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Conceptual design of an intense positron source based on an LIA

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Abstract: Accelerator based positron sources are widely used due to their high intensity. Most of these accelerators are RF accelerators. An LIA (linear induction accelerator) is a kind of high current pulsed accelerator used for radiography. A conceptual design of an intense pulsed positron source based on an LIA is presented in the paper. One advantage of an LIA is its pulsed power being higher than conventional accelerators, which means a higher amount of primary electrons for positron generations per pulse. Another advantage of an LIA is that it is very suitable to decelerate the positron bunch generated by bremsstrahlung pair process due to its ability to adjustably shape the voltage pulse. By implementing LIA cavities to decelerate the positron bunch before it is moderated, the positron yield could be greatly increased. These features may make the LIA based positron source become a high intensity pulsed positron source.

Key words: positron source, slow positron, moderator, linear induction accelerator

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1 Introduction

Slow positrons are widely used in many fields such as materials science. They may be produced by moderating the fast positrons from a radioactive source or from a bremsstrahlung-pair effect to thermal energies [1, 2]. The latter effect is usually based on an electron accelerator. Traditionally, RF or electrostatic high voltage accelerators are used. Pursuing higher intensity of the positron yield is one of the goals. The purpose of this paper is to present a new intense pulsed positron design based on another kind of accelerator, the LIA (linear induction accelerator), which has more higher pulsed power than others.

A brief introduction to the LIA is presented in Section 2. A composite slowing technique is discussed in Section 3, which may increase the positron yield more than conventional techniques. Then the conceptual design of a positron source based on an LIA is presented. This new source has the potential to be the highest pulsed positron source.

2 Brief introduction to an LIA [3]

An LIA is mainly used to generate pulsed high-current electron beams from several kA up to tens of kA, with the energy from several MeV to tens of MeV. The beam pulse width ranges from tens of nanoseconds to several microseconds. There could be 10^{15}–10^{16} electrons in one single pulse to produce intense positrons. The high charge per pulse is the first merit of an LIA that has been selected here.

To some extent, an LIA works like a transformer. The electron beam could be regarded as a single turn secondary with multiple parallel primary inputs from high-voltage modulators. Each cavity acts as a 1:1 transformer. A schematic describing how it works is shown in Fig. 1. A modulator supplies a voltage pulse of magnitude V_0 into the cavity. The ferromagnetic core is activated to generate magnetic flux in the azimuthal direction. This varying magnetic field could induce an axial electrical field to accelerate charged particles. The wave shape of the induced voltage is mainly determined by the output of the modulator.

3 Composite slowing down technique

The conventional slowing down process of the position source is to use a moderator to slow the fast

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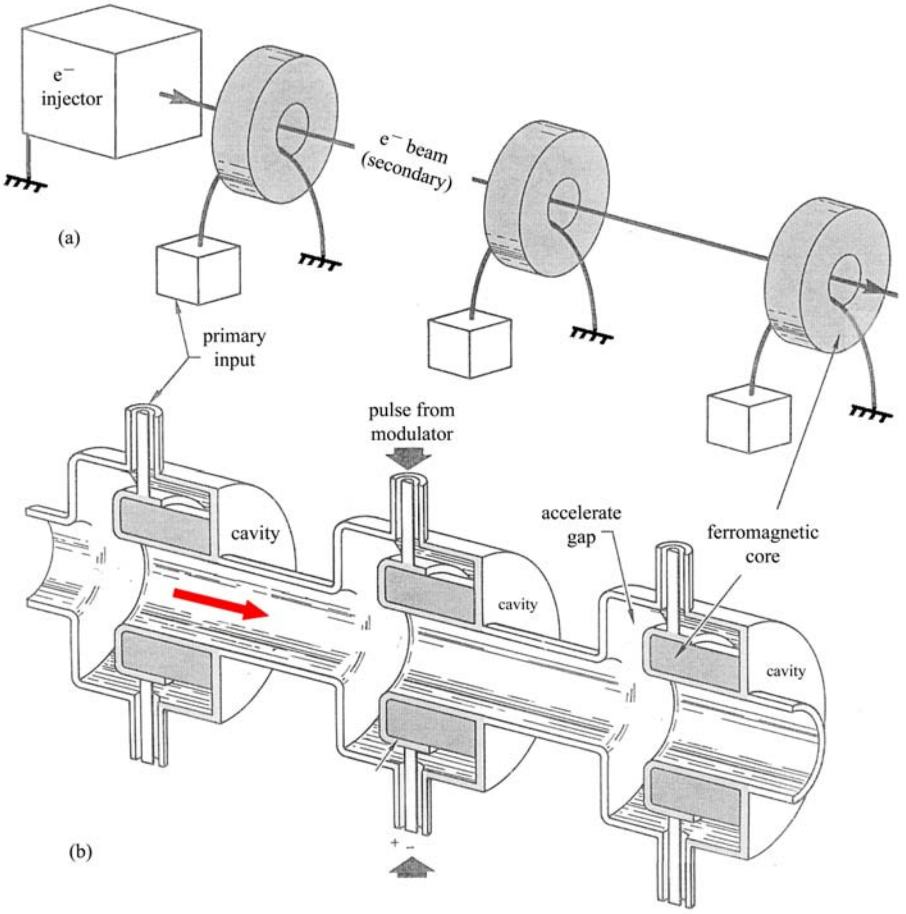

Fig. 1. Illustration of the LIA working principle.

positrons down to thermal positrons. However it is a process that features high loss. Most of the fast positrons will be lost by annihilation before they come out of the moderator. In principle, the slow positron yields could be increased if we could increase its surviving rate in the moderator by reducing its path or time in the moderator. But the path is unchangeable due to a fact that the stopping power of the moderator is an inherent feature of the material. So one solution is to remove part of the energy of the fast positron before it enters the moderator, which could result in a shortened path length in the moderator. Calculations from JAERI show that the amount of thermal positron depends on the thickness of the moderator and the energy of the incident positrons. When the energy of the incident positrons equals 1, 2, 3, 4 and 5 MeV, separately, the relative yield of thermal positron is 0.472, 0.213, 0.0575, 0.0186 and 0.0161 in series [4]. So the slow positron yield may be greatly increased by softening the energy spectrum of the incident positrons.

Another benefit of decreasing the fast positions is that if the average energy of the positrons is reduced down to 100 keV or lower, then the positron bunch could be injected into alternative positron cooling devices, such as a Penning trap, which has much higher slow positron yield than the moderators.

Naturally, an accelerator may be used to decelerate the fast positrons if the phase or polarity of its electrical field is inversed from the state which speeds the charged particles. This idea was given by C. Jonah and S. Chemerisov [5, 6]. The RF cavity has been studied by them to decelerate the fast positron beam, showing that it could increase the positron yield by 2–3 orders of magnitude [7]. At the same time, it is found the RF cavity could only decelerate a small fraction of the beam bunch effectively due to its time-dependent feature. Because the positrons are the products of a photon-pair process, its energy spectrum is a continuous spectrum like the bremsstrahlung photon spectrum. So the positron bunch has a large energy spread and a wide scattering angle. As is known, only particles with a certain energy and that enter the RF cavity at a corresponding time can be decelerated or accelerated effectively, which are called synchronized with RF field. So the two features of the positron bunch make it hard for an RF cavity to select synchronized particles, causing the RF cavity here to have very small acceptance.

Electrostatic gap has much larger acceptance than an RF cavity because all the charged particles could be decelerated in the same way in the gap. A major problem in electrostatic accelerators is how to control and supply power to the particle source due to the high potential with respect to the laboratory. Another constraint is its low beam current. So an electrostatic accelerator is not suitable to handle the high current positron beam with high average energy either.

4 Advantages of the LIA for slowing techniques

Compared with others, the LIA has some advantages to decelerate the positron beam, which are summarized as follows.

1) High acceptance

During the beam pulsed lasting time, it works like electrostatic accelerator, resulting in high acceptance.

2) Beam transportation ability

An LIA is good at transporting a high current beam because of the strong axial magnetic field inside the cavities. The field could also be very favorable to transporting a positron bunch with bad beam quality.

3) Ability to handle high energy positrons

In principle, there is no energy limitation for accelerating or decelerating a charged particle in an LIA. The high change of particle energy can be gained by adding the cavities in series, expressed by Eq. (1).

$$E_{\mathrm{o}} = E_{\mathrm{i}} + n \cdot qV_{\mathrm{cell}}, \qquad (1)$$

where V_{cell} is the voltage in a single cavity, E_{i} and E_{o} are the initial energy and final energy of the charged particles.

4) The shape of the cavity voltage is adjustable

While softening the energy spectrum of positron bunch, reducing the energy spread is favored. To fulfill this purpose, the shape of the decelerating voltage should correlate to the energy of incident positrons. The required voltage shape depends on the energy distribution of the positron bunch and its travelling path length. For an RF cavity, its resonant cavity could not produce an arbitrary function of E-field. While in the case of an LIA, the wave shape of the induced voltage is mainly determined by the output of the power modulator. It means that an arbitrary voltage function can be obtained if the power source could offer it. An alternative solution is based on Eq. (1), which means that multiple voltage functions could be added together to form a new function, similar to series expansion. Right now, this kind of feature of an LIA is being studied to compress the ion beam longitudinally in the field of high energy density physics.

These above features make an LIA become a good candidate to implement the composite slowing down techniques.

5 A conceptual design based on an LIA

A conceptual design is given in Fig. 2. The electron beam pulse from the LIA enters a convert target to generate a positron pulse. An AMD (adiabatic matching device [8]) is used to modulate the phase space distribution of the positron bunch. Inside the AMD there is a tapering axial magnetic field which could shift part of the transverse momentum of the positrons to its longitudinal direction. The beam spot size will increase in this process.

In order to correlate the positron energy with the time when it arrives at the decelerating gap, a drifting tube is necessary. The positron bunch will expand longitudinally. The higher energy positron will arrive earlier and the lower one will be later. Strictly speaking, it is the longitudinal momentum of the positron collating with the arriving time not the energy. That is why an AMD is applied to shift the phase space distribution of the bunch.

The decelerating unit is composed of three induction cavities. The inner hollow metal tube inside the cavities plays three roles: a transmission line to transmit voltage pulse, a drifting tube and the low potential part of the decelerating gap. The tapering shape of the tube is designed to meet the impedance matching requirement. This step-up cavities design is commonly used for high-voltage electron beam injectors in the LIA field.

6 Intensity estimation of the pulsed positron source

The intensity of this kind of positron source is estimated roughly based on the data of KEK [7] and the benefit from the composite slowing down technique. The relevant parameters are listed in Table 1. According to the electron charge amount pulse or second of each accelerators, as well as taking into account the 2–3 order yield increase contributed from the slow technique and the energy difference of each case the

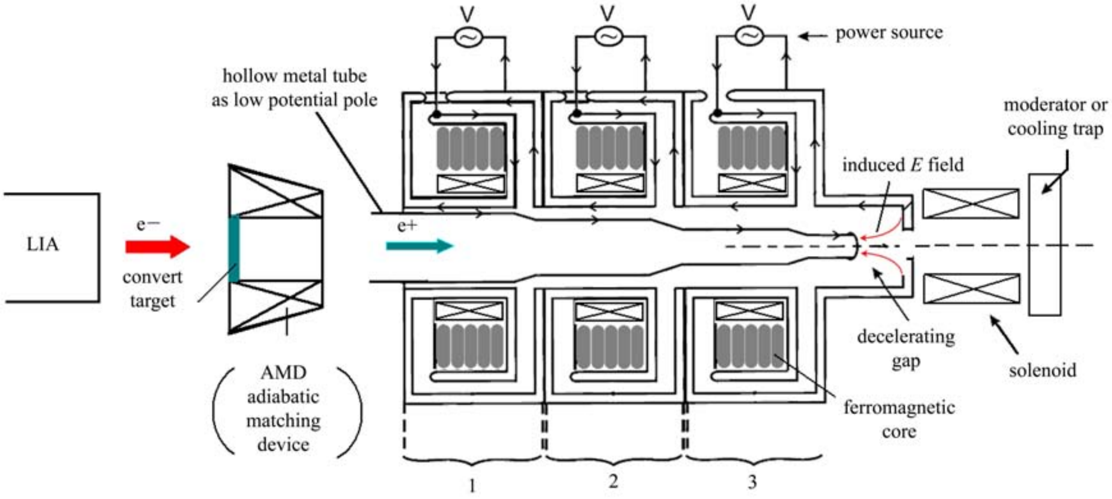

Fig. 2. A conceptual design schematic of pulsed positron source based on an LIA.

Table 1. Parameters comparison of two kinds of accelerator-based positron sources.

equipment	e^- current/A	e^- energy/MeV	pulse width FWHM/ns	number of pusles	charge/μC	yield of e^+
KEK	2	50	20	50/s	2/s	10^7/s
KEK	0.4	25	2000	50/s	40/s	10^8/s
12 MeV LIA*	2500	12	60	burst	150/p	10^8–10^{10}/p
DARHT-II LIA [9]	2000	18	1.6	burst	3200/p	10^9–10^{12}/p

∗12 MeV LIA is in the China Academy of Engineering Physics.

positron source of the LIA may reach 10^8–10^{12}/p, which is higher than most present sources.

7 Conclusion

The LIA could be a good candidate dedicated to accelerator based positron source. Our analysis shows this kind of source could reach 10^8–10^{12}/p which is a high pulsed intensity value. Its average intensity is pretty low, because it works in burst mode. The interval time of two shots is longer than minutes. So its application may be constrained in some special cases which need high pulsed intensity more than continuous yields. By developing a repetition technique on the power source of an LIA or using Penning-trap storage techniques, the average intensity of this source could be greatly increased. So we hope this new kind of positron source could meet some needs of positron study projects. If so, the retired 12 MeV LIA of CAEP could be remodeled for dedicated positron study.

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