Performance of the plugged-in ^{22}Na based slow positron beam facility *

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Abstract The Beijing intense slow positron beam facility is based on the 1.3 GeV linac of Beijing Electron-Positron Collider (BEPC) aiming to produce mono-energetic intense slow positron beam for material science investigation. The plugged-in ^{22}Na based slow positron beam section has been newly constructed to supply continuous beam time for the debugging of positron annihilation measurement stations and improve the Beijing intense slow positron beam time using efficiency. Performance testing result of the plugged-in ^{22}Na based slow positron beam facility are reviewed in this paper, with the measurement of the beam transport efficiency, the view of beam spot, the adjustment of beam position, the measurement of beam intensity and energy spread etc. included.

Key words slow positron beam, transport efficiency, beam intensity, energy spread

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1 Introduction

Slow positron beam is a nondestructive probe to investigate the depth profiling of defects in surfaces and interfaces, it has been used widely in material sciences and condensed matter physics[1]. Utilizing the 1.3 GeV linac of BEPC, the Beijing intense slow positron beam facility at the institute of high energy physics (IHEP) aims to produce intense slow positron beam and develop advanced measurement techniques in future[2]. It has limited running time of the linac designed for BES and BSRF operation. The plugged-in ^{22}Na based slow positron beam section has been newly constructed to supply continuous beam time for the debugging of positron annihilation measurement stations and improve the Beijing intense slow positron beam time using efficiency[3]. Limited to the activity of radioactive sources, the beam intensity based on radioactive sources is lower by about two orders of magnitude than that based on the linacs.

This paper first gives a brief description of the experimental setup and then emphasizes the detailed performance testing results, including the measurement of the beam transport efficiency by electron beam simulated testing, the view of beam spot by micro channel plate (MCP), the measurement of beam intensity by calibration of the radioactive source which has known intensity, the calculation of moderator efficiency, the adjustment of the beam position by cosine coils during the long distance beam transport, and the measurement of beam energy spread by a retarding analyzer.

2 Experimental setup

The overall design of the plugged-in ^{22}Na based slow positron beam facility is schematically shown in Fig. 1. The positron source is 52.2 mCi of ^{22}Na bought from the iThemba laboratory for accelerator based sciences in South Africa, and the moderator contains twelve layers of tungsten mesh (0.02×100×100 mm, Φ8 diameter). The moderated slow positrons magnetically transported at 177 eV are selected by cylindrical $\boldsymbol{E}\times\boldsymbol{B}$ energy filter and stepped down 30 mm through a 12 mm orifice, while the fast positrons and the γ rays from the ^{22}Na source are completly

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shielded by a 8 cm thick W80Cu20 alloy. The acceleration of the slow positrons is achieved by applying a regulated bias (0—30 kV) at the floated source end. At last the variable mono-energetic positrons (0—30 keV) are magnetically (100 Gs) guided to the sample chamber for positron annihilation measurements.

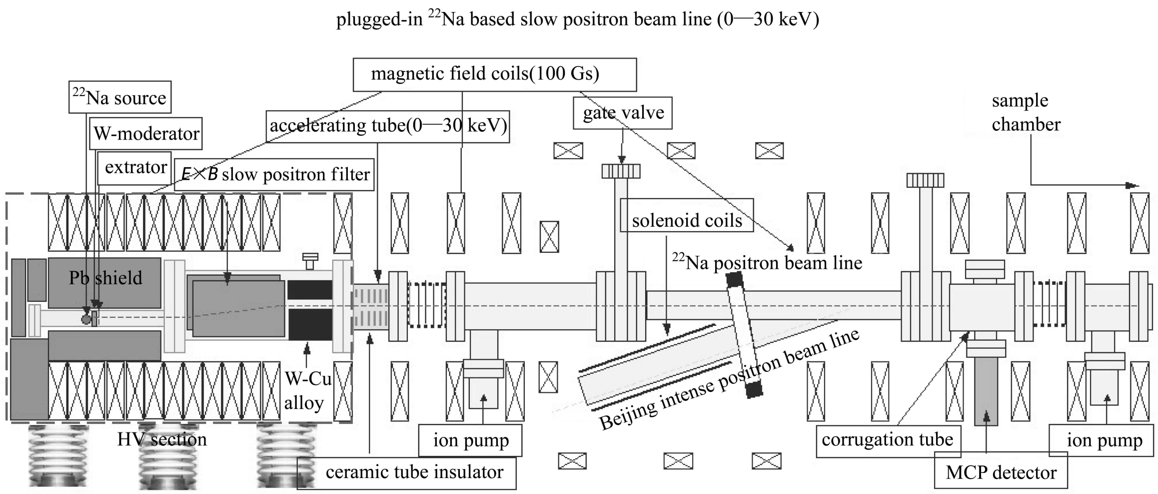

Fig. 1. Schematic view of the plugged-in ^{22}Na based slow positron beam facility.

3 Performance testing

3.1 Beam transport efficiency

As the moderator efficiency is uncertain and it is hard to measure the intensity of moderated positrons in the source end, the slow positron beam transport efficiency could not be directly measured. The electron beam emitted from the hot cathode is used to substitute the slow positron beam as it has much higher current ($\sim10^{-6}$ A) than the slow positron beam ($\sim10^{-14}$ A) and can be easily detected by μA amperemeters, the electron beam has similar characters with the slow positron beam (beam energy , energy spread, etc.).

As shown in Fig. 2, the electrons emitted from the hot cathode are accelerated by the grid anode and transported through the $\boldsymbol{E}\times\boldsymbol{B}$ energy filter, the accelerating tube and the vacuum tubes to the sample chamber with the guide of 100 Gs[1)] axially uniform magnetic field. An aluminium plate is put in the sample chamber to collect the electric current, as I is the total electric current emitted from the hot cathode, I_g is the electric current absorbed by the grid anode, I_c is the collected electric current in the sample chamber, then the beam transport efficiency η could be calculated as: $\eta=I_c/(I-I_g)$. The maximum beam transport efficiency η is achieved by adjusting the parameters of the $\boldsymbol{E}\times\boldsymbol{B}$ energy filter and the grid voltage, which is 95% ($I=44.7$ μA, $I_g=10$ μA and $I_c=33$ μA).

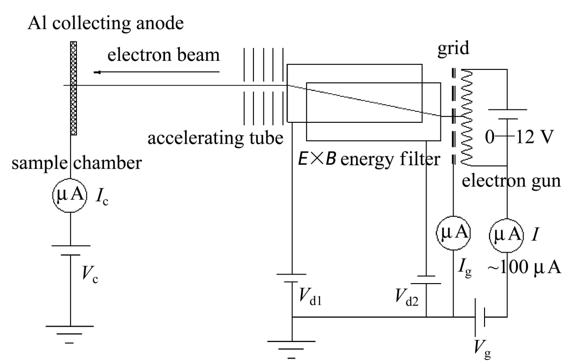

Fig. 2. Schematic view of electron beam simulated testing.

3.2 View of beam spot

Limited to the activity of radioactive sources and moderator efficiency, the slow positron beam has very low current ($\sim10^{-14}$ A) and can not be observed by ZnS phosphor screen. A micro channel plate (MCP) is used to detect the slow positron beam spot. The principle is that the positrons hitting into MCP will induce multiplied secondary electrons (gain: 10^7), the image of secondary electrons on the ZnS phosphor screen indirectly reflects the positron beam size and position. A weak brightness beam spot was observed through the viewport in the experiment, which has a diameter of $\Phi10$.

1) 1 Gs = 10^{-4}T

3.3 Beam intensity and moderator efficiency

The slow positrons annihilate in samples and γ rays are emitted in 2π solid angle, which is similar to the annihilation of fast positrons from radioactive source in samples. The slow positron beam intensity can be concluded from the contrast between the amplitude of PMT signal induced by a ^{22}Na radioactive source which has known intensity and that induced by the slow positron beam at the same distance away from the source.

As shown in Fig. 3, a plastic scintillator detector is used to detect γ rays that have high detecting efficiency, and an optical conductor is installed between the plastic scintillator detector and the PMT to keep the PMT away from the helmholtz coils considering the magnetic shield of the PMT. The signal from the tenth dynode of PMT is converted to an exponential decay pulse through an integrator, at last the signal amplitude could be read from the oscilloscope, which is directly proportional to the intensity of γ rays.

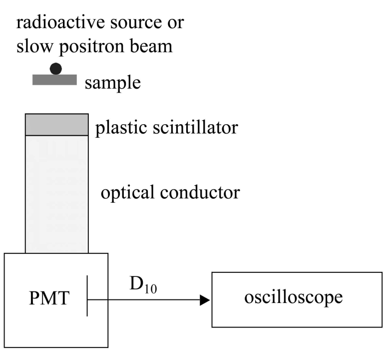

Fig. 3. Physical principle of the beam intensity measurement.

The activity of ^{22}Na radioactive source is 1.3 μCi and the intensity of positrons produced per second is: $1.3\times10^{-6}\times3.7\times10^{10}=4.8\times10^{4}$ e^{+}/s. The ^{22}Na radioactive source emits a 1.28 MeV γ ray simultaneously with a positron per decay, so the amplitude of PMT signal induced by a ^{22}Na comes from the contribution of 511 keV γ rays (annihilated positrons) and 1.28 MeV γ rays, which is much different to that induced by slow positron beam. The product of the total amplitude and 44% is the contribution of 511 keV γ rays.

The amplitudes of PMT signal induced by a ^{22}Na or slow positron beam at different distances away from the source are shown in Table 1, d/cm is the distance from the plastic scintillator to the positron sources, V_{c1}/mV is the amplitude of 511 keV γ rays induced by a ^{22}Na, and V_{c2}/mV is the amplitude of 511 keV γ rays induced by slow positron beam. Then the slow positron beam intensity N (10^4 e$^+$/s) at a certain distance can be solved from Eq. (1), that is:

$$N=4.8\times10^{4}\times V_{c2}/V_{c1}\,. \tag{1}$$

V_{c1} and V_{c2} are amplitudes at the same distance d in Eq. (1), so the beam intensity could be the mean value of N at different distances in Table 1, which is about 1.8×10^{5} e^{+}/s.

Table 1. Amplitude of PMT signal induced by ^{22}Na radioactive source or slow positron beam at different distances.

d/cm	V_{c1}(^{22}Na)	V_{c2}(slow e$^+$)	N (slow e$^+$)
5	12.54	47	17.99
6	9.24	35	18.18
7	7.48	28	17.97
8	6.16	23	17.92
9	5.39	20	17.81
10	4.69	18	18.44
11	3.92	15	18.39
12	3.56	14	18.86

In the plugged-in ^{22}Na based slow positron beam facility, the moderator efficiency n can be expressed as:

Intensity of ^{22}Na radioactive source (1.93×10^{9} e^{+}/s) $\times$ geometrical efficiency of ^{22}Na (39%) $\times n\times$ transmission efficiency of grid (88%) $\times$ beam transport efficiency (95%) $\times$ transmission efficiency of meshes in the chopper (68%)= intensity of slow positron beam (1.8×10^{5} e^{+}/s).

The moderator efficiency n can be determined by this formula, which is 4.2×10^{-4}, and relatively high moderator efficiency is due to the anneal of tungsten meshes at 1623 K under high vacuum.

3.4 Beam position adjustment

During the long-distance beam transport to the sample chamber, slow positrons may drift away from the axis of the vacuum tube and some of them or all can not reach the sample due to the geomagnetic field and other disordered magnetic fields. A pair of cosine coils mounted around the vacuum tube produce uniform magnetic field and compensate for the offset of slow positron beam position, as shown is Fig. 4. Slow positrons move along the direction of the resultant magnetic field $\boldsymbol{B}$ of the beam guidance magnetic field $\boldsymbol{B}_0$ and the adjusting magnetic field $\boldsymbol{B}_y$ in cosine coils, then the positrons come back to the axis of the vacuum tube.

The adjusting distance D of slow positron beam is directly proportional to the current I in cosine coils. If the current I is too small or too big, some positrons annihilate in vacuum tubes and will not reach the sample, so the signal amplitude of PMT behind the sample will become lower. As shown in Fig. 5, when the current I in cosine coils is between 0.3 A and 0.7 A, there is a peak interval of the signal amplitude, so the middle value of current I at peak interval is the best value that all positrons just reach the sample on the axis of the sample chamber, which is 0.5 A.

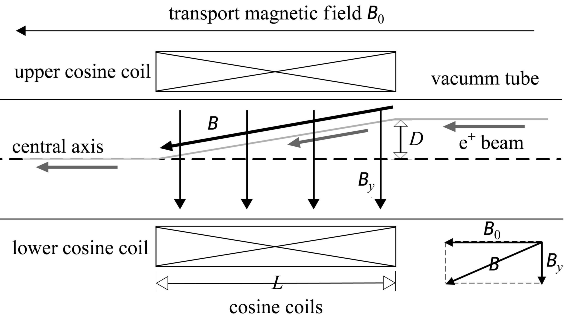

Fig. 4. Schematic of the slow positron beam position adjusting.

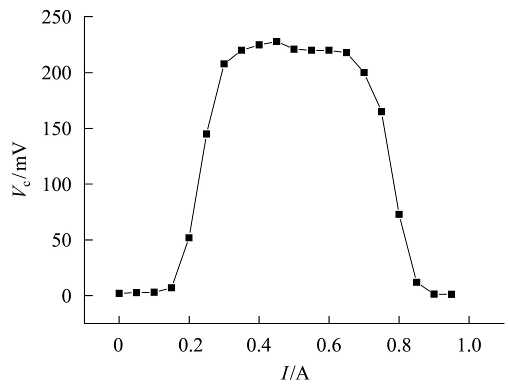

Fig. 5. Amplitude of PMT signal along with the change of current I in cosine coils.

3.5 Beam energy spread

The variable mono-energetic positron beam in labs often has definite energy spread (ΔE), some slow positron beam techniques such as positron lifetime experiments with the pulsed positron beam need smaller beam energy spread[4]. A retarding electric potential analyzer is used to measure the energy distribution of slow positron beam and the energy spread is the value of FWHM in the curve of energy distribution.

As seen in Fig. 6, the peak value of slow positron energy is 178 eV and the low energy positrons have relatively high proportion in the energy distribution. The beam energy spread ΔE is about 3.3 eV, which is mainly due to the natural energy spread (work function) in the moderator and the accelerating process between the moderator and the grid.

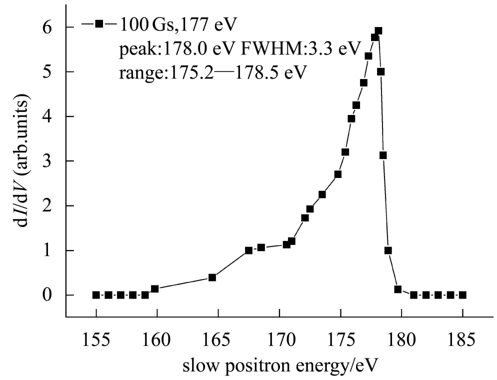

Fig. 6. Energy distribution of the slow positron beam measured by a retarding analyzer.

4 Conclusions

The plugged-in ^{22}Na based slow positron beam facility has been successfully constructed and tested.The electron beam simulated testing shows that the beam transport efficiency is 95%, the beam diameter is about $\Phi 10$ observed by MCP, the slow positron beam intensity in the sample chamber reaches 1.8×10^5 e^+/s and the moderator efficiency is 4.2×10^{-4}, the appropriate current parameter for cosine coils which is used to adjust the beam position is 0.5 A, and the beam energy spread is 3.3 eV at 178 eV positron energy. Performance testing result shows that the plugged-in ^{22}Na based slow positron beam facility has realized the design goal. Now it is running stably and supplying beam for the slow positron beam lifetime measurement of polymer samples.

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