BEAM DYNAMICS ISSUES IN UNDULATOR BASED PPA

V.A. Moiseev[1], V.V. Paramonov[1], K. Flöttmann[2]
[1]INR RAS, Moscow, Russia
[2]DESY, Hamburg, Germany
E-mail: moiseev@inr.troitsk.ru

The analysis of the beam dynamics simulation for an undulator based Positron Pre-Accelerator was carried out to produce a high positron capture with the reliable and reasonable design solution. From beam dynamics and taking into account a lot of parameters for optimization the attempt to ground the proposal PPA design was done. The possible choice of any other design solution is discussed.

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1. INTRODUCTION

The Positron Pre-Accelerator (PPA) will be the beginning part of the positron branch of the International Linear Collider (ILC). There are two main modes of positron production. The first one is conventional and the second one is undulator based. The conventional method uses multi-GeV electrons impinging on a high-Z thick (in radiation length units) target. Whereas the second method applies a very high energy electron beam passing through undulator to make multi-MeV photons (150…250 GeV electrons, 100 meter or more of undulators), which will hit a thin (in radiation units also) target to yield the positrons [1]. The undulator based method has a number of advantages with respect to the conventional one. The main advantage is considerably more compact transverse and longitudinal positron momentum distributions. The next ones are the possibility to produce polarized positrons and much lower neutron activation. Improved initial positron momentum distribution for undulator based PPA permits to get higher positron capture efficiency, which is determined as ratio of a number of positrons for further use to number of positrons emitted from the target. For conventional positron production schemes this parameter is about few percents whereas for undulator based PPA the value more than 20% may be reached [3].

There are few main requirements for PPA operation for any type of positron production. At first, it needs to have high positron capture efficiency in 6-dimensional phase space for PPA beam output energy more than 250 MeV. Secondly, it needs to have final positron beam quality: single output positron bunch with minimum of useless particles. And finally it needs to have the reliable and reasonable PPA design solution. For TESLA project the undulator based PPA scheme was designed [2] and it is presented in Fig.1.

2. PPA COMPONENTS

For any PPA design there are main elements used: base rf-klystron, magnetic device placed behind the target to match the positrons beam from the target with accelerator acceptance, room temperature accelerating structure with rather high field gradient embedded in a constant field long solenoid. Additionally, an insertion unit for particle separation and collimation as well as an acceleration part with periodic transverse focusing may be used [2].

2.1. MATCHING DEVICE

An adiabatic matching device (AMD) is suitable decision for the PPA beginning. It consists of a tapered solenoid field, which starts with a higher initial field and tapers down adiabatically to the constant end field. Technically it is a special solenoid with combined pulsed and time constant magnetic field [2]. The AMD on-axis field law is $B(s)=B_0/(1+gs)$, where s is the longitudinal coordinate, Bo is the maximum magnetic field and g is the taper coefficient. The final AMD field is equal to the constant magnetic field of the PPA solenoid. The modern reliable B_0 value is ~6 T [2]. The optimum value for g is closed to 30 m^{-1}. This result has been received by simulation [3].

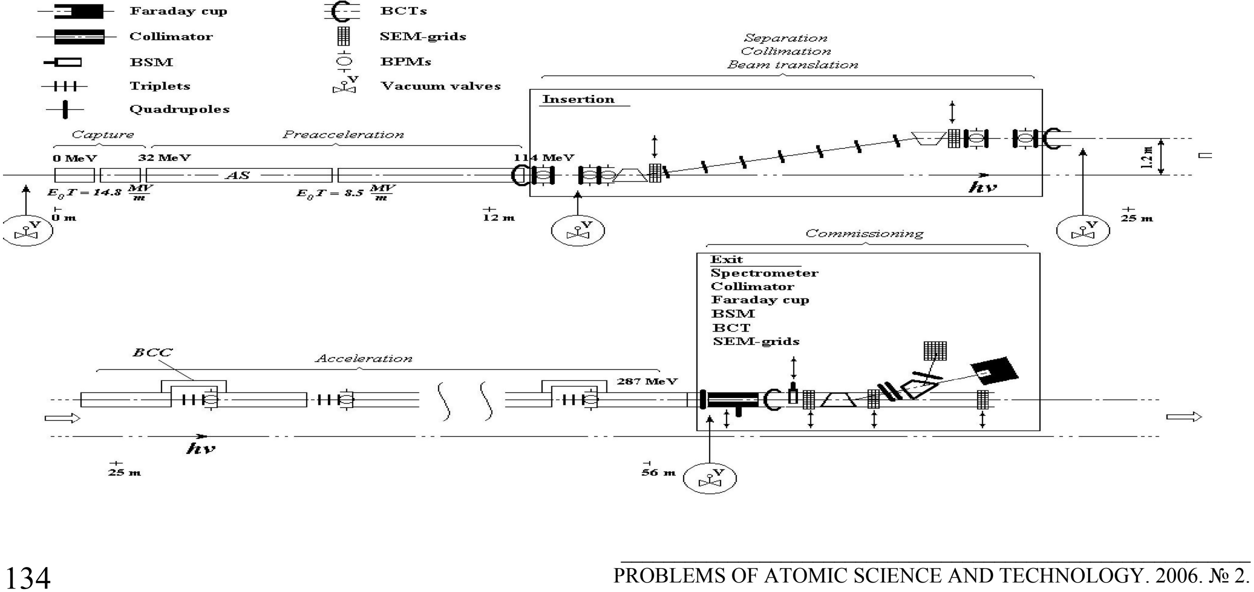

Fig.1 The general PPA proposal

2.2. FOCUSING SOLENOID

To keep positrons in the PPA initial acceleration part a focusing solenoid field has to be used. The value of solenoid field B_{sol} is equal to the AMD downstream end field. The acceptance of solenoid accelerating channel is $A_0 \sim B_{sol}a^2$, where a is the radius of an accelerating structure. In dependence of desired acceptance value (for TESLA PPA A_0 =0.036 π mrad) and taking into account the technically reasonable B_{sol} (for 0.22 T and solenoid length ~11.5 m DC power consumption, which is ~ B_{sol}^2, will be ~450 kW) the minimum radius of acceleration section can be determined. It is evident that the higher solenoid field is better. However, from some value of B_{sol} the growth rate for the capture efficiency slows down essentially. It results from the PPA acceptance exceeding the transverse emittance requirement for positron beam [2].

In Fig.2 the positron capture efficiency is presented in dependence on the accelerating section radius a. The higher radius does not lead to essential growth for the capture efficiency. The saturation of capture efficiency begins when the acceptance of system becomes higher than desired positron beam emittance. Due to the square dependence of acceptance from aperture radius there is not essential decreasing of aperture size with solenoid field growth. Thus, there is a choice to have the large solenoid field and moderate aperture radius or small solenoid field and slightly higher aperture. For TESLA PPA [2] the second solution was chosen taking in account the low DC power consumption in solenoid and reduced influence of uniform solenoid field perturbations on particle dynamics.

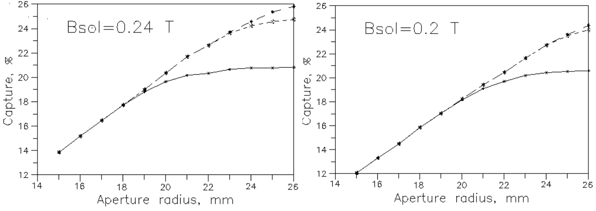

Fig.2 Capture efficiency in dependence of rf-section radius

2.3. ACCELERATION

The main goal of the PPA beginning part is as fast as possible to accelerate positron beam up to high energy where the bunch lengthening will be negligible and the transverse momentum becomes much less than longitudinal one. For L-band operation (1.3 GHz) both Stand - ing Wave (SW) Coupled Cells (CC) structures and Traveling Wave (TW) structures may be used in dependence on the ILC operation. However, it was shown [4] that for TESLA operation the SW structures are more preferable. The first TESLA PPA part consists of the four Accelerating Cavities (ACs) embedded in a focusing solenoid. The first two ACs have a high accelerating gradient (<14.5 MV/m) to reduce the bunch lengthening, whereas the others have a moderate gradient (<8.5 MV/m) to diminish the rf-power consumption. Each AC is powered by one standard TESLA 10 MW klystron. There are some reasons for this solution. At first, energy increase per section is less for higher gradients ($L_{sec}\sim E_0^{-2}$ whereas energy gain per AC ~ $E_0L_{sec}\sim E_0^{-1}$). The beam dynamics simulation has shown [3] that bunch lengthening effect becomes small for bunch energy more than 40 MeV. Therefore, further acceleration can be done with lower gradients and higher energy gain per AC. The higher accelerating gradient in first ACs will increase the number of klystrons and ACs. Also there will be additional perturbations in uniform solenoid field due to AC feeding lines and alignment equipment. Moreover, the using of 20 MV/m gradient in first ACs leads only to ~2.5% growth of positron capture efficiency on the level of ~25%, but electron losses were risen in 1.5 times in these ACs. Additionally adjusting the bunching rf-phase (optimum value is ~-200 for a reference particle) in high gradient ACs it is possible, reducing the final energy, to prevent the large lengthening in ACs. In this case the capture efficiency growth will be ~ 2%.

2.4. TRANSVERSE PERIODIC FOCUSING

There is positron beam energy when it is possible to change the solenoid focusing on transverse periodic focusing by quadrupoles. The advantages of this solution are smaller DC power consumption in short solenoid and better maintenance for ACs and diagnostics. For TESLA requirements beam energy more than 100 MeV is acceptable for transition [3]. The triplet periodic structure was chosen because of the maximum of free space to place ACs and moreover a beam will be practically round in ACs. In addition, the periodic structure can be used for beam cleaning from electrons and positrons with large energy deviation due to the mismatching of the dynamic parameters of the useless particles with periodic focusing.

2.5. SEPARATION AND COLLIMATION

There is a problem to separate positrons, electrons and photons for undulator based PPA. And it is necessary to clean 6-dimention positron phase space to have beam quality acceptable for further operation. These problems can be solved in any PPA point except the solenoid part. At least two solutions may be proposed. The first one is to make separation and collimation at the PPA exit. And the second one is to place special insertion at the transition point from solenoid to periodic focusing if it exists. The advantages of the last solution are lower power of useless accelerated electron beam (~ 15 kW for TESLA PPA proposal [2]) and lower requirements for equipment misalignments with respect to the photon beam. However, at lower energy for separation it will be stronger nonlinear chromatic effects that can lead to the abrupt drop of positron beam quality [2]. The main requirements for special insertion for separation and collimation the positron beam are to be achromatic or isochronous system and to have small optical functions to reduce the nonlinear chromatic effects (not good for collimation) [2].

3. BEAM DYNAMICS SIMULATION

For TESLA PPA proposal (Fig.1) the following parameters and decisions were accepted. The PPA is a standing wave normal conducting linac. Its first part consists of the four ACs embedded in a focusing solenoid with B_{sol} = 0.22 T. Behind the first PPA part (final positron energy ~114 MeV) there is a magnetic insertion to separate the positron and electron beams. Additionally it serves to collimate the positron beam. The insertion has a standard achromatic design with two bending dipoles and matching sections on both ends [2]. The second PPA part consists of five ACs with moderate gradient (<8.5 MV/m). The quadrupole triplets carry out the transverse focusing. AMD has the following parameters: g = 29.5 m^{-1}, length ~ 0.9 m.

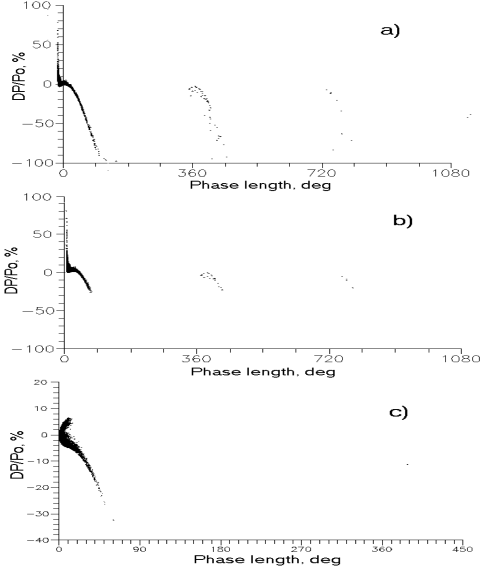

Fig.3 Longitudinal positron beam phase spaces

In Fig.3 the longitudinal positron beam phase spaces are presented at PPA exit with different design solutions. In Fig.3,a the simulation results are presented for PPA with solenoid focusing only. There is a train of positron bunches. The first one includes ~90% of accelerated positrons. In Fig.3,b the results are for PPA with combined transverse focusing (solenoid + periodic triplet focusing). There is an obvious cleaning of low energy train momentum region. In Fig.3,c the simulation results are presented for TESLA PPA proposal (Fig.1) with magnetic insertion [2]. Negligible number of positrons is in tail train (~0.7% of total positron number) and the first bunch is more compact compared with previous cases.

In Table the simulation results for different PPA designs are presented.

Comparison of different PPA designs

Parameter	Solenoid	Solenoid & triplets	Solenoid & separator & triplets
Final energy, MeV	274	278	287
Capture efficiency, %	24.8	24.3	21.3
Solenoid length, m	34	11.4	11.4
Number of klystrons	9	9	9
Total length, m	34.3	45	55.5
DC power consumption, kW	~ 1350	~ 450	~ 480

4. CONCLUSIONS

The undulator based PPA permits to get output positron beam with satisfied parameters. It is possible to design the flexible PPA proposal in dependence on the required purposes and existing equipments.

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АНАЛИЗ ДИНАМИКИ ПУЧКА В ПОЗИТРОННОМ ПРЕДУСКОРИТЕЛЕ НА БАЗЕ ОНДУЛЯТОРА

В.А. Моисеев, В.В. Парамонов, К. Флеттманн

Приведен анализ динамики пучка в позитронном предускорителе с целью получения значительного захвата позитронов при надежном и целесообразном решении конструкции ускорителя. Исходя из динамики пучка и принимая во внимание значительное число параметров оптимизации, сделана попытка обосновать предлагаемое решение предускорителя. Обсуждается возможный выбор любого другого решения конструкции предускорителя.

АНАЛІЗ ДИНАМІКИ ПУЧКА В ПОЗИТРОННОМУ ПЕРЕДПРИСКОРЮВАЧІ НА БАЗІ ОНДУЛЯТОРА

В.А. Моісеєв, В.В. Парамонов, К. Флоттманн

Наведено аналіз динаміки пучка в позитронному передприскорювачі з метою одержання значного захвату позитронів при надійному і доцільному рішенні конструкції прискорювача. Виходячи з динаміки пучка і беручи до уваги значне число параметрів оптимізації, зроблена спроба обгрунтувати пропоноване рішення передприскорювача. Обговорюється можливий вибір будь-якого іншого рішення конструкції передприскорювача.