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SIMULATIONS AND MEASUREMENTS OF THE CCL MODULES OF THE LIGHT ACCELERATOR

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Abstract

A 230 MeV proton LINAC system for medical applications is being developed and commissioned for the LIGHT (Linac Image Guided Hadron Therapy) project by AVO-ADAM. The LINAC system consists of a 749.48 MHz RFQ (Radio frequency quadrupole) for the low energy proton acceleration, 2997.92 MHz SCDTL (Side Coupled Drift Tube Linac) for the medium energy and 2997.92 MHz CCL (Coupled Cavity Linac) for the high energy acceleration. In particular, the CCL accelerating modules are used in the energy range from 37.5 – 230 MeV. In this paper we discuss the 3D EM (electro-magnetic) simulation results and measurements of the CCL modules.

INTRODUCTION

The accelerating system of the LIGHT machine [1] is being commissioned by AVO-ADAM in Geneva, Switzerland. Three different types of accelerators are utilised for the nominal energy acceleration of 230 MeV. The proton injector assembly (PIA) delivers a pulsed proton beam of 40 keV energy to the RFQ. The beam gets bunched, focused and accelerated to 5.0 MeV in RFQ at 749.48 MHz RF frequency. The SCDTL modules accelerate the beam from 5.0 MeV to 37.5 MeV. The CCL modules accelerate the beam from 37.5 MeV up-to 230 MeV. The SCDTL and CCL structures operate at 2997.92 MHz RF frequency. The LIGHT machine is modular and, the output energy depending upon the user/medical requirement is variable from 70 to 230 MeV. In total, the CCL structures are divided in 15 modules.

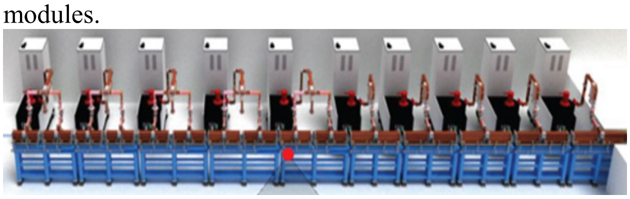

Figure 1 : CCL modules of the LIGHT accelerator.

As shown in Figure 1, the first ten CCL modules are powered with 5 klystrons and the last five modules are powered with one klystron each. The peak RF power delivered by the klystron is 7.5 MW. Each module is operated with 0.1% duty cycle at 200 Hz repetition rate for the nominal operation. Each CCL module consists of two accelerating tanks connected by a bridge coupler [2] working as an RF power coupler. The accelerating tank consists of several accelerating and coupling cells.

CCL RF DESIGN

The CCL accelerating tanks are based on the side coupled design where each accelerating cell is on axis and coupling cell is off axis operating in Standing Wave (SW) mode. For the operating mode, the accelerating cell to accelerating cell phase advance is π enabling the tank to reach maximum possible shunt impedance. Whereas each accelerating cell to coupling cell phase advance is $\pi/2$ ensuring the stability of the operating mode.

In order to design the accelerating tanks, we utilise a commercially available EM code called CST microwave studio [3]. As a simulation model, we use the basic 3D - RF design of accelerating and coupling cells that has a periodicity within the structure to represent the full tank. In this way, the computational time is minimised. Once the parameters of the accelerating and coupling cells are optimised, then we create the full 3D model of the tank to check the final frequency of the structure. The beam aperture diameter of the accelerating cells is 5 mm and the accelerating cell diameter is about 70 mm. The coupling cell diameter is about 55 mm. The coupling coefficient between the accelerating and coupling cavity RF field is ~3%. In order not to keep the manufacturing tolerances too-tight, the accelerating and coupling cells are equipped with two tuners each. These tuners are inserted in the cavity as part of the RF design. In this way the tuning is facilitated as the frequency of the cavity could be tuned by moving the tuners ± 5 mm giving a tuning range of 2997.92 ± 4.00 MHz.

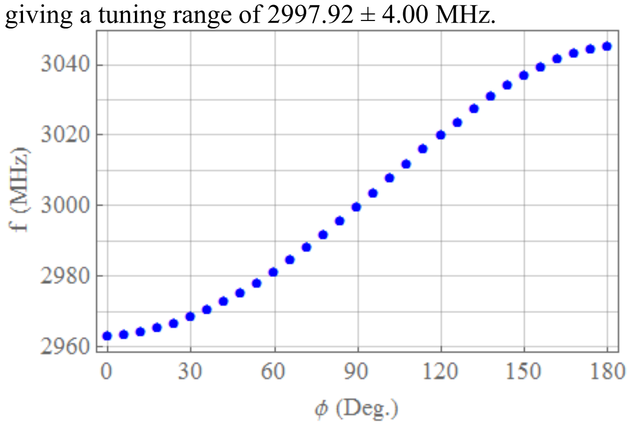

Figure 2: Dispersion curve of a tank.

The dispersion curve of a tuned structure is shown in Figure 2. As it is clearly seen in the dispersion curve the stop band between the accelerating chain and coupling chain is negligibly small hence the band gap is practically closed at the $\pi/2$ phase advance. Once all accelerating cells resonate at the same frequency the accelerating field set up in the fundamental mode has same field amplitude (i.e. field flatness) and coupling cells have practically no field as shown in Figure 3. The pictorial presentation of the E-field in the accelerating tank is shown in Figure 4. It must be noted that even though the proton energies are non-relativistic, in order to facilitate the manufacturing of the tanks, all the accelerating cells in a given tank are designed

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with the same length, i.e. $\beta\lambda/2$ where β is the relativistic factor and λ is the wavelength at the operating frequency. This β is the average of input and output energies of the given tank.

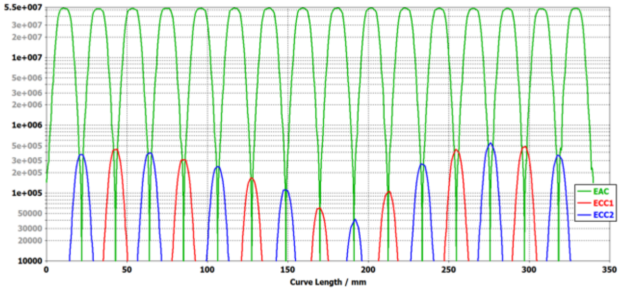

Figure 3: Accelerating and coupling cell fields in a tank.

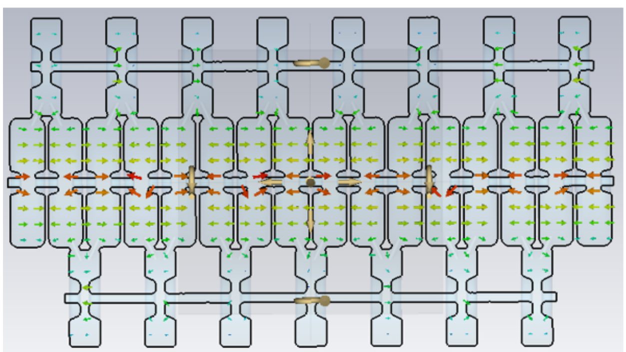

Figure 4: RF design of a tank showing accelerating field.

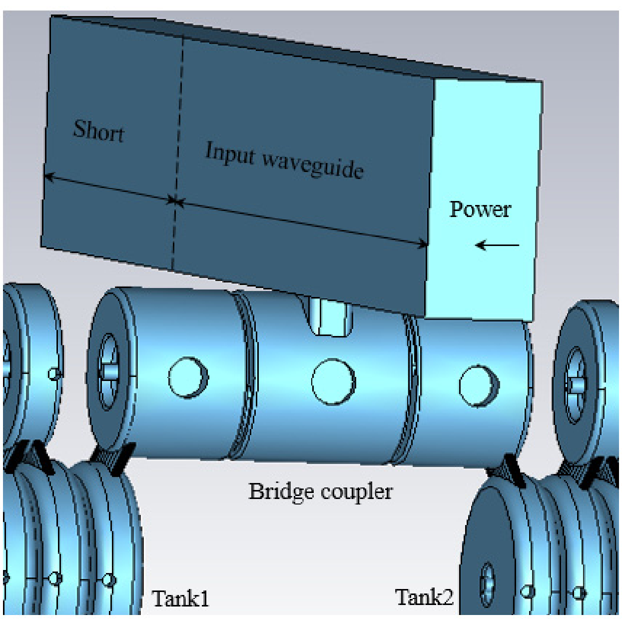

Figure 5: Bridge coupler RF design.

One CCL module consists of two accelerating tanks that are connected with an off-axis bridge coupler as shown in Figure 5. A bridge coupler [2] is similar to a power coupler, however it consists of three resonating cells. Each bridge coupler cell is also equipped with two tuners. The bridge coupler receives RF power through a WR284 waveguide and splits it in half i.e. works as a 3dB power splitter to power both the accelerating tanks. In addition, the bridge coupler geometry and the field pattern in its cells are such that it guarantees the continuity of the $\pi/2$ accelerating mode ensuring the correct phase relation between the two tanks. The WR284 waveguide is used to input the required RF power in the module. As depicted in Figure 5, one end of the waveguide is used as an input port and the length of the other end is used as a short circuit to fine tune the minimum reflection from the module, i.e. to ensure the critical coupling of the structure without changing the power feeding slot dimensions between the waveguide and the bridge coupler.

CCL MANUFACTURING AND TUNING

The CCL module cells are manufactured with low surface roughness in order to minimise the power loss on the surface. In LIGHT machine, CCL modules have typically 14 to 22 accelerating cells per tank. Each accelerating cell of a tank is built by brazing two half discs. The bridge coupler cells are also brazed similarly. The half cells of a CCL module are shown in Figure 6.

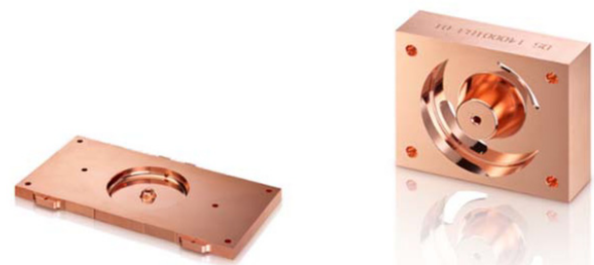

Figure 6: Half disc (left) and bridge coupler disc (right).

In the first stage all the half discs of a tank are brazed, and individual tanks of a module are tuned by moving the tuners in or out depending on the case. We use the perturbative bead-pull [4] method for measuring the accelerating field excited in a tank. By analysing the bead-pull measurement results, local tuners are moved to flatten the field. Once a required level of field flatness is reached all the tuners are uniformly moved in or out to achieve the operating frequency of 2997.92 MHz. After tuning both the tanks, the tank tuners are brazed so as to ensure the vacuum tightness of the tanks. In the next step, bridge coupler is assembled with the brazed tanks and tuned to achieve the mode frequency 2997.92 MHz. This is a critical step as this step defines the final operating frequency of the module. After this tuning step, the length of the short is adjusted to minimise the power reflection at the operating frequency. After simulating the full module in CST microwave studio, we estimate the short length. This estimation is in a good agreement with the measured length after tuning the full module. Figure 7 shows a comparison of simulated and measured short lengths of some CCL modules. In the worst case, the deviation in the short lengths is about 8.0%. This way we minimise the cost of re-machining the feed-slot dimensions. Similarly, the designed and measured loaded quality factor (Q_L) of the modules show a good agreement as illustrated in Figure 8, in the worst case the difference is 7.0%. At the end, the complete module is brazed and is presented

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in Figure 9. The spectrum of scattering parameter (S_{11}) of a completely brazed module after finalising the short length is presented in Figure 10.

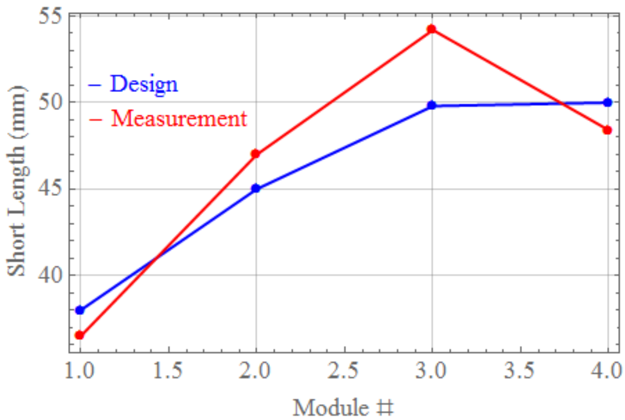

Figure 7: Simulated and measured short lengths.

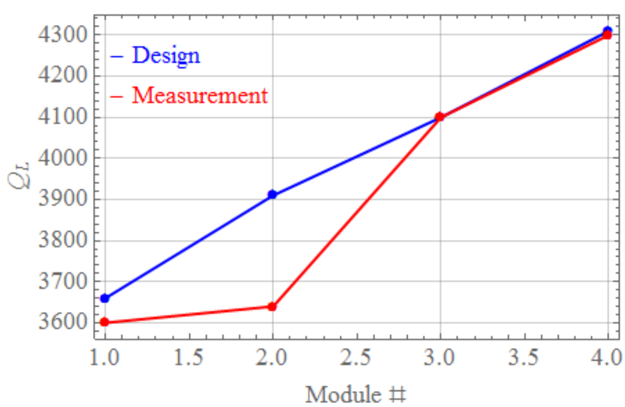

Figure 8: A comparison of simulated and measured Q_L.

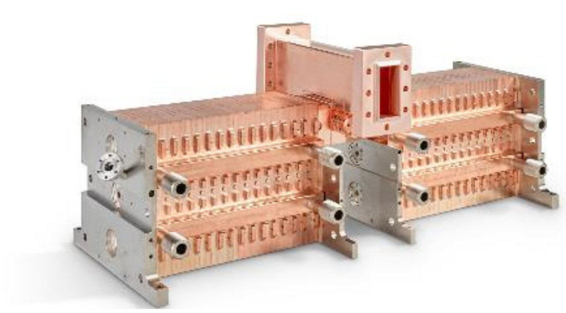

Figure 9: Completely brazed CCL module.

The field flatness measurement of a module using the bead-pull method is presented in Figure 11. A number of CCL modules have been high power tested at the nominal power. A model of single klystron with RF network feeding two CCL modules is presented on the left side of Figure 12. A complete high-power test bench including the water cooling channels is presented on the right side of Figure 12.

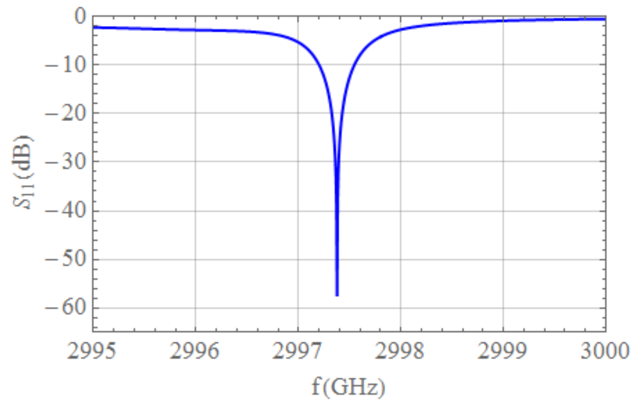

Figure 10: Measured S_{11} spectrum of a tuned module.

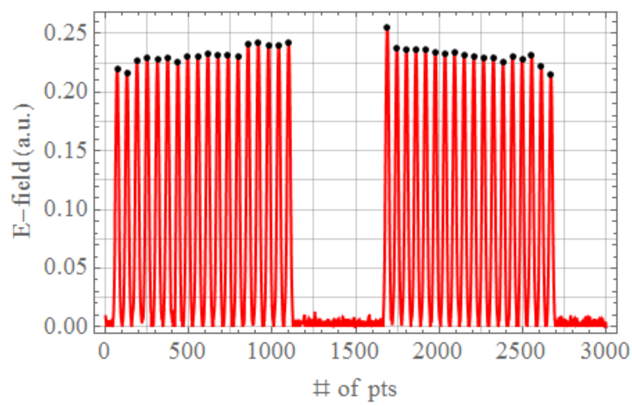

Figure 11: Measured field amplitude of a tuned module.

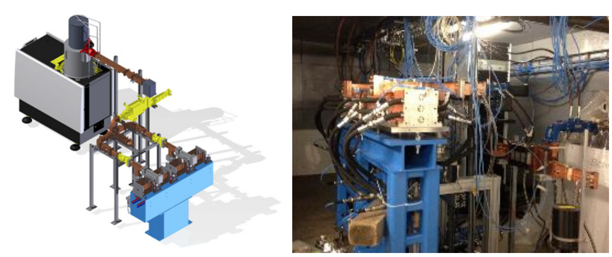

Figure 12: High power test bench of a CCL module.

CONCLUSION

The CCL modules for the LIGHT accelerator have been designed and benchmarked with the measurements.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the CERN collaboration for the LIGHT accelerator.

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