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Simulation of time bunching for a pulsed positron beam*

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Simulate anneal arithmetic has been used to settle the problem of time bunching on a pulsed slow-positron beam device. This paper has searched for the parameters of the device in a large scope and achieved the time resolution within 150ps at the target with accelerating voltage in a range of 0.5–30kV.

Keywords: pulsed positron beam, time resolution, simulate anneal arithmetic
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1. Introduction

Positron annihilation lifetime spectroscopy (PALS) is an efficient method for the study of material properties.[1–3] In order to study the depth-dependent characteristics near the surface of metal and semiconductor with PALS, a system for pulsed slow positrons is under development at the University of Science and Technology of China (USTC). In our system, a ^{22}Na radioactive source with an activity of $\sim 1.85\times 10^9$Bq is used as the positron source. To obtain a short-pulsed slow-positron beam, appropriate radio-frequency fields are used to bunch a slow-positron beam. The pulsing system consists of a chopper, a pre-buncher and a main buncher running at repetition rates of 50 MHz and 200 MHz respectively. The energy of the positrons can be adjusted between 0.5 and 30keV by changing the potential of the sample.

The time bunching of positron beam is a crucial part of the design, but it is still a hard work without good resolution. To solve this problem perfectly, we introduce an optimization method to simulate the time of focalization.

2. Physics Model

The new pulsed positron beam system is shown schematically in Fig.1. The spot diameter of ^{22}Na source is 3 mm. High energy positrons which come from ^{22}Na source are injected into the tungsten transmission moderator and then are re-emitted as slow positrons by the moderator, whose energy distribution is about 3 eV. The slow positrons were collected and accelerated by an electric grid with related potential of −280 V. The produced positron beam was guided by a longitudinal magnetic field of 8×10^{-3}T, which is achieved by a set of solenoids accurately positioned through the axis of the beam. First, the positron beam passes through a beam chopper with 3 grids, to which an approximate rectangular wave signal of 50 MHz is applied with a time window of 5ns, then the positron beam becomes a pulsed positron beam with a time window of 5ns. A 50 MHz sine wave is applied to the pre-buncher. The chopped positrons pass the pulsing apertures of pre-buncher firstly, and then are bunched to a pulse with a time width of 1 ns [full width at half maximum (FWHM)]. After that, they are compressed into a time window of 150–200 ps (FWHM) by the main buncher, to which a 200 MHz sine wave was applied. Finally, they are accelerated to arrive at the target where the sample is situated. On this platform, a variety of experiments can be performed, such as regular slow positron measurement, lifetime spectrum, coincidence Doppler broadening spectroscopy, and age–momentum correlation spectrum.

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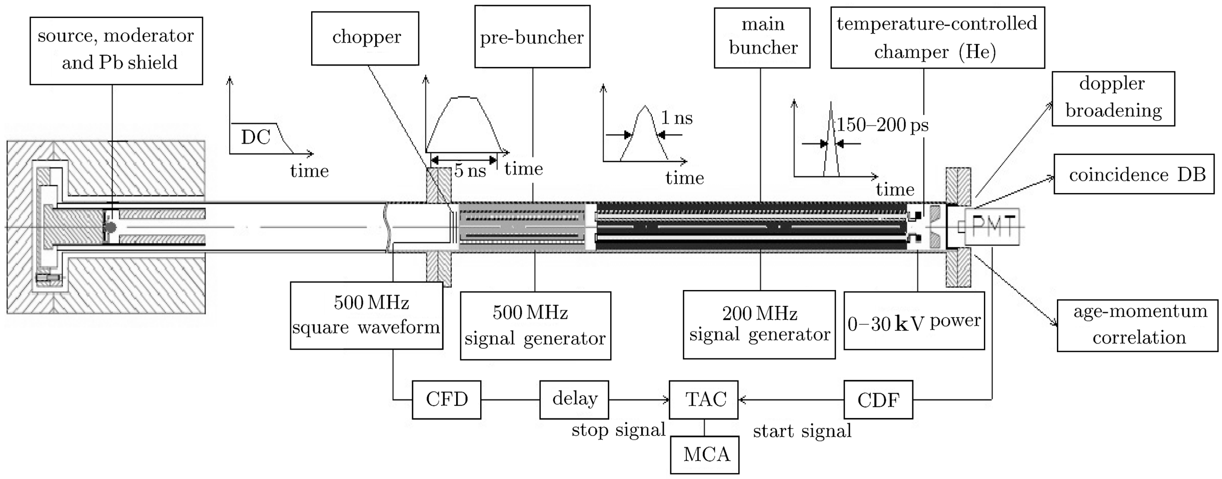

Fig.1. Schematic diagram of pulsed positron beam device.

3. Simulating methods and discussion

3.1. Simulating methods

There are many ways to acquire a pulsed positron by compressing time, of which high frequency means is the most popular.[4–6] Although the ideal signal is a sawtooth wave,[4] it is always replaced by a sine wave signal as a result of technical problems. In our design, a sine wave signal is applied to the pre-buncher operating at 50MHz and the main buncher at 200 MHz. The electric field in the resonator is simulated by Mafia program,[7] while in the accelerator it is simulated by Simion program.[8] The factors which lead to different widths of pulsed positron beam include the positron energy (W_0), vertical energy dispersion, the time of positron entering into the resonators (phase Ψ_1, Ψ_2), the positions of the resonators and the accelerator (P_3, P_4), and the intensity of the electric field in the accelerating gap of the resonator (E_a, E_b). It is a complicated and onerous work to obtain pulsed positron beam with a good time resolution by adjusting these parameters. To settle the problem, we have employed the Monte Carlo modelling method combined with simulate anneal arithmetic (SAA) to study the position–time characteristics of the positron.

SAA, which dates from the early 1980s, is a random method to solve the large scale optimization problem. It employs the Metropolis method to control the decline of the temperature properly in order to simulate the annealing process. An improved SAA[9] is used to search for the best device parameters. The parameters consist of W_0, Ψ_1, Ψ_2, E_a, E_b, P_3, P_4, whose goal function is the time resolution at the target. This model relies on the temperature Cauchy distribution as follows:

$$m_i' = m_i + y_i(B_i - A_i), \tag{1}$$

$$y_i = T\mathrm{sgn}(u - 0.5)[(1 + 1/T)^{|2u-1|} - 1], \tag{2}$$

where m_i is the ith parameter in this model, u is the random number of the [0, 1] uniform distribution, [A_i, B_i] is the numerical value range of m_i; sgn(X) is the sign function.

The merit of this model is that the new procreant parameters' numerical value ranges are related to the temperature. When the temperature is high, the new parameter comes from a large numerical value range. On the contrary, while the temperature is low, it is searched around the last parameter.

The selective qualification is given by

$$P = [1 - (1 - h)\Delta E/T]^{1/(1-h)}. \tag{3}$$

In the arithmetic, all of the qualified parameters under certain conditions are recorded in order that the best time resolution is obtained.

Figure 2 shows the time resolution of the pulsed positron beam before focus and after focalization at the target. According to the present signal generator, a wave of 7 ns in width is chosen as an initial signal to put into the chopper and both of its rise time and decline time are 2 ns. The right graph of Fig.2 is the time resolution at the target, and the calculated FWHM is about 138 ps.

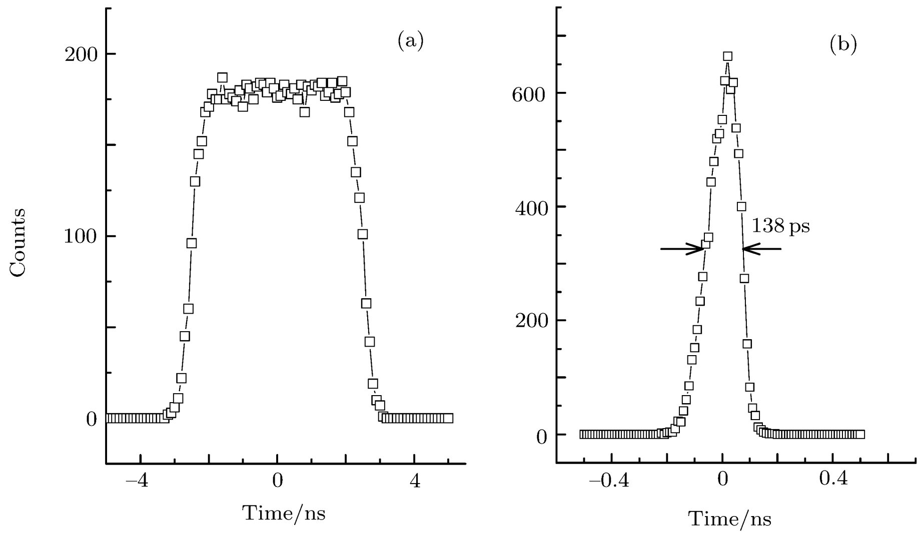

Fig.2. The time resolution of pulsed positron beam prior to focus (a) and after focalization (b).

The arithmetic procedure is described by Fig.3.

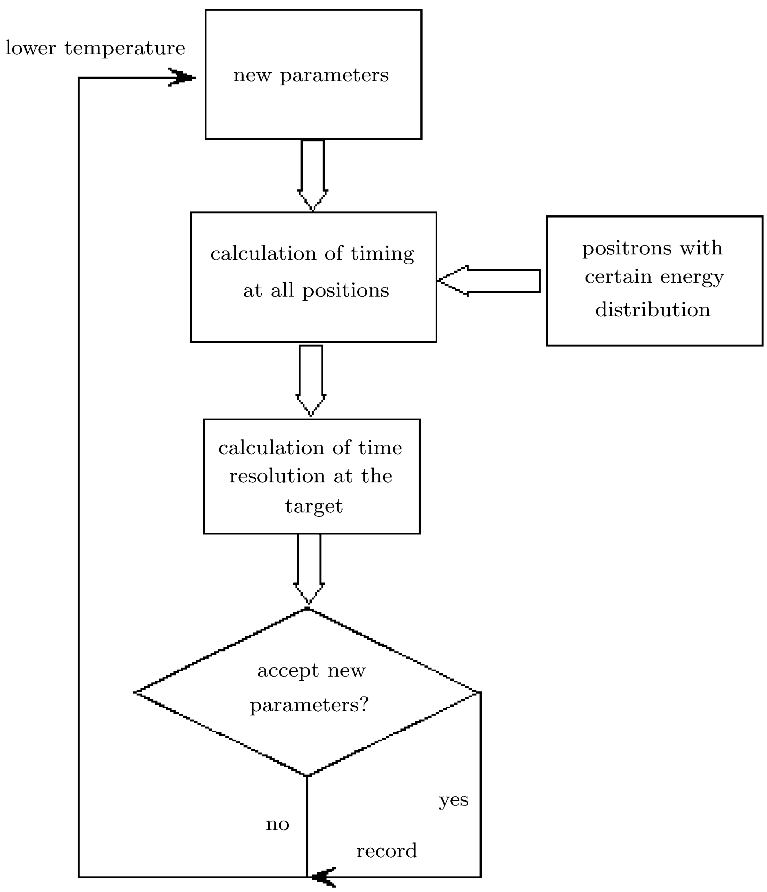

Fig.3. The arithmetic procedure.

3.2. Discussions of the results

1) According to the repeated calculation by the program, the positron that has transmission energy about 250eV gets the best time resolution. It is coincident with the results of Willutzki[4] entirely.

2) To shorten the distance between the accelerator and the target, it makes a smaller gap between time resolutions which results from the different accelerating voltages. The accelerating voltage in our design is from 0.5–30 kV. According to the calculation, we conclude that when a good time resolution with accelerating voltage of 0.5 kV is achieved, with the increase of accelerating voltage, the time resolution is getting worse. Similarly, when a nice resolution with a higher accelerating voltage is obtained, with the decrease of voltage, it is getting worse, either. The cause for this phenomenon is that the accelerating electric field with a spatial distribution and different accelerating voltages make different focuses. It is shown in Fig.4.

Change of the distance between the accelerator and the target is limited by the influence of reflected positrons. So an alternative way is varying the device parameters at different accelerating voltages.

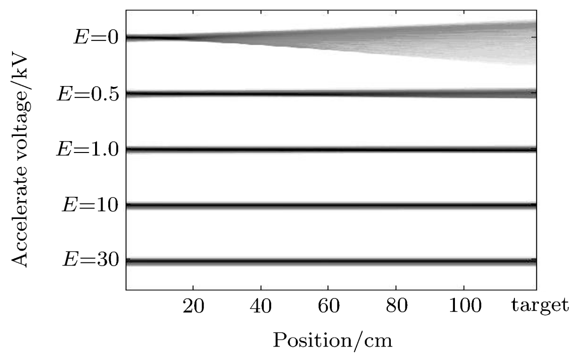

Fig.4. Time focalization with different accelerating voltages.

4. Conclusion

An optimization method (SAA) has been introduced in this article for the design of a time bunching system. Calculation is simplified and the result is inspiring. The time resolution is less than 150 ps at the accelerating voltage 0.5–30 kV. This system can be used for the PALS of metal and semiconductor.

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