in absence of acceleration the PMQ focusing line arranged in a DOFO-like scheme in the inter-tank space of SCDTL-1 allows to transport the 84% of the beam through the structure for a 7 MeV beam with a nominal energy spread included in ± 100 keV. The matching is done by four electromagnetic quadrupoles placed in the 2.5 meter long LEBT following the injector. The injector current is controlled by the extraction voltage and the voltage on an einzel lens placed before the RFQ. The main settings are reported in table 2.

Table 2: Main settings for the beam transport experiment

Parameter	Value
Extraction voltage,kV	28.2
Einzel voltage,kV	27.8
Q1 Gradient, T/m	-9.1
Q2 Gradient, T/m	8.87
Q3 Gradient, T/m	-10.15
Q4 Gradient, T/m	12.02

The input current in the SCDTL structure is measured on a removable flag intercepting the beam at a distance of about 10 cm from the SCDTL entrance and the output current is measured at the exit of the last tank.

Figure 6 shows the oscilloscope screen with the trace recorded during the beam transport experiment: a signal proportional to the arc current on the proton source (yellow trace), the electric field probe in the RFQ (blue trace), the electric field probe in the DTL (magenta trace), (the pulse duration of the accelerated beam is given by the temporal superposition of these three signal and can be adjusted varying the relative delay) the input current in the SCDTL (the green trace) and the output SCDTL-1 current (white trace).

The input current is around 200 μ A and more than 60% is transported at the exit of SCDTL-1.

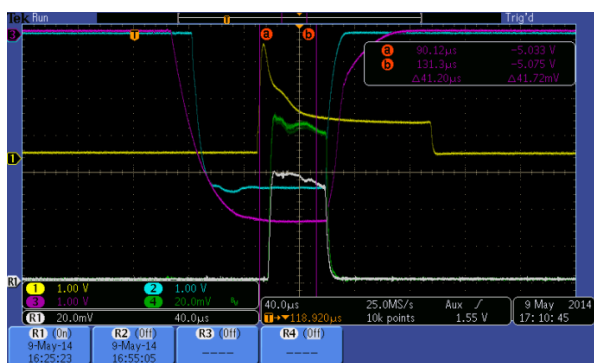


Figure 6: Oscilloscope screen during the measurement of the beam transmission through SCDTL-1 with RF off.

The final beam spot on a fluorescent target is shown in Figure 7. It is included within a diameter of 4 mm.

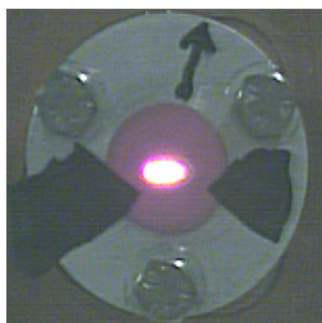


Figure 7: Beam spot at SCDTL-1 exit. Pink area is a 10 mm diameter alumina disk.

The reduction of transmission respect to the computed value is mainly due to the presence of a low energy satellite in the input beam (fig. 8). The energy spectrum was obtained doing the derivative of the measured beam transmission curve in increasing thickness Aluminium absorbers and using the relation between energy and range in Al.

The further small reduction is caused by residual misalignments.

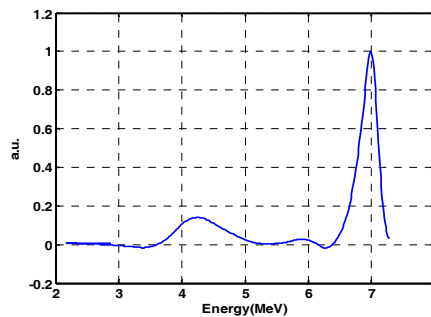


Figure 8: Measured beam energy spectrum at the entrance of SCDTL-1.

RF hot tests

In the final configuration the four SCDTL modules will be powered by one TH2157A klystron (10 MW). For high power RF tests SCDTL-1 structure has been coupled to the high power RF line coming from a TH2090 Klystron (max. delivered power=15 MW) available in ENEA lab and since the second week of June is under RF conditioning. The pulse length is 3.5 μ s (flat-top) and repetition rate available is only 6.25 Hz. Power has been measured by a E4117A Agilent power meter with EPM-P probe controlled via GPIB. The total attenuation was 97.7 dB (57.7 from a WR284 Thomson directional coupler, and further 40 dB with cable attenuators). After about 10 h of conditioning it has been possible to feed the structure with a forward power of 0.9 MW.

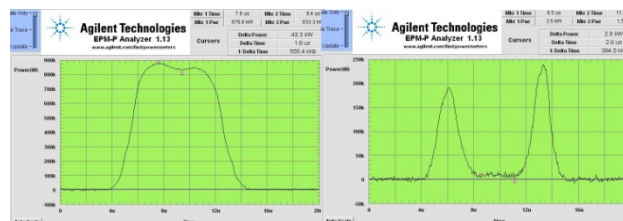


Figure 9: Signals acquired from power meter:(left) reflected power, (right) forward power

CONCLUSIONS

The 9-cells SCDTL-1 module of the TOP-IMPLART accelerator has been successfully tested at low RF power. The phase of commissioning recently started with the beam transport in absence of acceleration and the conditioning at high RF power. The next modules have been designed and are under realization.

REFERENCES

- [1] C.Ronsivalle et al. "The TOP IMPLART Project", Eur. Phys. J Plus (2011) 126,number 7,68.
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