THE POSITRON INJECTOR LINAC FOR TESLA

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Abstract

The TESLA linear collider with integrated X-ray FEL is based on superconducting accelerating cavities. Behind the positron production target normal conducting cavities have to be used in order to cope with high particle losses and with focusing solenoids surrounding the cavities. With the long rf pulse ($800\mu s$ flat-top) the achievable gradients are limited by rf power and heat load restrictions. Beam dynamics calculations of a standing wave preaccelerator will be discussed. The proposed preaccelertor includes an electron-positron beam separator section and is followed by a long transfer line and a matching section into a superconducting booster linac in which the positrons are accelerated to the damping ring energy of 5 GeV. The overall layout of the injector linac and the optimization of relevant parameters, as well as beam dynamics calculations will be presented.

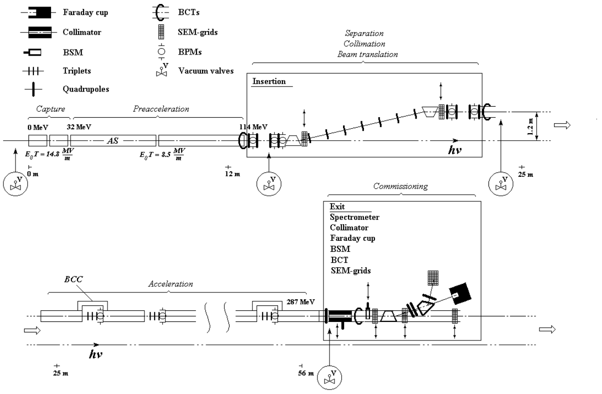

Fig.1 The general PPA scheme.

1 INTRODUCTION

The TESLA collider will use the $250 GeV e^-$ beam to produce a positron beam, by passing the electron beam through a wiggler to produce photons, which will hit a thin target to yield the positrons.

To match the positrons to the acceptance of the preaccelerator, an Adiabatic Matching Device (AMD) is used. After the AMD the positron beam should be captured and pre-accelerated to ≈ 250 MeV in the normal conducting Positron Pre-Accelerator (PPA) linac, transported with the Long Positron Transport Line (LPTL) to the superconducting Main Positron Accelerator linac (MPA), accelerated to ≈ 5 GeV and injected into the Damping Ring (DR) [1].

The main results of the total Positron Injector Linac (AMD-PPA-LPTL-MPA) design are presented below. For scientifical and technical details of the design we strongly refer to the detailed reports [2].

2 PPA PARTICULARITIES

The general PPA purpose is to provide a maximum capture efficiency for the useful part of the totally acceptable positron beam with technically reasonable parameters of the linac. The useful part of e^+ has an energy spread of $\Delta W/W_f = \pm 6\%$ at the PPA output energy of $(250 \div 300)$MeV and a phase spread of $\Delta\varphi = \pm 7.5^o$ for the PPA rf-frequency of 1.3 GHz. The capture efficiency is the ratio of the number of positrons in the useful part with the required limitations in the transverse phase space to the total number of positrons escaped from the target. The total normalized transverse e^+ beam emittance is limited by the DR acceptance to $\varepsilon_x < 0.036$m, $\varepsilon_y < 0.036$m, $\varepsilon_x + \varepsilon_y < 0.048$ m both for the PPA and for the other parts of the injector too.

The general PPA scheme is shown in Fig.1. The PPA is a standing-wave normal conducting linac. The PPA first part consists of the four Acceleration Cavities (AC) embedded in a focusing solenoid. The first two ACs have a high accelerating gradient (< 14.5MV/m), to reduce the bunch lengthening, whereas the others have a moderate gradient (< 8.5MV/m) to diminish rf power consumption. Each AC is powered by one standard TESLA 10 MW klystron. An additional bunch lengthening reduction is done by entering the first AC into the AMD at ≈ 60cm.

About 65% of the incoming positrons and 76% of the incoming electrons will be lost in the AMD and the first four ACs, resulting in an additional heating.

Behind the first PPA part (with a positron beam energy $\approx 114 MeV$) there is a magnetic insertion to separate the positron and electron beams. Additionally it serves a parallel translation the PPA axis to a distance of $\sim (1.0 \div 1.2)$ m (to pass the a powerful photon beam through) and to collimate the positron beam. The insertion has a standard achromatic design with two bending dipoles and matching sections on the both ends. It was shown [2] that mainly the nonlinear chromatic effects have the dominant role for the final beam quality when a beam with high energy spread and low energy has to be transported. The total positron losses in the separator are estimated as $\sim 8.4\%$ of the incoming e^+ beam, composing mainly from the particles with a large momentum deviation. Behind the first dipole of the separator a dump is foreseen which can handle the e^- beam power of $(12 \div 15)$ kW.

After the separator the positron beam has practically a single bunch structure (the first e^+ bunch has $\sim 99.3\%$ of

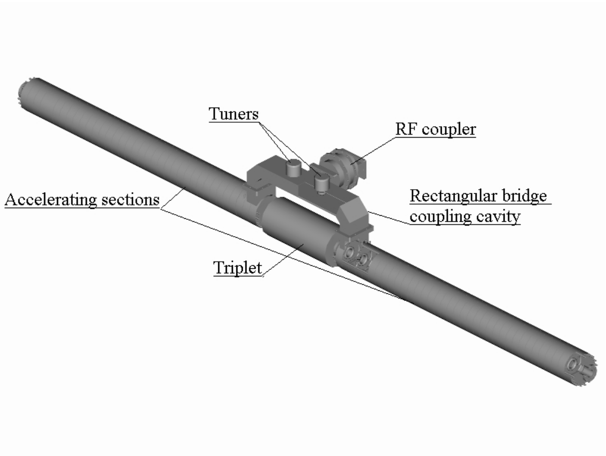

Fig. 2: Accelerating cavity in the second PPA part.

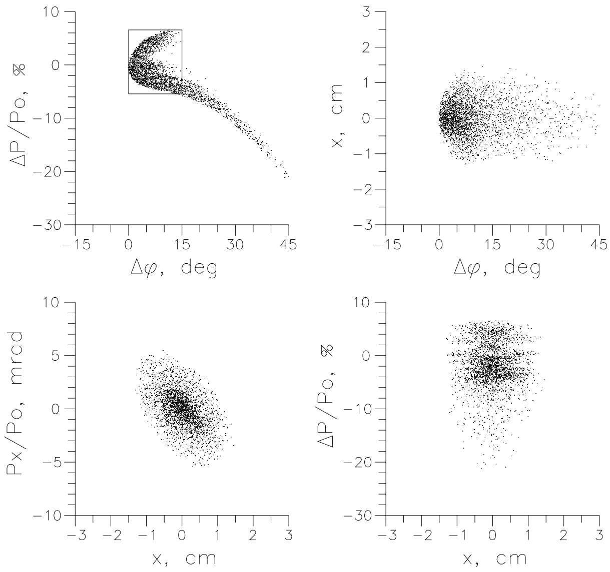

Fig. 3. Positrons phase space portraits at the PPA exit.

Table 1. The main PPA parameters.

Parameter	**value**
Final energy W_f, MeV	287
Total capture efficiency, %	21.3
Solenoid length, m	∼11.4
Solenoid field, T	0.22
Number of quadrupoles	42
Number of dipoles	2
Number of klystrons	9
Total length, m	∼55.5

the total positron number), instead of a multi-bunch structure before the insertion [2]. The second PPA part consists of five ACs with moderate gradient (< 8.5MV/m). Each AC has two accelerating sections (Fig. 2). The transverse focusing is carried out by quadrupole triplets, placed between sections. The sections are separated by a drift space of $4\lambda_{rf}$. To combain two sections into a single resonant system, bridge coupling cavities are used. Each AC is powered by one 10 MW klystron.

The final phase space portraits at the PPA exit are shown in (Fig. 3). The main PPA parameters are collected in Table 1. The PPA subsystems are described in details in [2].

3 LPTL PARAMETERS

The requirements for the LPTL are simple. The transport line must use the existing TESLA tunnel, provide a bypass section under the Detector Hall using the beam dump halls, provide adjustable matching with the beam parameters at the PPA exit and MPA entrance, avoid to introduce dispersion except for a small part of the bypass section with bends, not alter the bunch length. On the other hand there are a few special aspects which make the task of the beam transport not so simple:

- the LPTL is long, so there arises a problem of optimization of the aperture and the number of magnetic elements.
- the LPTL must provide a beam passage with a large transverse emittance and a large energy spread that results in a large aperture of magnetic elements and leads to a design of a quasi-isochronous bypass.

For the long straight LPTL parts a FODO type structure is used. The parameters of the FODO cell have been chosen basing on some optimum between the maximum of the beam size, the maximum tolerable modulation of the β-function and the number of quadrupoles in the line.

The following scheme is proposed for the bypass as a result of our investigations :

- each arc of the bypass section consists of two quasi-isochronous cells and a matching section between them (Fig.4). It is convenient to make this matching section consisting of the same FODO cells (without bending magnets) as an isochronous cell. Two FODO cells 4.8 m long each, allow one to obtain the translation base equal to 17.3 m.
- each quasi-isochronous cell has an identical FODO type structure, but the dipoles in the second cell have reversed angles to provide the bypass of the interaction point.

The isochronous cell of the bypass is based on a modified four-cell FODO structure with missing magnets, allowing to tune the momentum compaction factor and to tune the LPTL as an isochronous or a quasi-isochronous line in total.

Between the exit of the PPA linac, the entrance of the MPA and the FODO structure matching sections are used. Also there are matching sections between the FODO structure and the bypass arcs. All matching sections consist of four quadrupoles.

The aperture diameter for all the quadrupole lenses is equal to 0.16 m, providing a safety factor of 1.7 for the FODO cells and more than 2 for all the others quadrupoles, except for four quadrupole in each bypass cell. This choise is a reasonable compromize between a safety factor value and the number of magnetic elements.

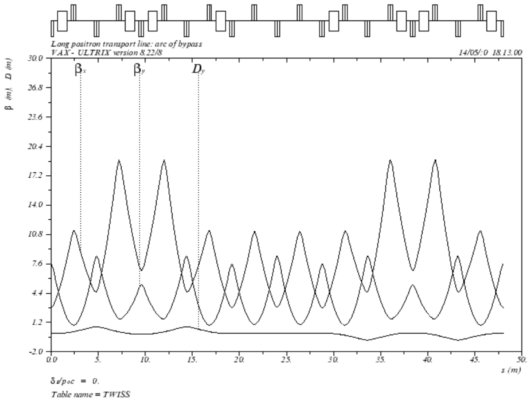

Fig. 4. Behaviour of optical functions along one bypass arc.

Table 5.1. The LPTL main parameters.

Parameter	**Value**	**Unit**
Kinetic energy	287	MeV
Total length	2208.3	m
Length of bypass arc	48	m
Translation base	17.3	m
Number of quadrupoles	272	
Number of dipoles	16	

4 MPA LINAC DESIGN

The MPA is based on the standard TESLA 9 cells superconducting Accelerating Structure (AS). Due to the large transverse emittances for the e^+ beam (by three orders of magnitude greater than those on the e^- beam emittances for TESLA [1]), the MPA transverse focusing is carried out by Quadrupole Doublets (QD). Two types of cryomodule design (common with the ones for the TESLA project) are supposed in the MPA design. The first type ($CM1$) contains (in the main TESLA linacs) eight ASs only and the second one ($CM2$) additionally has a superconducting quadrupole [3]. The MPA doublets are proposed on the base of the new TESLA quadrupole. It is possible to keep the doublet field $\sim\ 60$ T/m with an effective length $\sim\ 200$ mm for each quadrupole [3]. Two QD types are foreseen for the MPA. The first one has the same length as a TESLA quadrupole. The second one has an increased length by adding the drifts for the quadrupole assembly ends to replace AS in the module $CM1$.

In the MPA beginning eight $CM1$ modules are used with even ASs being replaced by QDs for each cryomodule. The eighth $CM1$ is used for matching (Fig.5). Then, after the e^+ beam energy $\approx 1080 MeV$, the 20 $CM2$ modules follow (with QDs instead of single quadrupoles) up to the MPA exit. The MPA final beam energy is $\sim 5.08 GeV$, the MPA length is $\approx\ 338m$. The safety factor, calculated as the ratio of the inner element radius to the maximum beam envelope in this element, is $>\ 2$. The standard TESLA rf-feeding scheme and rf-hardware is applied for rf powering.

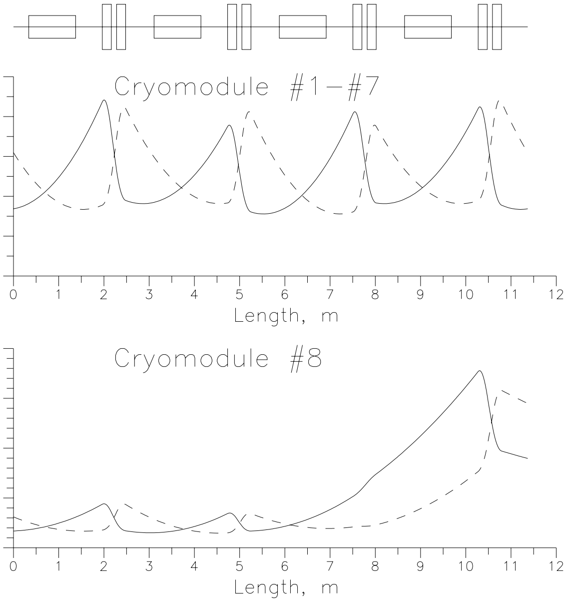

Fig. 5. Structure β-functions for the eight $CM-1$.

5 SUMMARY

The present report summarizes the results of the design for the total TESLA positron injector. It consists of several essentially different parts - a normal conducting Positron Pre-Accelerator, a Long Positron Transport Line with bypass sections and a superconducting Main Positron Accelerator. Parameters both of each part and the total line are optimized in order to obtaine scientifically effective, technically reasonable and cost saving solutions.

The PPA is a standing wave normal conducting linac. All solutions for the PPA systems base on experience of exsisting linear accelerators with usage of the standard TESLA RF equipment. The LPTL structure is adequate to unique beam parameters. The LPTL magnetic elements have conservative cost-saving parameters. The MPA is designed consisting of the standard TESLA equipment.

The total transmission of the line for the positron beam is estimated as $\approx 16\%$. This value is sufficient to provide the necessary positron number required for the TESLA collider luminosity.

REFERENCES

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[2] K. Flöttmann, V. Paramonov ed., Conceptual Design of a Positron Injector for the TESLA Linear Collider, TESLA 2000-12. K. Flöttmann, V. Paramonov ed., Conceptual design of a Positron Pre-Accelerator for the TESLA Linear Collider, TESLA 99-14, DESY, 1999

[3] S.Wolff, Private communication, DESY, 1999.