MINIMIZATION OF PRIMARY ELECTRON BEAM RADIUS ON THE POSITRON PRODUCTION TARGET

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Abstract

To have a high positron yield, it is extremely important to minimize the primary electron beam radius at the positron production target. Various effects on electron beam blow-up are analyzed. By comparing the measured beam radius with simulated ones at current BEPC positron source, some concrete effects on beam blow-up caused by the initial beam energy spread, beam offset and machine errors, have been practically described. A design study on minimizing the electron beam radius at the upgrading BEPC-II positron source is given.

1 INTRODUCTION

Positrons are usually created by electron-positron (e^-/e+) pair production formed by an electron beam hitting on a high Z thick target. A considerable gain in numbers of (e^--e+) pair is realized by the cascade shower. The cross sections of the pair production, particularly of its cascade showers are strongly dependent on the beam spot size of the primary electron beam on the target.[1] The smaller spot size, the bigger cross section. Hence it is extremely important to minimize the primary electron beam radius at the target for having a high positron yield. Aiming at this goal, we first analyzed the most effects on the beam spot size, and practically studied this issue on the existing BEPC-Linac, given a comparison and its explanation to the differences between measured and calculated results. Then we discussed a design study on minimizing the electron beam radius at the upgrading BEPC-II Linac Positron source.

2 EFFECTS ON THE BEAM SPOT SIZE AT THE TARGET

The primary electron beam spot size at the target is essentially dominated by two factors: a) The beam focusing lattice upstream the target. Usually the optics should be designed and tuned to form a minimum spot size at the target. It means the transverse beta-function should be minimum (β_x=β_y=β_{min}) and the beam envelopes are at the waist (α_x=α_y=0) on the target. b) The transverse emittance (ε_x andε_y) at the target. Combining a) and b) we have the beam radius at the target: $\sigma = \sqrt{\beta\varepsilon}$. Usually it is easy to make a), but not easy to control b), since there are a lot of factors that affect on the beam emittance, as described in follows.

2.1 Beam mismatching

As a primary electron beam leaves from the bunching system (with solenoid focusing) for entering the main linac system (with quadrupole focusing), and if the beam is mismatched with the acceptance of the later system, then an emittance growth is occurred: $(\gamma\varepsilon)_t = B_{mag}(\gamma\varepsilon)_i$, where and are the normalized emittance at the exit of bunching system and at the positron production target, respectively. and Bmag a mismatch factor [2]. To cure this emittance growth, a well beam matching must be done and to do so, the actual beam emittance should be precisely measured at the exit of bunching system.

2.2 Initial beam energy spread

Usually at the exit of bunching system, the electron beam has low energy (a few tens MeV) and with large energy spread (about 5% ~ 15%), since the longitudinal beam bunching is realized at a cost of beam energy spread. As the beam enters into a quadrupole focusing system, a strong chromatic effect leads a normalized emittance growth by a factor of 20% ~ 40%. To partially cure this effect, high gradient acceleration is preferred to reduce the relative energy spread as quickly as possible.

2.3 The initial beam transverse offset

If an high current electron beam has a transverse offset, then a severe normalized emittance growth will be produced downstream, due to the transverse wake effect in the accelerating structures and the dispersive effect in the quadrupole system. These effects are proportional to the electron bunch charge (usually 2.5 nC ~ 10 nC), the amount of offset (say 0.1 mm ~ 0.5 mm), and the distance from the start point of offset to the target. To partially cure these effects, one has to strictly control the beam jitter at the beginning, and adopt an orbit correction system. The later is most necessary for high energy electron beam which is transferred in a long distance.

2.4 Machine misalignment errors

An accelerating structure offset will cause a wake effect, and a quadrupole offset will cause a dispersive effect., both causing a normalized emittance growth. To partially cure these effects, one has to strictly control the alignment torrance and to use the orbit correction system.

3 EXPERIMENTAL STUDY AT THE POSITRON SOURCE OF BEPC

To practically study the relations of beam spot size with above effects, we have measured the primary electron beam spot sizes on the existing BEPC-Linac positron source, and compared to the beam modeling results. First an optimized emittance measurement device was established at the exit of bunching system [3], for making a well beam matching into the downstream accelerating and quadrupole focusing system. The longitudinal distance from the bunching system exit to the target is 19.40 m, where there are four accelerating sections (3.05 m long each) used to increase the beam energy from 30 MeV to 140 MeV at the target, and two triplet quadrupoles to focus the beam on the target. Since there is no beam profile monitor directly on the target, hence instead, we studied the beam spot size at the closest profile monitor PR2 located at 0.56 m upstream the target. We confined the "ideal" beam spot sizes of 2.0 mm, 1.5 mm and 1.0 mm on the PR2 with TRANSPORT-code [4] by varying the four quadrupole strengths of the two triplets, respectively. These four variable strengths are used to fit the four beam parameters at PR2, such as σx=σy=2.0 mm (or 1.5 mm and 1.0 mm) andαx=αy=0. Then we measured the beam spot sizes for fitted quadrupole strengths, and compared them with the modeling ones. The results show the measured beam radius（1σ） are bigger than the confined ones as listed in Table 1, where B1-B4 are the magnetic field at the pole tip of the two triplets. For the confined beam spot size, no any beam and machine errors are taken into account. Checked by beam modeling with LIAR-code [5], we found that most contribution to the beam blow-up is the large beam energy spread induced chromatic effect in the quadrupols.

Table 1 Comparison of measured and confined beam radius

σ_x=σ_y (Confined)	2.00 mm	1.50 mm	1.00 mm
B1 (kG)	0.208	0.206	0.202
B2 (kG)	0.184	0.177	0.173
B3 (kG)	0.443	0.483	0.613
B4 (kG)	0.605	0.615	0.675
σ_x (Mea.)	2.24 mm	1.66 mm	1.50 mm
σ_y (Mea.)	2.42 mm	2.07 mm	1.67 mm
$\Delta\sigma_x/\sigma_x$	12 %	11 %	50 %
$\Delta\sigma_y/\sigma_y$	21 %	38 %	67 %

In BEPC-Linac case, the energy and energy spread at the exit of the bunching system are 30 MeV and 2.0 MeV, respectively, while the accelerating gradadient is low (9.5 MeV/m). Thus the chromatic effect induced normalized emittance growth is about 48% and the spot size blow up about 24%. Some small parts of the blow-up are the initial beam offset and machine alignment errors induced dispersive / wake effects. According to the estimated initial beam offset (about 0.15mm (x) and 0.35 mm (y)) and machine alignment errors, the modeled emittance growth and beam blow up are about 15%(x) ~ 20%(y) and 10%(x) ~ 15%(y), respectively. The beam radii's differences between measured ones and confined ones of 2.0 mm, 1.5 mm and 1.0 mm are about 20%, 40% and 70% respectively. The smaller confined one, the stronger focusing strength of the triplets and hence the bigger chromatic / dispersive effects in the quads due to the large initial beam energy spread and initial beam offset.2.6

4 STUDIES ON BEAM RADIUS AT BEPCII-LINAC POSITRON SOURCE

In BEPCII case, the primary electron beam energy at the target will be upgraded from 140 MeV to 240 MeV, leading to the non-normalized emittance about 42% smaller and beam radius about 21% smaller. In addition, the accelerating gradient in this region will be upgraded from 9.5 MeV/m to 17.5 MeV/m, leading to the chromatic / dispersive effects induced beam blow up reduced to ~5%. Finally if we control the beam jitter and machine alignment errors to 0.3mm and 0.1mm (1σ), respectively, then a small beam radius is possible to be obtained, even though the primary electron bunch charge (2.33nC) in BEPCII is larger than the existing BEPC (1.1nC) and hence the energy spread (2.5 MeV) at the exit of BEPCII bunching system may be larger than the existing BEPC one (2.0 MeV).

Figure 1 shows the optimum primary electron beam optics from pre-injector to the target for BEPCII-Linac, where the "ideal" beam parameters at the target (σ_x=σ_y=1.0 mm and α_x=α_y=0.) are obtained by fitting the two triplet's gradients with TRANSPORT-code.

Figure 1 The primary electron beam optics from pre-injector to the target for BEPCII-Linac.

Table 2 and Figure 2 show the modeling results of beam radii on target vs. initial beam offset and machine errors with LIAR-code. By this table, if one can well control the initial beam offset and machine errors, then a beam radius of less than 1.5 mm at the target is possible to be reached., while the at existing BEPC target it is about 2.5 mm. The further study on reducing the beam radius at the target is underway. Figure 3 shows the positron yield vs. the primary electron beam radius at the target [6].

Table 2. Beam radius vs.beam offset and machine errors.

Beam Offset (mm)	Quads Offset (mm, 1σ)	Structure Offset (mm, 1σ)	σ_t(mm)
0.1	0.1	0.1	1.09
0.2	0.2	0.2	1.25
0.3	0.3	0.3	1.46
0.4	0.4	0.4	1.76
0.5	0.5	0.5	2.06

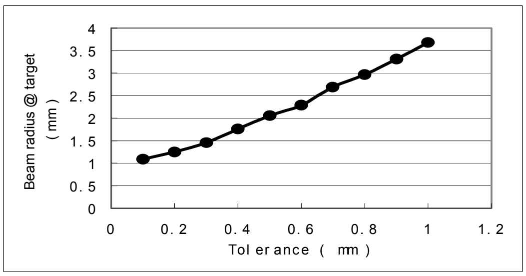

Figure 2 Electron beam radius @ the target vs. initial beam offset and machine errors.

5 CONCLUSION

To have a minimized primary electron beam radius on the positron production target is extremely important to get the highest positron yield. Based on the experimental and modeling studies described in this paper, the following approaches may be considered to meet with this goal:

1) Precisely match the beam into the downstream system.
2) High accelerating gradient is preferred for the structures from bunching system exit to the target, to reduce the energy spread of low energy beam induced beam blow-up due to chromatic effect.
3) A high energy primary electron beam is of a benefit to have a high positron yield, not only due to the fact that the yield is directly proportional to the primary beam energy, but also a small beam spot size on the target due to its smaller non-normalized emittance.
4) A stricte control on the beam offset and machine alignment errors, using orbit correction scheme as well, is very important to minimize the beam spot size on the target.

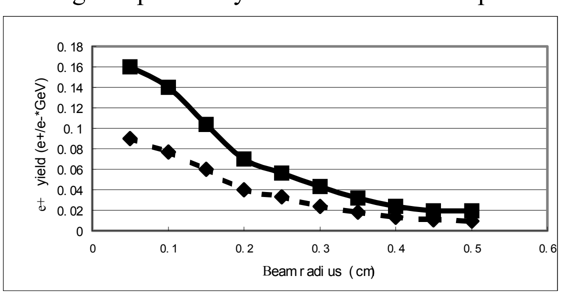

Figure 3 Positron yield vs. the primary electron beam radius at the target.
-◆-BEPC Positron Source [Acceptance = 0.22π(MeV/c).cm]
-■-BEPCII Positron Source [Acceptance = 0.31π(MeV/c).cm]

6 REFERENCES

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