Comparison of Standing and Travelling Wave Operations for a Positron Pre-Accelerator in the TESLA Linear Collider

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Abstract

The Positron Pre-Accelerator (PPA) for the TESLA linear collider should be a normal conducting linac and use the standard TESLA rf hardware. For L-band frequency range both Standing (SW) and Travelling Wave (TW) operations are possible. For comparison, rf parameters for TW Disk Loaded Waveguide (DLW) as well as for SW Coupled Cells Structures (CCS) have been optimized at an operating frequency of 1300 MHz in a wide range of cells dimensions. General properties for the two operating modes have also been compared. Taking into account the beam dynamic particularities, a SW mode has been chosen. It provides a higher flexibility and allows one to combine the required beam performance with a cost saving problem solution. With an increased aperture diameter, the SW PPA has an enlarged acceptance, in comparison with the TW PPA, and a reduced power consumption.

1 INTRODUCTION

Today L-band linacs are known both in TW and SW operating modes. A choice between SW and TW modes should be made after considering the complete set of linac particularities.

The TESLA collider will use the spent electron beam to produce a positron beam, by passing the former through a wiggler to produce photons, which will hit a thin target to yield the positrons [1]. The quality of the positron beam is mainly formed within the adiabatic matching device and the PPA. The main PPA purpose is to provide a maximum capture efficiency for the useful part of the positron beam with technically reasonable linac parameters.

2 PPA PARTICULARITIES

The positrons have a broad distributions of transverse and longitudinal momenta and have to be accelerated in an accelerating sections embedded in a solenoid field. The acceptance of a solenoid channel is $A_c \sim B_0 a^2$, where B_0 is the solenoid field inductance, a - is the accelerating section aperture radius. The DC power P_{DC} and DC hardware for solenoids is less expensive than RF power P_{rf} and rf hardware, but $P_{DC} \sim A_c^2, P_{rf} \sim A_c$ and an enlarged aperture radius for the accelerating structure seems to be reasonable.

In the PPA beginning positrons should be accelerated (to the energy $\approx 30MeV$) with a high accelerating gradient $E_0T \approx 14MV/m$ to prevent bunch lengthening. Then E_0T can be reduced to save rf power. (The PPA length is not limited for external reasons.)

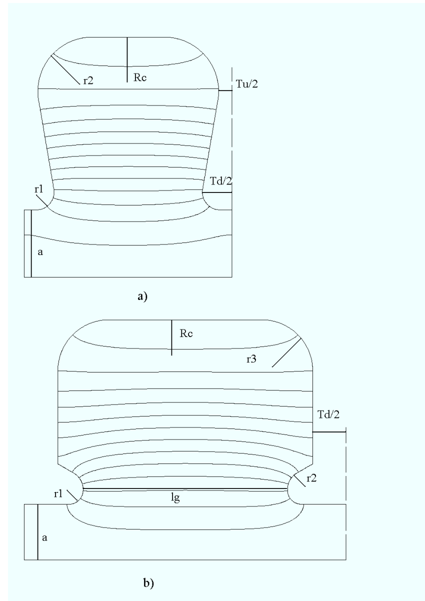

Figure 1: Geometry definition for different shapes of the DLW (a) and CCS (b) cells.

The PPA should use the standard TESLA rf hardware, especially the 10 MW TESLA klystron.

3 OPTIMIZATION OF THE ACCELERATING STRUCTURE

The shapes of the DLW and CCS cells have been optimized at the operating frequency of $1300MHz$ in 2D approximation to study the parameters dependence. The procedure of such an extensive wide-range optimization is given in [2].

The shape of the DLW cell can be described with five independent parameters:
- aperture radius $a = (5.0 \div 30.0)mm$, 6 steps;
- lower web thickness $T_d = (4.0 \div 28)mm$, 5 steps;
- upper web thickness $T_u = (4.0 \div 28)mm$, 5 steps;
- lower web circular radius $r_1 = (0.2 \div 1.0)T_d$, 5 steps;
- upper web circular radius $r_2 = (0.2 \div 1.0)(R_c - a - 2r_1)$ or $(0.2 \div 1.0)(L - T_u)$, 5 steps.

The cell radius R_c should be adjusted to set the resonant frequency. As one can see from (Fig. 1), this set of parameters allows one to consider a large variety of DLW cell shapes with a wide range of dimensions.

By means of a very powerful set of 2D codes [3], the DLW cells were calculated with an automatic tuning of the $2\pi/3$ mode frequency up to 1300 MHz. For each variant all

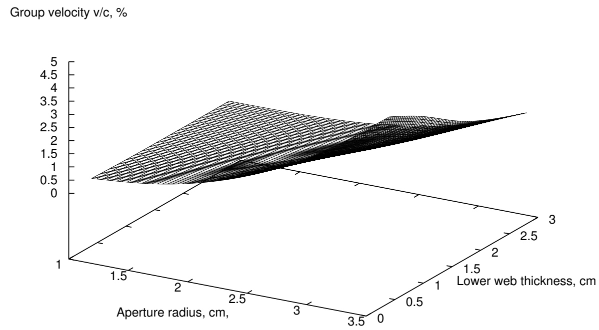

Figure 2: The surface $\beta_g(a, T_d)$ for a DLW with $r_1 = 0.3cm, T_u = 1.2cm$

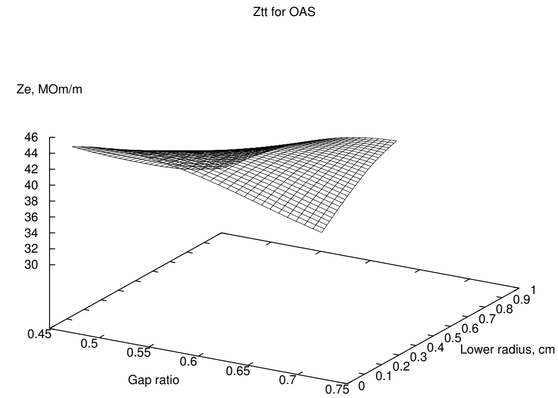

Figure 3: The surface of $Z_e(\alpha_{gp}, r_1)$ for a SW structure cell with $a = 2.0cm, T_d = 3.0cm$.

important DLW parameters have been stored. The resulting data library may be presented in the form of a five-dimensional cube. Then, using an interpolating procedure with a cubic spline algorithm, one can consider different DLW realizations with different limitations. For example, with the specification $E_{smax} \le E_{fixed}, T_d \ge T_{dfixed}$ (for cooling) $a = const$ or $a \ge a_{fixed}, P_{in} = P_{fixed}$, the best solution can be found with respect to effective shunt impedance Z_e for the constant gradient DLW section with cell dimensions within the limits. During this interpolation search all cell dimensions may vary in an attempt to find the best variant. (The simultaneous change of the aperture radius and the iris thickness to find the required group velocity β_g with the minimal Z_e reduction for a constant gradient DLW section was done in [5]).

Another useful possibility of this approach is the presentation of the general behavior of the parameters. For example, a two dimensional surface $\beta_g(a, T_d)$ is shown in (Fig. 2).

The SW structures cell dimensions have been optimized with the same procedure. But the SW cell has seven independent parameters (Fig. 1):

- aperture radius $a = (5.0 \div 30.0)mm$, 6 steps;
- lower drift tube radius $r_1 = (0.5 \div 9.7)mm$, 5 steps;
- upper drift tube radius $r_2 = (1.0 \div (2.83 - 1.5r_1)(1.33 + a/3))r_1$, 4 steps;
- gap length $g = (0.225\lambda_0 \div g_{max})$, 10 steps;
- drift tube cone angle $\phi = 30^o$;
- total web thickness $T_w = (0.0 \div 36.0)mm$, 4 steps;
- upper circular radius $r_3 = (0.2 \div 1.0)(0.25\lambda_0 - 0.5T_w)$, 4 steps.

Like in the previous case, the cavity radius R_c was adjusted to set the resonant frequency.

After storage of the data library in the six dimensional cube, for every r_1, r_2 was fitted to have the same electric field value both at the lower and at the upper drift tube circles. Then, for the specified T_w and a an interpolation was used to find the maximum Z_e with limited

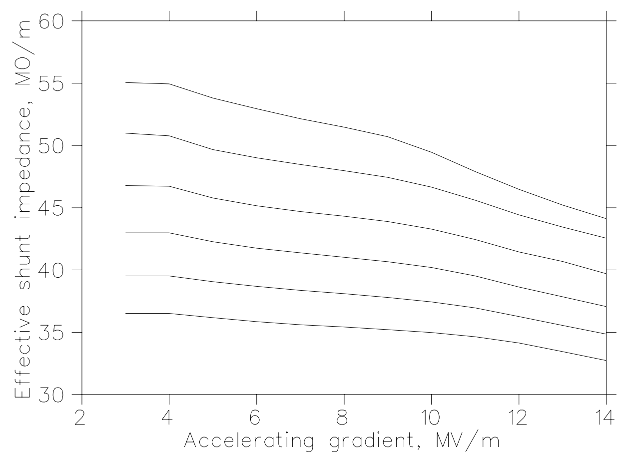

Figure 4: Z_e dependencies on E_0T for a SW CCS cell with different aperture radii. Up to down - $a = 27mm, 24mm, 21mm, 18mm, 15mm, 12mm$.

$E_{smax} \le 40.0MV/m$. The surface in Fig. 3 shows the typical behavior of $Z_e(\alpha_{gp}, r_1)$. The optimized Z_e dependencies on E_0T value for CCS cells are shown in Fig. 4. More extended results of the cell shape optimization are given in [6].

4 TW AND SW MODE COMPARISON

In the design of a TW accelerating structure with DLW a choice of the total attenuation α_t per section is of primary importance. It defines the rf efficiency of the accelerating sections, because the input rf power P_{in} should be distributed between the total rf power losses in the section P_s and the rf power losses in rf load P_{load}.

$$P_s \approx P_{in}(1 - e^{-2\alpha_t}), \quad P_{load} = P_{in} - P_{st} \approx P_{in}e^{-2\alpha_t}. \tag{1}$$

$$\alpha_t = \frac{\pi f_0}{c} \int_0^L \frac{1}{Q\beta_g} dz, \tag{2}$$

where Q is the quality factor of the DLW cell, β_g is the DLW relative group velocity and L is the length of the section.

To work as constant gradient structure, β_g must change along the DLW section [4] like this:

$$c\beta_g = \frac{2\pi f_0 L(1-(1-e^{-2\alpha_t})z/L)}{Q(1-e^{-2\alpha_t})}. \quad (3)$$

In order to reach an accelerating gradient E_0T, one should provide rf power flux P_t according to:

$$P_{tw} = \frac{c\beta_g Q(E_0T)^2}{2\pi f_0 Z_e}. \quad (4)$$

Combining (3) and (4), for the beginning of the TW section ($z = 0, P_{in} = P_{tw}$) we have:

$$P_{in} = P_{tw} = \frac{L(E_0T)^2}{Z_e(1-e^{-2\alpha_t})}. \quad (5)$$

It is the same expression as for the SW structures, except for the multiplier $(1-e^{-2\alpha_t})^{-1}$:

$$P_{in}^{sw} = \frac{L(E_0T)^2}{Z_e^{sw}}, \quad P_{in}^{tw} = \frac{L(E_0T)^2}{Z_e^{tw}(1-e^{-2\alpha_t})}. \quad (6)$$

To be of a similar rf efficiency, the TW and SW structures should have $Z_e^{sw} \approx Z_e^{tw}(1-e^{-2\alpha_t})$. The results of the optimization for the DLW and CCS cells show $Z_e^{sw} \leq Z_e^{tw} \leq 1.05Z_e^{sw}$ [6], [5] for the same aperture diameter. To obtain $(1-e^{-2\alpha_t}) \approx 1, \quad e^{-2\alpha_t} \ll 1$ one needs $\alpha_t \geq 1$. In this case we have very small β_g values in the end of the TW section (see (3)). It is sure to rise serious problems with the section tuning as well as with the parameter stability during operation.

For constant gradient DLW in S-band the usual value $\alpha_t \sim 0.55 \div 0.7$ ($P_{load} \approx (0.33 \div 0.25)P_{in}$) is the result of a compromise between rf efficiency and parameter stability (defined by β_g). In general, scaling relations as $\beta_g \sim f^{1/2}$, (3), from S-band to L-band are not favorable for DLW.

The main parameter in the DLW cell is the aperture radius a. It defines both Z_e and $\beta_g \sim a^3$ at the same time. Equation (4) excludes the opportunity to have a DLW with high $E_0T \geq 12.0MV/m$ and large $a \geq 20mm$ at moderate $P_{in} \approx 8MW$ simultaneously. It is not possible to have a DLW section with moderate $P_{in} \approx 8MW$ $E_0T \leq 6.0MV/m$ and moderate $a \leq 18mm$ (to save total rf power). Since only two parameters, aperture radius a and lower aperture thickness T_d are available for changing in DLW cells, the DLW section is restricted in combination of high rf efficiency, parameter stability and a variety of a and E_0T.

From this point of view, the CCS are more flexible and open wider prospects to choose high E_0T values at the beginning of the linac to prevent bunch lengthening and moderate E_0T to save rf power at its end.

The main advantage of the TW mode - the smaller filling time τ_{tw},

$$\tau_{tw} = \int_0^L \frac{dz}{c\beta_g}, \quad (7)$$

is not realized for the L-band range, because for the room-temperature SW CCS the rise-time is $\tau_{sw} \approx \tau_{tw} \approx 2 \div 4\mu s$. This parameter is not important, taking into account the long ($800\mu s$) PPA rf pulse.

One preferable point for a DLW is a lower $E_{smax}/(E_0T) = (1.8 \div 2.0)$ ratio for simple DLW cell configuration. With the optimization of the cell to have higher Z_e or lower β_g values the DLW loses this preference.

5 CONCLUSION

The operating mode choice for the Positron Pre-Accelerator defines important linac parameters, such as beam performance, power consumptions and cost. Both TW and SW modes have been considered in details together with another linac parameters in [5], [6].

Taking into account that:

- for reasonable stability of the parameters the TW mode of operation needs more rf power for the same E_0T and a values;
- the standing wave CCS structures open a wider range of flexibility in choice of E_0T and a, allowing a high E_0T at the PPA beginning for bunch lengthening reduction and moderate E_0T to save rf power in the main PPA part;
- the difference in filling time for the TW mode and rise-time for the SW mode is not so big and important for the long PPA pulse,

a SW mode for the PPA accelerating structure is chosen.

With the aperture diameter increased to 46 mm, the SW PPA has an enlarged acceptance, in comparison with the TW PPA ($2a = 30mm$), reduced power (and expensive rf hardware) consumption and increased positron beam energy.

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