

A DTL WITH SHORT TANKS AND EXTERNAL FOCUSING FOR HIGH POWER CW LINACS

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Abstract

Recently, major projects, for the transmutation of nuclear waste, the production of tritium or more generally for the production of neutrons by spallation, have been proposed using high power linacs and a CW operation. See for example [1] or [2]. In this context, the manufacturing of the low or medium energy part of the linac with a standard DTL, appears to be a tricky job, particularly the insertion of high gradient quadrupoles into the drift tubes, with a specific cooling system needed for CW operation, and many brazing or welding processes. Moreover the reliability and the maintenance of the DTL could be affected sooner or later. It is proposed in this paper to use a DTL with short tanks (let say 2 to 5 cells) with a focusing system outside the tanks. The mechanical design is in that way very simplified, the drift tube geometry can be optimised for a better shunt impedance, the cooling system is easy and efficient and the alignment problem is greatly reduced. This concept is applied to a 5 MeV to 100 MeV CW proton linac operating at 352 MHz, with a 40 mA beam current, and shows moreover that the linac global efficiency is increased compared with a classical approach. Preliminary beam dynamics studies are included.

1. INTRODUCTION

A classical DTL could generally be divided in long Alvarez-type tanks, with a FODO focusing system integrated inside the drift tubes. As part of the design of

new high power proton linacs operating in a CW mode, the cavities cooling system is thus an important task to take into account. It must be designed to ensure the removal of heat due to high RF wall losses on drift tubes and quadrupole heating at once. This is especially difficult at low energy where the drift tubes are short and the quadrupole gradient could be high. In that case the bore diameter should be moreover minimised, adding a restriction to the beam dimensions. The manufacturing of such drift tubes, including a compact quadrupole, its power feeding with cooled wires, the cooling circuit for the drift tube itself, and associated with the stem, implies in particular many multi-stages brazing and welding processes which are significative in terms of risks and costs. To date, two solutions among others have been proposed to move the focusing system outside the tanks:

- the Coupled-Cavity DTL (CCDTL) developed at Los Alamos [3], designed to work at 700 MHz for the APT linac.
- the Separated-type DTL (SDTL) from KEK [4], [2] at 432 MHz, for medium proton energies between 150 MeV and 300 MeV

2. A SDTL FOR LOW ENERGY PROTON BEAM

It is proposed here to apply the SDTL concept at 352 MHz [1], with a CW operating mode, for low proton energies from say 5 MeV to 100 MeV, just behind an RFQ for example, in place of a conventional DTL.

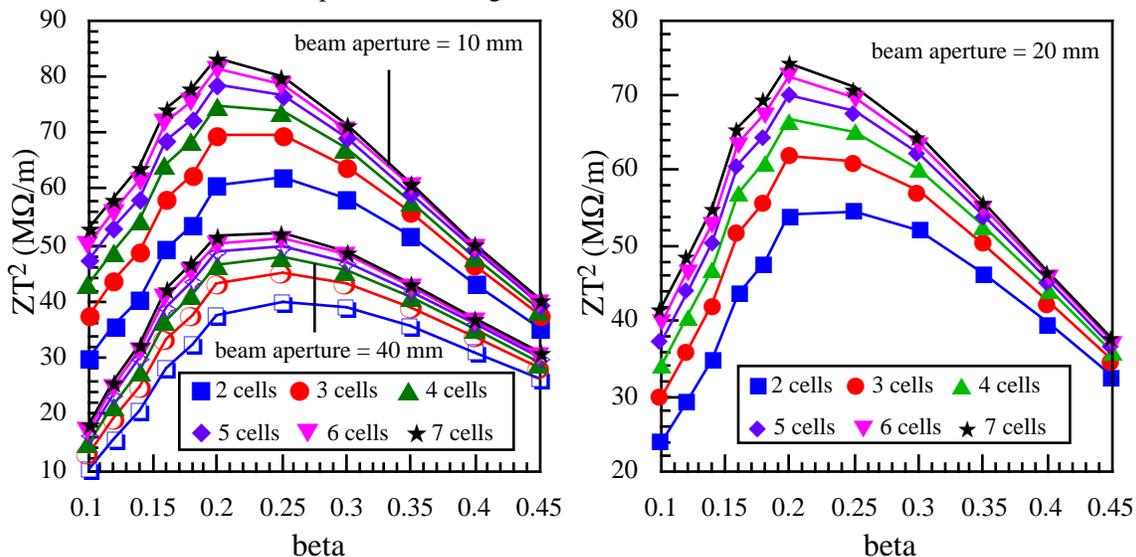


Fig.1 Shunt impedance (100 %) for multi-cells tanks (352 MHz). Bore radius = $\phi 10$ mm, $\phi 20$ mm, $\phi 40$ mm

The tanks are necessarily short, with few cells to not lengthen too much the transverse focusing period. They are not RF coupled together, but are fed independently with a power splitting scheme, according to the power that couplers can handle. Several potential advantages, previously mentioned elsewhere, could be pointed out:

- a mechanical simplification and efficient cooling of the drift tubes, including its inner part exposed potentially to the beam
- a better shunt impedance with an optimised geometry, or alternatively a greater beam aperture if desired.
- post-couplers in short tanks no longer needed
- lower manufacturing costs

The overall SDTL has the following properties:

- easier to align with a magnetic axis separated from the RF one.
- diagnostics could be set up between tanks.
- a manufacturing simplicity implies in principle a better reliability and maintenance.

2.1 The SDTL Shunt Impedance

No quadrupoles inside the drift tubes allows to optimise its geometry to find the best shunt impedance. The outer drift tube radius is minimised, leading to a light and compact tube, including exclusively a cooling circuit. See for example fig. 2. The gap of the cell is optimised for a maximum ZT^2 . Two key points must be kept in mind:

- the limited number of cells implies that the power losses in end walls have to be taken into account for the global shunt impedance of the tank.
- the reduced size of the drift tube, associated with a short gap, could lead to a high peak field on copper.

This maximum field is here arbitrarily limited to about 1 Kilpatrick (i.e. 18.4 MV/m at 352 MHz) which is enough conservative to avoid sparking. This restriction applies to tanks below 16 MeV, which are thus non-optimised for maximum shunt impedance, with a gap larger than expected.

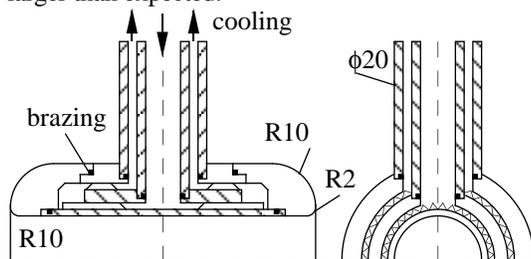


Fig.2 A SDTL Drift Tube with cooling system

Superfish [5] computations are made with various beam apertures from $\phi 10$ mm to $\phi 40$ mm, versus the particle velocity from $\beta=0.1$ (4.7 MeV) to $\beta=0.45$ (112.4 MeV) and the global ZT^2 is thus estimated for multi-cells tanks from 2 to 7 cells. (Fig. 1). The maximum shunt impedance is obtained around 20-30 MeV, which justifies the use of a SDTL at low energy. Compared with a

conventional DTL with a same bore radius, a 40% to 70% increase in ZT^2 could be gained particularly above 15 MeV.

2.2 A 5MeV to 100 MeV SDTL Linac

The design of the linac includes at the beginning some beam dynamics constraints. To limit the longitudinal phase advance without current σ_{o1} below 90 deg, on account of beam stability, short tanks with 2 cells are used at low energy, with an RF power level restricted to 62.5 kW max, which is also compatible with the maximum field on copper. The number of cells is gradually increased up to 5 cells at 23 MeV. The transitions in number of cells are smoothed by choosing specific laws of synchronous phase, while keeping a regular and constant RF power splitting scheme (1/16 and 1/8 of 1 MW klystrons). The design is an iterative process between the beam dynamics, the parameters of the tanks and the choice of transitions.

The solution proposed here includes a drop of 17.5% on the theoretical shunt impedance , as a safety margin. The beam current is 40 mA CW. The beam aperture is kept constant at 20 mm. The parameters are the following:

- 8 klystrons (1 MW, 352 MHz) of which the two first are divided by 16 (62.5 kW per tank), and others divided by 8 (125 kW per tank)
- 80 tanks, 336 $\beta\lambda$ cells, divided as follows:
 - 2 cells (tanks 1 to 12, 5 MeV to 8.8 MeV, $\phi_s=48$ deg to 52 deg)
 - 3 cells (tanks 13 to 20, 8.8 MeV to 13.5 MeV, $\phi_s=40$ deg)
 - 4 cells (tanks 21 to 32, 13.5 MeV to 23 MeV, $\phi_s=35$ deg to 45 deg)
 - 5 cells (tanks 33 to 80, 23 MeV to 103.2 MeV, $\phi_s=25$ deg to 30 deg, up to tank 40, and $\phi_s=30$ deg beyond)
- active length = 83.36 m
- average field $E_0T = 1.44$ MV/m
- average shunt impedance $ZT^2 = 42.6$ $\text{M}\Omega/\text{m}$
- copper power losses = 4.07 MW
- beam power = 3.93 MW
- efficiency = 49.1 %

The high energy part of the SDTL beyond 20 MeV, because of its high shunt impedance, compensate largely the low energy part which is not designed at its potential maximum capability, due to the transitions and large synchronous phase (which however increases the phase acceptance). This SDTL example shows in fact a gain of at least 10% in efficiency compared with a standard DTL which could be designed even with a smaller beam aperture. The SDTL saves 1 or 2 klystron power units.

The overall linac uses here a doublet focusing scheme which is well suited to the set up of free space between the quadrupoles for various beam diagnostics. Here, a regular $\beta\lambda$ drift is used. In that case the total length of the linac is 124 m (about 1.5 times the active length) which

is also 20% or 30% longer than a standard DTL. A triplet focusing could also be used, leading to a longer linac, but with the advantage of a round beam in the cavities. Fig 3 shows the main parameters of the beam dynamics for an initial 40 mA matched beam, with an ellipsoidal uniform space charge model and 5 times the RMS beam emittance at the output of an RFQ before the SDTL. (i.e. $\epsilon_{tn} = 1.2 \pi \text{ mm.mrad}$ normalised, and $\epsilon_l = 0.6 \text{ MeV.deg}$)

3. CONCLUDING REMARKS

The SDTL scheme presented here seems to be an attractive solution for a low energy high power linac operating in the CW mode, especially for its manufacturing simplicity and its potential low cost. It uses moreover an independently-phased cavities scheme, well known in superconducting linacs [6], which must be favourable for larger velocity acceptance. Nevertheless, a great care must be taken for the beam dynamics at low energy, because of the transitions and the matching to the RFQ [7]. Other

lay-out schemes are now under investigation for a smoother beam behaviour.

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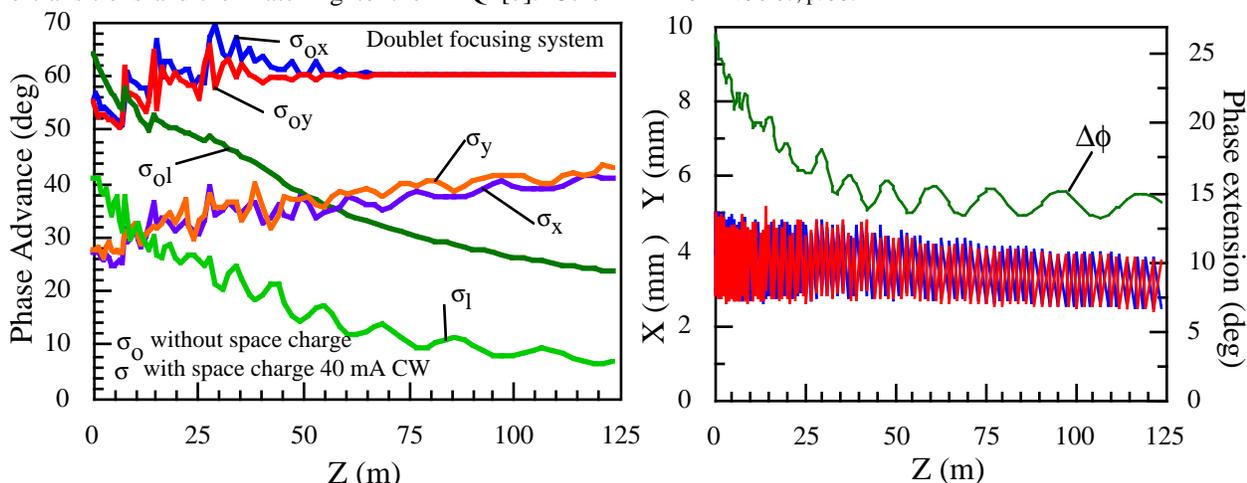


Fig. 3 Phase advance laws along the SDTL, Transverse beam envelopes and Phase extension

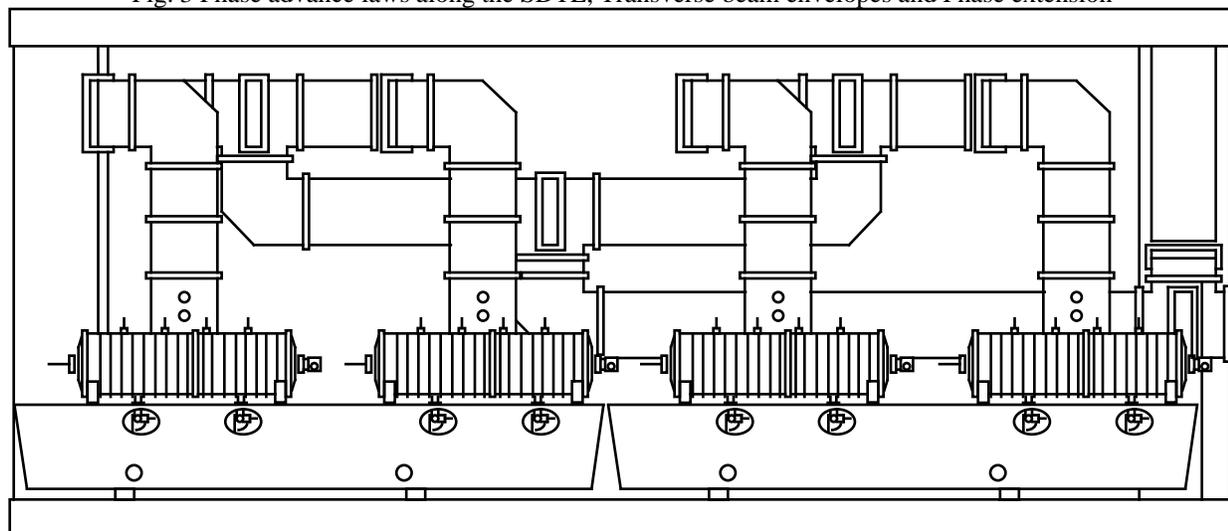


Fig.4 Lay-out of a 100 MeV, 5 cells SDTL (125 kW per tank, 1/2 klystron, 352 MHz)