POST ACCELERATION OF LASER GENERATED PROTON BUNCHES BY A CH-DTL*

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Abstract

Laser driven proton beam sources applying the TNSA process show interesting features in terms of energy and proton number per bunch. This makes them attractive as injectors into RF linacs at energies as high as 10 MeV or beyond. The combination shows attractive features like a very high particle number in a single bunch from the source and the flexibility and reliability of an RF linac by one pulsed magnetic solenoid lens only. A Crossbar H-type CH – structure is suggested because of its high acceleration gradient and efficiency at these beam energies. It is intended to realize the first cavity of the proposed linac and to demonstrate the acceleration of a laser generated proton bunch within the LIGHT collaboration at GSI Darmstadt. Detailed beam and field simulations will be presented.

INTRODUCTION

With advanced lasers like PHELIX (Petawatt High Energy Laser for Heavy Ion eXperiments), one can achieve focused intensities approaching 10^{20} W/cm^2. Under these conditions, intense protons with energies of ten to several tens on MeV are accelerated normally from the rear surface of the target by quasistatic electric fields of the order TV/m [1-2]. This process is called Target Normal Sheath Acceleration (TNSA) [2].

An interesting application for these proton beams is the matching into the acceptance of a succeeding RF accelerator for further post acceleration.

The LIGHT (Laser Ion Generation, Handling and Transport) collaboration aims to inject the laser accelerated protons into a conventional accelerator structure [3-4]. Due to the available energies, drift tube linacs are the most adequate choice. A CH – DTL is suggested as the linac structure [5-6].

This work is intended to realize the first cavity of the proposed CH-DTL and to demonstrate the acceleration of a laser generated proton bunch within the LIGHT project.

HYBRID RF ACCELERATOR OF THE LASER GENERATED PROTON PULSE

In PHELIX experiments protons with energies up to 30 MeV and with a total yield of 10^{13} protons per bunch were observed [7]. For the reference energy of 10 MeV, the yield within ± 0.5 MeV was exceeding 10^{10} protons. To compare this number with the conventional currents, the equivalent current of these bunches might add up to 500 mA beam current if every bucket would be filled with that proton number at 325 MHz.

The matching of laser – accelerated protons into a conventional RF linac is difficult due to the high particle number at large energy spread and large beam divergence. The coupling will be done by a pulsed magnetic solenoid. Figure 1 shows a schematic view for the hybrid accelerator.

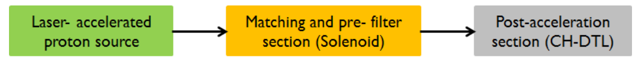

Figure 1: Scheme of the hybrid configuration.

Magnetic Solenoid

In order to collimate the laser – accelerated protons, a pulsed magnetic solenoid was chosen [5]. The 10 MeV p bunch in this lens layout (Figure 2) affords a magnetic field level of about 18 T in order to focus directly into a CH-DTL at a distance of about 210 mm from the target.

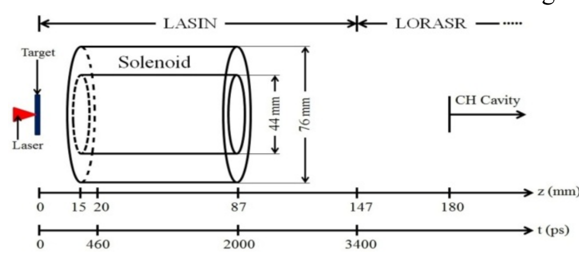

Figure 2: Schematic view on the laser target, the focusing solenoid and the drift to the rf linac. The longitudinal axis is marked in mm and in ps time of flight for a 10 MeV proton beam.

The output distributions, 60 mm behind the solenoid, are shown in Figure 3. The beam dynamics studies including the effect of co-moving electrons is described in Ref. 5.

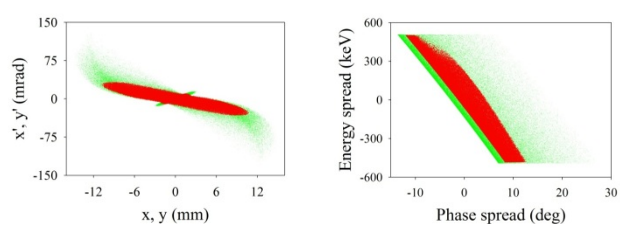

Figure 3: Particle distribution in transversal (left) and longitudinal (right) planes at the DTL – entrance within the energy range 10 MeV ± 0.5 MeV (green). The red 72% subsets of the particle distribution fall within the CH – DTL acceptance area and are used for DTL beam dynamics simulations.

Dedicated 40 MeV CH - DTL

The layout of the CH-DTL [5] was performed in two main steps. At first a 500 mA equivalent beam current design was developed by using a waterbag - type input distribution. In a second step, this linac layout was used to simulate the acceleration of the laser – accelerated bunch,

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resulting from the complex transport simulations along the matching section (Figure 3).

The linac design consists of four CH cavities operating at 325 MHz, to accelerate the bunch from 10 to 40 MeV. The accelerating field gradient per cavity varies from 9 to 12 MV/m.

Due to the shape of protons in phase space behind the solenoid, it was not possible to match the whole distribution into the CH-DTL. Consequently, 70% of the total number of the protons is effectively fitted into the acceptance of the CH-DTL (see Figure 3).

All particles were effectively accelerated through the whole structure to the exit. Figure 4 shows the transverse 90, 99 and 100% beam envelopes. The quadruploes between the cavities were adapted allowing a loss free transport along the structure.

The longitudinal and transversal output distributions are shown in Figure 5 for 25000 macroparticles.

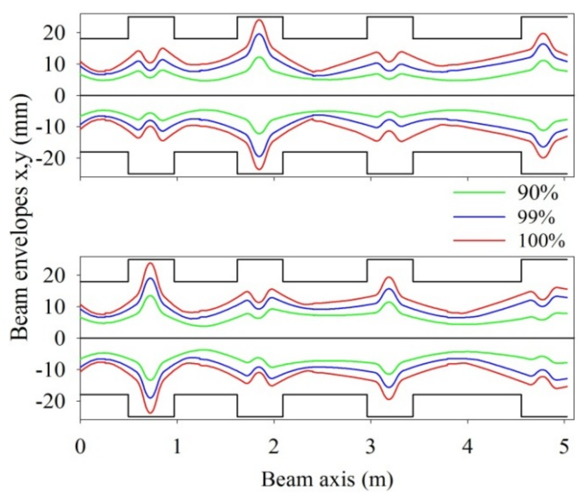

Figure 4: Transverse 90, 99 and 100% beam envelopes.

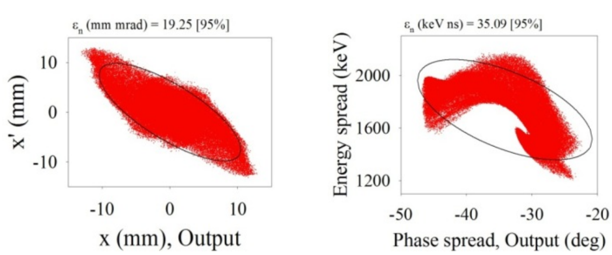

Figure 5: Transverse (left) and longitudinal (right) particle distributions at the CH – DTL exit.

THE FIRST CAVITY OF THE PROPOSED CH – DTL

The first cavity in the proposed linac has a length of about 668 mm and an outer diameter of about 386 mm (Figure 6). In this cavity, the proton bunch will be accelerated from 10 – 16.1 MeV.

In the CH – structure, the current flows from the outer cylinder to the drift tubes along the stems in order to generate the axial electric field which is needed for particle acceleration.

The stems are supporting the mechanical stability in the CH – structure, and they show the highest surface current density (Figure 7).

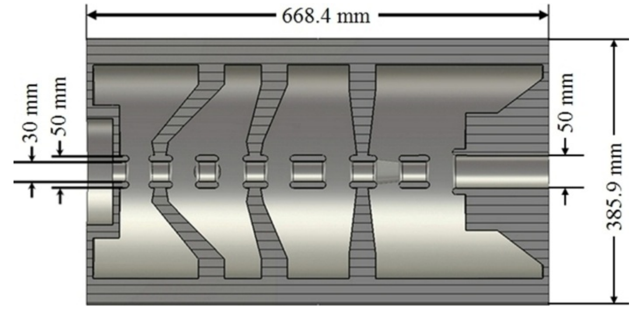

Figure 6: Schematic view for the first CH – cavity of the proposed linac.

The stem array allows for an efficient water cooling. Close to the beam axis the stems have to be kept slim to reduce the capacitance between neighbored stems and drift tubes.

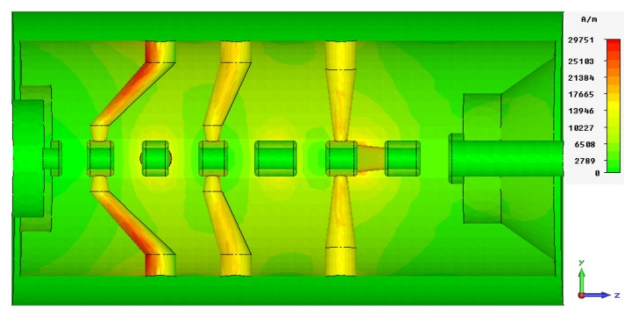

Figure 7: A MWS plot of the surface current density flowing along the stems. The inclined stems are carrying the highest density because the magnetic field flux is turning transversally into the neighbored quadrants at the cavity ends.

The on axis electric field distribution as calculated with MWS [8] is shown in Figure 8. The corresponding voltage value for this electric field distribution in each gap is calculated accordingly, and the results are compared with the reference values as given by the LORASR code (see Figure 9).

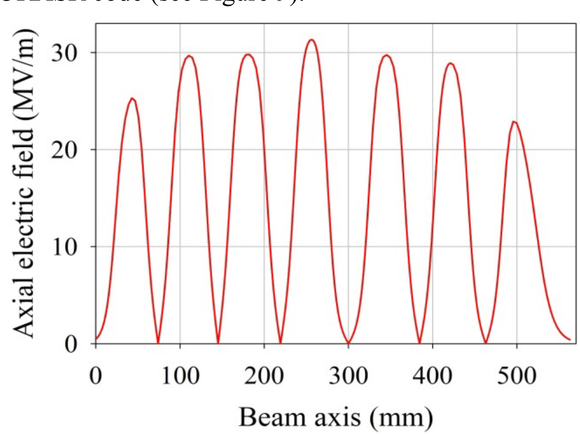

Figure 8: The axial electric field distribution as calculated by MWS along the beam axis.

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The electric field is roughly uniform along the central 5 gaps and is reduced in the end gaps. This gives the optimum effective shunt impedance values.

In order to increase the magnetic flux in the end cells, the concept based on an inclined stem geometry for the end cells was applied. This choice helps to increase the voltage values in the end gaps.

The main characteristic parameters of this cavity are given in Table 1.

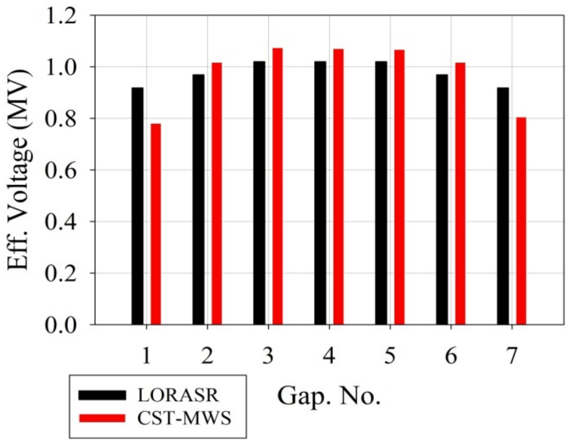

Figure 9: A comparison between the corresponding voltage distribution as calculated from the electric field which is given in Figure 8 with the reference design values as given from the LORASR code.

Table 1: The Main Parameters of the First CH – Cavity of the Dedicated Linac for Laser Accelerated Protons

Number of Gaps	7
Frequency (MHz)	325.2
Energy Range (MeV)	10.05 – 16.09
Power Loss (MW)	1.92
Q_0 – value	13289
Effective Shunt impedance (MΩ/m)	45.7
Accelerating Field Gradient (MV/m)	12.6
Beam Aperture (mm)	30
Outer Drift Tube Diameter (mm)	50
Total Length (mm)	668.4

Because of no internal focusing elements in this CH – DTL, the adaption of slim drift tubes is possible. This drift tube geometry results in attractive features like a very high sparking limit when compared to other structures like an Alvarez DTL.

The maximum effective accelerating gradient for this cavity layout would reach 12.6 MV/m. This corresponds to a 94 MV/m surface electric field spot at the third drift tube. The reason to have the maximum surface field on this position is mainly due to the inclined stems. As a consequence, these stems will be redesigned to reduce this effect.

In order to get a good estimation for the real peak field values, the drift tube edges have to be modelled carefully in the input files.

CONCLSION AND OUTLOOK

Laser driven proton beam sources have attractive features as rf linac injectors at energies above 10 MeV. They might become superior to the ion source, RFQ, and the first DTL stage of conventional linacs for special applications.

A CH linac with high space charge limit and large transverse and longitudinal acceptance was designed to accept a maximum fraction of the laser generated proton bursts.

Attractive applications for single bunch operation as delivered naturally by laser driven systems might occur, involving time of flight techniques or the study of secondary reactions at low noise level, for instance.

The study of the surface electric field for this cavity shows, that maximum local surface fields of about 94 MV/m are occurring on one drift tube. This value is about 5.2 times greater than the Kilpatrick limit. However, it appears very locally only - at the drift tube ends.

Further optimization and development is needed in order to optimize the proposed CH - cavities by using the CST – MicroWave Studio (MWS), and by improving cavity surface preparation techniques. This concept might lead towards intense single proton bunch acceleration with bunch particle numbers far above levels reached at present.

Within a funded project, cavity 1 of the proposed linac will be further developed towards a high gradient cavity. The availability of the GSI 3 MW klystron test stand will be very important for these investigations. The results will influence the rebuilt of the Unilac - Alvarez section, where the existing 1m thick concrete linac cave with fixed length should house a powerful pulsed heavy ion linac, optimized for achieving finally the beam intensities specified for the GSI-FAIR project. The 1.4 to 11.4 AMeV Alvarez section is in operation at duty factors up to 25 % since 4 decades now and was not optimized for pulsed high current operation.

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