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COMMISSIONING STATUS OF THE LIGHT DEVELOPMENT MACHINE

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Abstract

ADAM (Application of Detectors and Accelerators to Medicine) is a CERN spin-off company currently working on the construction and testing of the LIGHT (Linac for Image-Guided Hadron Therapy) machine. LIGHT is an innovative high-frequency linac based proton therapy system designed to accelerate protons up to 230 MeV: it consists of three different linac sections i.e. a 750 MHz Radio Frequency Quadrupole (RFQ) accelerating the beam up to 5 MeV; a 3 GHz Side Coupled Drift Tube Linac (SCDTL) up to 37.5 MeV; and a 3 GHz Coupled Cavity Linac (CCL) section up to 230 MeV. The compact and modular design is based on cutting edge technologies developed for particle colliders and adapted to the needs of hadron therapy beams. The LIGHT development machine is currently being built at CERN and this paper describes its design aspects and its different stages of installation and commissioning.

INTRODUCTION

The LIGHT solution is a unique technology based on years of research at ADAM. There are several advantages of such machine w.r.t. accelerators currently used in proton therapy such as cyclotrons and synchrotrons: among others the fast beam energy change, a smaller beam emittance, reduced losses allowing for less shielding, and modularity that allows an easy installation and fit in already built infrastructures.

This paper is a continuation of the previous report [1].

THE LIGHT DEVELOPMENT MACHINE

The LIGHT development machine is being built and commissioned by ADAM at CERN. It consists of a proton injector assembly (PIA), a high frequency RFQ [2], a four modules SCDTL structure and a four modules CCL structure, designed to deliver a proton beam at 70 MeV. The latter proton energy will suffice to prove the LIGHT technology and that all sub-components (PIA, RFQ, SCDTL, CCL) will work as an embedded system.

General Layout

The details of the lattice of the LIGHT development machine to reach up to 7.5 MeV protons are described in [1]. Figure 1 shows the current status of the installation with all four SCDTL modules on beam line. Another substantial difference w.r.t. the previous commissioning stage [1] is the introduction of the new movable diagnostic test-bench, described in [3], that replaces the spectrometer dipole with a combination of Time-of-Flight (ToF) and multi-layer Faraday cup measurements.

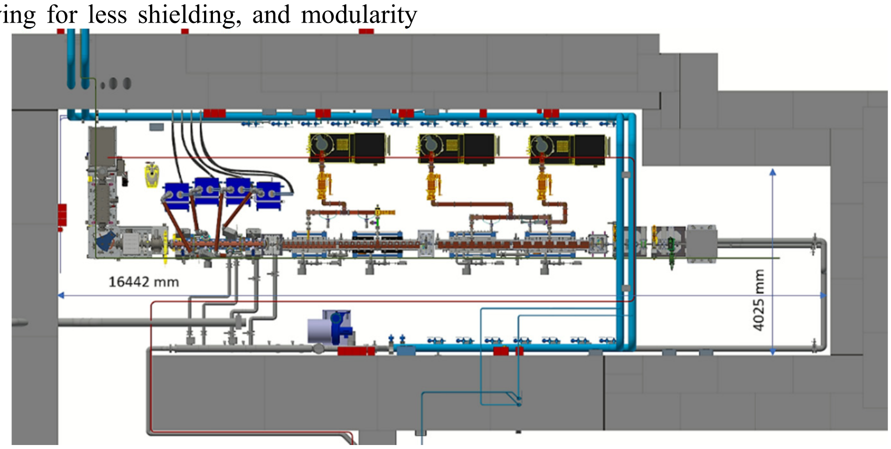

Figure 1: Top view of the current LIGHT development machine. From left to right: the L-shape PIA, the RFQ, four SCDTL modules and the medium energy diagnostic test bench without spectrometer.

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On the left of Fig. 1, the L-shape PIA delivers 40 keV protons that are injected into the RFQ powered by four Inductive Output Tubes (IOTs). The 5 MeV protons are then injected into the SCDTL modules powered by klystrons in order to get an acceleration up to 37.5 MeV. Table 1 and Table 2 show the main parameters of the RFQ and SCDTL structures.

Table 1: RFQ Parameters

Number of modules	4
Length [m]	1.96
Minimum aperture radius [mm]	1
Input/output energy [MeV]	0.040 / 5
RF power [MW]	0.350
RF frequency [GHz]	0.750

Table 2 : SCDTL Parameters

SCDTL modules	M1	M2	M3	M4
Number of tanks	11	13	9	7
Bore hole [mm]	4	4	4	5
Length [m]	1.12	1.70	1.52	1.60
Output energy [MeV]	7.5	16.0	26.5	37.5
RF power [MW]	0.83	2.59	2.46	2.48
RF frequency [GHz]	3	3	3	3

The Medium Energy Test Bench

As described in [3], increasing beam energy requires to change the beam diagnostic test benches configuration. Up to 16 MeV the medium energy test bench, without spectrometer, was used; among other devices it includes Time-of-Flight system, Beam Position Monitors (BPM), an emittance meter based on the double slit plus Faraday Cup method and a spectrometer sector so to measure energy and energy spread of the beam (Fig. 2). In the present commissioning phase of 26-37 MeV the test bench has been made more compact and it is equipped with an instrumented beam dump, capable to verify the beam energy, and a novel beam profiler for high energies. This test bench can be seen at the right-hand side of Fig. 1 and Fig. 3.

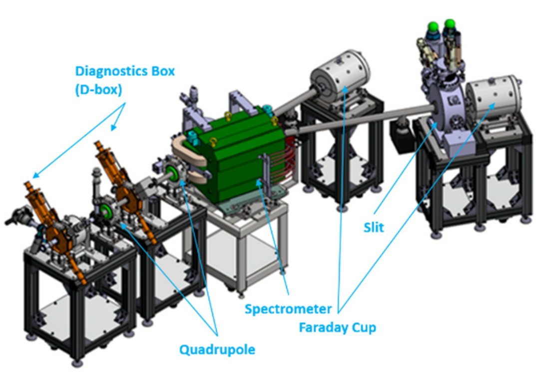

Figure 2: Layout of the medium energy test bench up to 16 MeV.

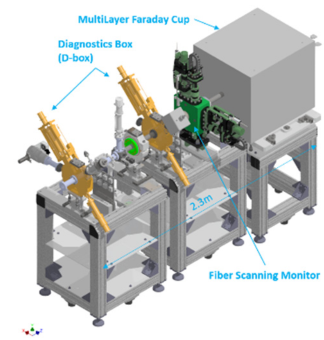

Figure 3: Layout of the test bench above 16 MeV.

COMMISSIONING STAGES

The commissioning of the LIGHT development machine started at the end of summer 2016 with the installation and tests of the PIA [4] followed by the commissioning of the high frequency RFQ at 5 MeV in 2017 [5] and by the commissioning of the low energy part up to 7.5 MeV in the first half of 2018 [1]. Measurements and results at medium energy up to 26.5 MeV are shown in this paper.

BEAM COMMISSIONING RESULTS

The beam commissioning of the LIGHT development machine has been finalized up to 26.5 MeV. The RF cavity phase and amplitude set points were characterized by varying the phase of the cavities at different amplitude levels and measuring the transmission (acceptance scans) and energy with the ToF system (ToF scans) (see Figs. 4 and 5). After operational RF parameters were set, the beam properties were characterized using the diagnostics in the test bench shown in Fig. 2.

Acceptance and ToF Scans

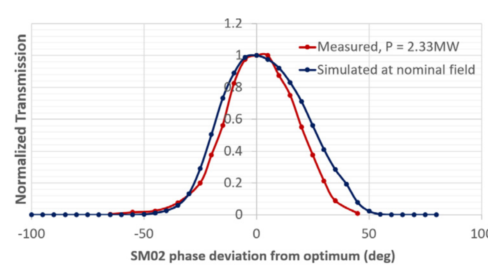

Figure 4: Comparison of measured and simulated curves from acceptance scans at nominal field level in SCDTL Module 02 (SM02).

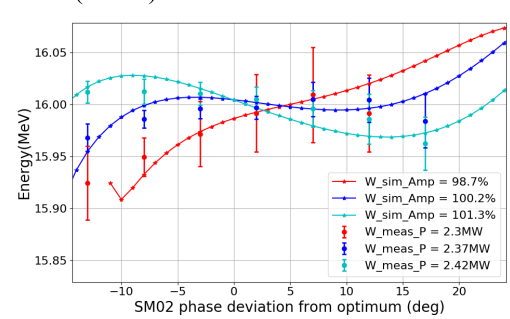

Figure 5: Comparison (best fit) of measured and simulated curves from ToF scans.

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Cavity RF power set point was determined to be 2.33 MW and 2.35 MW from acceptance and ToF scans, respectively. These numbers are consistent with those in Table 2 where a power margin of 30% w.r.t. the RF design has been used to take into account the manufacturing process. In the particular case of SM02 the beam measurements have shown that 20% margin is enough.

Beam Emittance

Figure 6 shows the comparison of measured and expected phase space plots of the beam measured at 16 MeV after second SCDTL module. Expected beam is obtained by tracking the beam from RFQ simulations until the emittance measurement location.

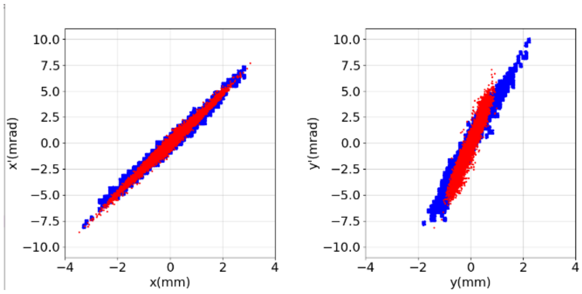

Figure 6: Comparison of measured (blue) and expected (red) transverse phase space plots of the beam at 16 MeV.

Beam at 26.5 MeV

For this energy the spectrometer dipole branch was removed and thus ToF system is acting as the reference for beam energy validation. Figure 7 represents a preliminary measurement of 2 uA beam in the present test bench (Fig. 3) with beam accelerated at 26.5 MeV, transported along SCDTL Module 04, which was not powered.

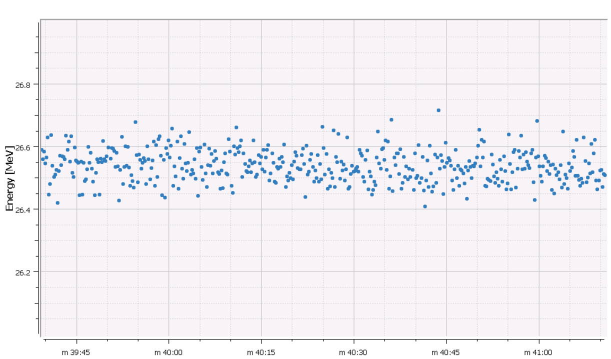

Figure 7: Beam energy of about 450 consecutive beam pulses. Each dot represents the average energy of 1.5 us beam pulse.

CONCLUSION

The LIGHT development machine has been commissioned up to 16 MeV. The validation of two out of three types of accelerating structures operated with beam has been completed. Table 3 summarizes the beam measurements at different sections along the linac.

Currently the LIGHT development machine is under commissioning at 26-37 MeV beam energy range. Installation works for the next commissioning stage (Fig. 8), bringing the energy up to 52 MeV, will start soon.

Table 3: Summary of Beam Measurements

	RFQ input	**MEBT1**	**SM02 output**
Beam energy [MeV]	0.04	5.03	16
Beam current [μA]	250	50	20
Hor emittance (norm, rms) [π mm mrad]	0.032	0.032	0.11
Ver emittance (norm, rms) [π mm mrad]	0.025	0.025	0.11

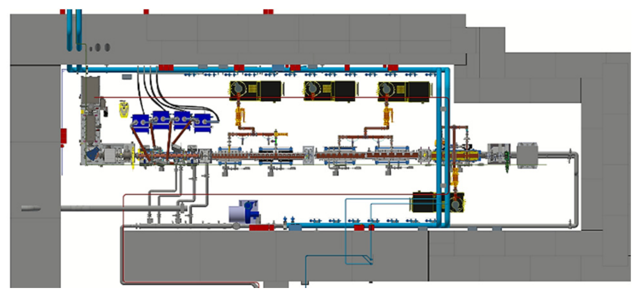

Figure 8: Integration drawing of the next commissioning phase of the LIGHT development machine. Two Coupled Cavity Linac modules will be added to the current configuration.

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