MEASUREMENT OF CAVITIES OF THE SIDE COUPLED DRIFT TUBE LINAC (SCDTL)[1]

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Abstract

The 3 GHz SCDTL structure has been developed at ENEA Frascati Laboratories to be used as the intermediate energy part of the Compact High Frequency Linac, envisaged by the TERA foundation for proton therapy. The compact linac [1] is composed of a 7 MeV, 428.3 MHz RFQ, followed by the 70 MeV, 3 GHz SCDTL and ending with a 200 MeV, 3 GHz Side Coupled Linac (SCL). A 5-cavity model of the SCDTL has been built and measured on a RF test bench. In addition, a 7-cavity prototype (accelerating till 13.35 MeV) is under construction and will be tested with beam at the INFN Laboratories at Legnaro in 1997. The paper describes the SCDTL structure, gives the results of RF measurements on the model and presents the experimental layout at Legnaro.

1 THE SCDTL STRUCTURE

The SCDTL structure [2] has been invented in order to overcome the problem of an efficient proton acceleration in the 7-70 MeV energy range. It is on the same development line of other high frequency intermediate energies structures for protons [3]. The SCDTL consists of short DTL tanks coupled together and each one followed by a permanent magnet quadrupole for focusing (fig.1). The resonant coupling is achieved by a side cavity, which extends in a space left free for the accommodation of the very short (3 cm long, 2 cm o.d, 6 mm i.d.) PMQs. As the neighbour tanks operate in phase opposition, the distance between them is done equal to an odd-integer multiple of $\beta\lambda/2$.

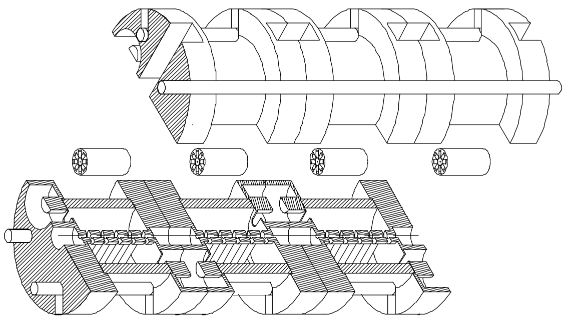

Figure 1 *Longitudinal section of three tanks of the SCDTL*

Each tank is built in three pieces: the body of the accelerating tank (which is a cylinder carrying the drift tubes inside) and two end flanges which complete the accelerating cavity with two half - drift - tubes and have one half coupling cavity and one half PMQ bed drilled in each of them. All these pieces are made in OFHC copper. The drift tubes are small cylinders 12 mm OD and 4 mm ID, with the proper length (the drift tubes of one tank have the same length) aligned and brazed - in a single step - with the stems and the accelerating tank body at 950°. The two end flanges are thereafter brazed at 780°. Then, the assembled tanks are aligned and bolted together to form a module. The SCDTL has six indipendently powered modules, each one being composed of an odd number of tanks and shorter than 2 m. Screw posts are left in the tank body and in the coupling cavities for the final tuning.

2 SHUNT IMPEDANCE CALCULATIONS

Fig.2 shows some computed values of the effective shunt impedance ZT^2 of a multigap 3 GHz DTL tank (cell length $=\beta\lambda$) and of a SCL tank (cell length $=\beta\lambda/2$) as a function of the relativistic β value of the particles. One sees that for $\beta<0.4$ (energies below 85 MeV) the SCDTL is quite superior to SCL. The output energy of the SCDTL has been chosen as 70 MeV, because this is the energy required to cure eye melanomas and the 70 MeV beam can be transported in the corresponding treatment room. From fig.2 one sees that ZT^2 increases with the number of gaps/tank; the bore hole (r_{bh}) is a parameter. At energy below 1-2 MeV (β=0.046 - 0.065) ZT^2 drops drastically.

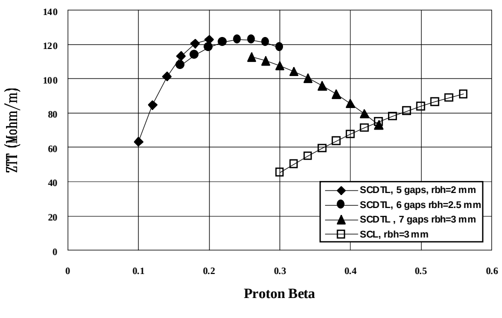

Figure 2 *Computed values of the effective shunt impedance of a multigap DTL cavity operating in zero-mode and SCL cavity operating in $\pi/2$ mode versus the particle β.*

The SCDTL tanks consist of 5, 6 or 7 equal length cells with a bore radius of 2, 2.5, 3 mm. The peak power consumption in the SCDTL is relatively low, calculated to be less than 8 MW for the entire structure from 7 to

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70 MeV, considering a correction factor respect to the SUPERFISH value of 1.25. The average electric field E_0 of about 12 MV/m keeps the peak surface fields E_s below 1.6 times the Kilpatrick limit. At this acceleration gradient, the length of the SCDTL is about 11 m.

3 LOW-POWER MODEL MEASUREMENTS

A five cavities (three accelerating and two coupling) OFHC copper model (fig. 3) was built and tested at low power. Differently from the above described structure it has the drift tubes machined together with the stems and screwed to a basis bolted to the cavity body. This turns in a lower Q value as mentioned in the following paragraphs. Each accelerating cavity is composed of five DTL cells (each one $\beta\lambda$ long, with β=0.127, 0.1316, 0.1357 respectively), and the total length is 276.5 mm.

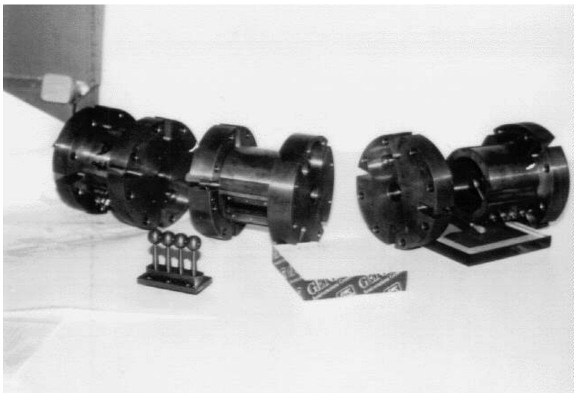

Figure 3 *SCDTL model photograph*

3.1 Mode Frequency distribution

The mode frequency distribution cannot be fitted by the usual dispersion relation, being the end cavities full rather than half, so a fit program has been developed in order to determine the values of coupling coefficients and stop band. As known [4], vanishing the $\pi/2$ mode in the coupling cells implies that the frequency ω_b of the end cavities is correlated to the central cavity frequency ω_a by the relation $\omega_b=\omega_a\sqrt{(1-k_1/2)}/\sqrt{(1-k_1)}$ where k_1 is the second neighbour coupling. This relation is included in the fitting program, which solves the general coupled circuit model. Table 1 compares the measured mode frequencies with the computed ones and table 2 lists the calculated parameters.

Table 1. Measured and computed frequencies

Measured Frequency (MHz)	Mode	Calculated Frequency (MHz)
2961.35	0	2961.25
2976.23	$\pi/4$	2976.40
3000.2	$\pi/2$	3000.31
3024.32	$3\pi/4$	3023.97
3043.5	π	3043.69

Table 2. Calculated fitting parameters

Parameter	Value
k	0.0317
k_1	-0.0012
k_2	-0.0011
ω_a (MHz)	3002.05
ω_b (MHz)	3001.18
Stop Band (MHz)	1.68

3.2 Electric field distribution

The cavities have been designed (fig.4) to have the same inner diameter (6 cm), the drift tubes are made from 1.45 cm diameter spheres, the gaps have been adjusted to reach 2997 ± 0.5 MHz without stems. SUPERFISH results are reported in table 3. The shunt impedance value is corrected for 3 mm diameter stems.

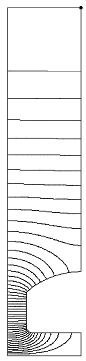

Figure 4 *SUPERFISH computation of half cell of DTL number 3; field lines are shown.*

Table 3: RF parameters as computed by SUPERFISH

DTL No.	Q	ZT^2 (MΩ/m)	T	R/Q (Ω/m)	R/Q (Ω)
1	14109	74.14	0.6861	5581	356
2	13842	77.99	0.6983	5596	368
3	14460	81.94	0.7106	5611	381

R/Q varies slightly among the cavities and its average is 5596 Ω/m, or 368 Ω/cavity; Q is about 14000. R/Q inside a cavity is computed from the single cells.

Measurements of the frequency shift induced by a 1 mm diameter stainless steel sphere traversing the cavities at constant speed were done. The results are shown in fig.5. From this distribution, extracting the square root, the electric field amplitude distribution can be derived. The average electric field E_o on the axis of the three cavities, is related to the peak fields E in the cells by $E_o=(E\cdot gap\cdot n)/L$ where the gap is the equivalent value considering the fringing, n is the number of cells and L is the cavity length. Since the ratio *gap/L* is not constant along the structure we expect that in order to have the same average axial electric field in the different cavities (which is the condition imposed in dynamics calculations), the distribution of the peak electric field is not uniform going from one cavity to another. The relative distribution of electric field can be understood thinking that tuning the system means vanishing the field in the coupling cavities for the π/2 mode, and this means, in turn, that the magnetic fields near the coupling holes have to be the same for all the cavities, and really turns out that the average electric field must be the same in all cavities. The measure reveals that respect to the last cavity the average electric field amplitude is almost flat, being only 0.6 % lower in the first cavity and 0.9 % higher in the second cavity. The peaks are not perfectly equal in a tank: the average value of peak values, relatively to the tank n.3, is 0.5% lower in the cavity n.2 and 2.5% lower in the cavity n.1 (compared to SUPERFISH value of 4%). Furthermore in the cavity n.1 the deviation of the amplitude of the peaks from the average is within ±3%, while in the cavity n.2 is roughly within ±2 % and in the cavity n.3 is within ±1.5 %. As the error study shows that the beam dynamics is affected by the uniformity of the average field among the tanks (the required uniformity is ± 2% in the first module) more than the uniformity of the average electric fields among the cells in a tank (the required uniformity is ± 5%), we can conclude that the electric field stability is well within the tolerances.

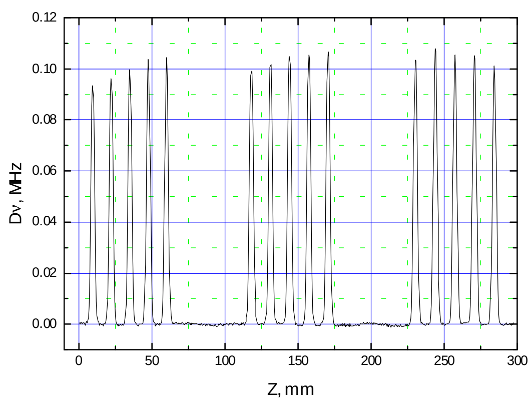

Figure. 5 *Results of an axial bead-perturbation measurement for the π/2 mode of the 5-cell SCDTL model*

Applying the Slater theorem [5] to the measured distribution, a R_o/Q_o value of 1116.7 Ω is obtained. Considering only the space inside the three cavities, whose length are 63.79, 65.83 and 67.89 mm, the specific value is R_o/Q_o = 5653 Ω/m on the average, which is only 1% larger than the theoretical (SUPERFISH) one (5596 Ω/m). To have an estimation of the Q value, a comparison has been done between a cavity body of the model (which suffers from screws, and bolts) and a cavity body to which drift tubes and stems were brazed. The second cavity has a considerably larger (10100) Q value than the model one (4700). Further improvement is foreseen for the final structure in which also the end flanges will be brazed: we expect Q to rise to the typical value of 75% of the SUPERFISH value.

4 PLANNED HOT TESTS AT LNL

An acceleration test on the SCDTL structure is planned next year using the 7 MeV - 3 μA proton beam produced by a Van de Graaf accelerator at INFN laboratories at Legnaro (LNL). At this aim a SCDTL prototype consisting of 11 accelerating cavities and 10 coupling cavities is under construction, which will be able to accelerate protons from 7 to 13.35 MeV. The injected beam will be adapted in the transverse plane by a quadrupole system, but not in longitudinal plane: we expect a 1.5 μA output beam filling the entire bore hole with all energies between 6 and 13.5 MeV. The experiment layout is shown in fig. 7. Briefly, energy spread will be measured by a 90° analysing magnet which will select a beam portion with an energy spread of ± 50 keV (30% of output beam). Emittance measurements are also foreseen after the magnet.

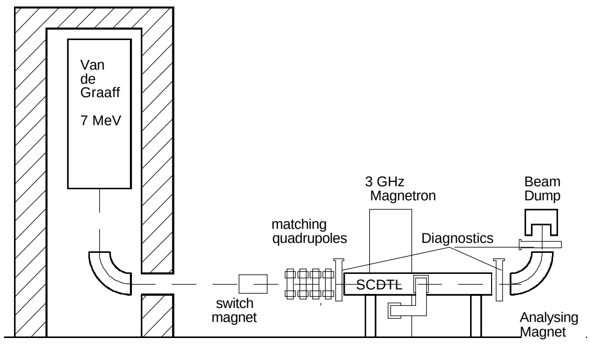

Figure 7*. Layout of the experiment of protons acceleration by SCDTL at LNL*

5 CONCLUSIONS

The low power measurements of the main RF parameters on a 5-cell model of the novel structure for proton acceleration at intermediate energies (7 - 70 MeV) named SCDTL agree with calculations. The results confirm the high efficiency and the good field uniformity of this novel structure, and encouraged us to build a longer model that will be suitable for acceleration tests.

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