PRESENT STATUS OF DESIGN STUDY FOR THE POSITRON FACTORY

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Abstract

We performed a conceptual design of an electron linac of 100 kW class with a beam energy of around 100 MeV to produce intense monoenergetic positron beams for the "Positron Factory". We proposed a new target system which consists of a "self-driven rotating converter" suitable for the high power beam and "multi-channel moderator assemblies" to supply multiple slow positron beams simultaneously.

Introduction

We have been promoting design studies for the "Positron Factory"[1], in which linac-based intense monoenergetic positron beams are planned to be applied to advanced materials characterization and new fields of basic research. A tentative goal of the slow (i.e. monoenergetic) positron beam intensity is 10^{10}/sec. In this report, the results of the investigation on an electron linac and a target system which is composed of an electron to positron converter and a positron moderator are described.

Design Study

Linac

We calculated energy and angular distributions *F(E, θ)* of energetic positrons ejected from tantalum converters of various thicknesses, onto which electron beams with wide range of energies are injected, by using an electromagnetic cascade shower Monte Carlo code EGS4[2]. Fig.1 shows the calculated relationship between the incident electron energy onto the converter and the energetic positron yield from the converter. Here the electron beam power is 100 kW for every electron energy (e.g. 1 mA at 100 MeV), and the tantalum thicknesses are selected to be optimum for respective electron energies. The production efficiency of the energetic positrons with energies below 10 MeV and with ejection angles of less than 20°, which are available to generate slow positrons, was maximum at the electron energy of about 100 MeV. A conservative estimate using this result and the empirical data showed that the aimed slow positron beam intensity could be attained with a linac of 100 kW class with a beam energy of around 100 to 150 MeV, combined with a conventional target system.

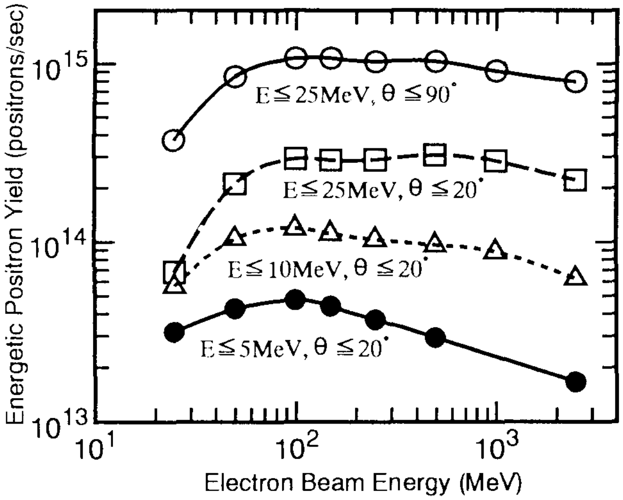
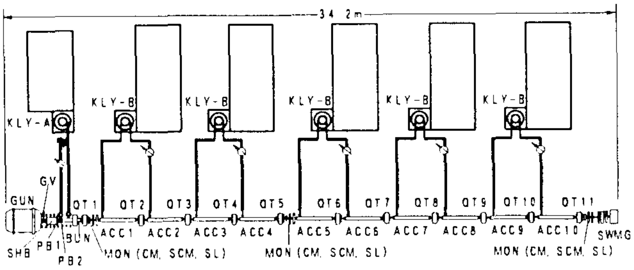


Fig.1 Relationship between the incident electron energy onto the tantalum converter and the energetic positron yield from the converter, calculated with EGS4. E and θ are the positron ejection energy and angle from the converter, respectively. The electron beam power is 100 kW for every beam energy.

Such a high power linac does not exist at present in the world. We performed a technical survey study on the dedicated linac, in cooperation with four linac manufacturers. The S-band travelling wave (TW), L-band TW and L-band standing wave (SW) types were proposed. Combination of established technologies for components such as an electron gun, klystrons and accelerator structures was investigated, which confirmed the technical feasibility of manufacturing the state-of-the-art linac of each type. Further detailed analyses were carried out concerning thermal deformation of the accelerator structures, beam instability, reliability of the components, down-sizing of the machine and a computer-aided control system. An example of the conceptual design is shown in Fig.2.



KLY (KLYSTRON) -A : 5MW (peak), 8. 5kW (av.), 2856MHz
KLY (KLYSTRON) -B : 20MW (peak), 45kW (av.), 2856MHz
GUN : ELECTRON INJECTION GUN   GV : GATE VALVE   SHB : SUB-HARMONIC BUNCHER
PB : PRE-BUNCHER   BUN : BUNCHER   MON : MONITOR   CM : CURRENT MONITOR
SCM : SCREEN MONITOR   SL : SLIT   QT : TRIPLET QUADROPOLE MAGNET
ACC : ACCELERATION TUBE   SWMG : SWITCHING MAGNET

Fig.2 An example of the conceptual design of the high-power electron linac.
[Normal Operation Mode]
Max. Energy: 150 MeV, Max. Current: 0.67 mA (av.)
Max. Power: 100 kW (av.) at 150 MeV
Pulse Width: 2 μs, Repetition: 750 pps
[Single Bunch Mode]
Pulse Width: 30 ps, Max. Charge: 5 nC/pulse

Electron to Positron Converter

We evaluated the energy deposition from a 100 MeV electron beam to a tantalum converter of 8.2 mm in thickness, with EGS4. The thickness is optimum for the electron energy. The total deposited power was about 38 kW, when the electron beam current was 1 mA. It was concluded from a thermal analysis with a finite elements method that a usual water-cooled converter might melt down.

To avoid this, it is essential to divide and rotate the converter. Under the strong radiation field, however, a motor and a rotating penetration are not available due to the irradiation degradation. We devised a "self-driven rotating converter" as shown in Fig.3(a). In this converter, the water has functions both for driving force and lubricating material, combined with pivot-type axles and bearings, in addition to cooling.

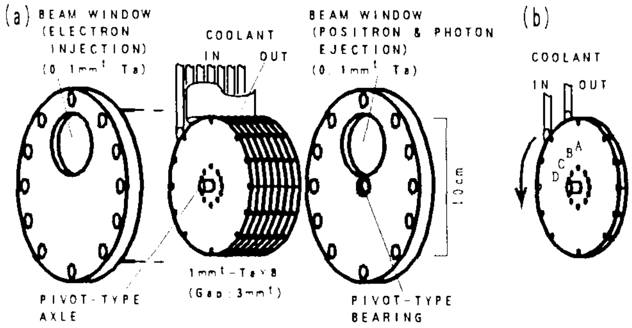


Fig.3 A concept of the self-driven rotating converter (a) and the pilot device for testing (b).

We calculated again the power deposition on every divided part including cooling water layers which composes the structure in Fig.3(a). The maximum deposition was 5.1 kW on a tantalum disk of 1 mm in thickness. Therefore, an issue of the heat removal depends on whether the disk melts down or not by this maximum power. We carried out an irradiation test on a pilot device as shown in Fig.3(b), with a 3 MeV electron beam. The scale of the power deposition was about 1/10 of the above maximum value. The cooling water velocity was 470 cm/sec, and the revolution rate of the disk was about 300 rpm. No changes on the disk were observed after the irradiation. In addition to the irradiation test, we evaluated the temperature rise of the disk which is rotated at 300 rpm and is cooled by the water of 470 cm/sec in velocity, with a finite elements method. The power was assumed to be deposited with a spread of 10 mmϕ. The result is shown in Fig.4. Even the maximum saturated temperature at the beam spot was sufficiently lower than a melting point of tantalum (2996 ℃). Furthermore, we carried out a mechanical performance test of the pilot device for three months. The disk was rotated continuously, and no abrasion of the axles and the bearings was observed after the test.

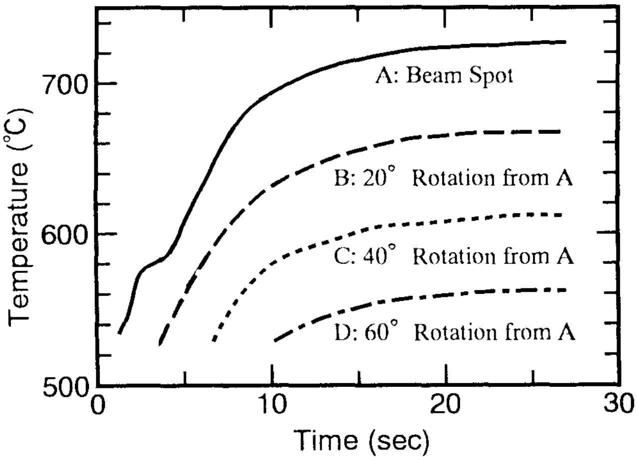


Fig.4 Temperature rise of a tantalum disk composing the self-driven rotating converter, calculated with a finite elements method. The maximum power (5.1 kW) is deposited on the disk by a 100 kW electron beam with a beam energy of 100 MeV. The power is centered at the point A with a spread of 10 mmϕ. The points indicated by A, B, C and D are identical to those in Fig.3 (b).

It was concluded from the above results that the feasibility of the "self-driven rotating converter" was confirmed.

Positron Moderator

In linac-based slow positron beam production, not only energetic positrons but also energetic photons are injected from a converter to a moderator assembly. Pair production reactions as well as slowing down processes of positrons occur in the moderator. The EGS4 is applicable to simulate higher energy processes, like pair production, than a few tens of keV. We[1] have developed a Monte Carlo code, which we call SPG (Slow Positron Generation). The SPG can trace lower energy positron reactions i.e. thermalization, diffusion, annihilation and emission as slow positrons. We developed a new Monte Carlo simulation system by combining the above two codes. It made it possible to trace the 3-dimensional positron motion from the birth by pair production to the rebirth as slow positrons. With the new simulation system, we compared contributions of energetic positrons and photons from the converter to generate slow positrons, as mentioned below.

By using EGS4, we calculated energy and angular distributions, $F_p(E_p, \theta_p)$ for energetic positrons and $F_\gamma(E_\gamma, \theta_\gamma)$ for energetic photons, from a tantalum converter of 8.2 mm in thickness, onto which a 100 MeV electron beam is injected. We also evaluated, with EGS4-SPG, partial slow positron yields, $y_p(E_p, \theta_p)$ from the energetic positrons and $y_\gamma(E_\gamma, \theta_\gamma)$ from the energetic photons. The yield is the ratio of the number of slow positrons emitted from the moderator to that of incident positrons or photons. The moderator was assumed to consist of three tungsten moderator assemblies sequentially set up as shown in Fig.5(a). Each assembly is composed of 10 tungsten foils of

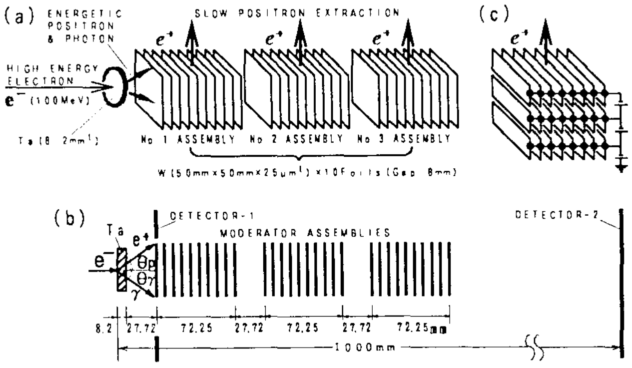


Fig.5 A concept of the simultaneous multi-channel extraction of slow positron beams by multiple moderator assemblies (a), the sectional view to indicate dimensions for the Monte Carlo simulation (b) and a moderator assembly used for actual experiments (c).

50 mm in width, 50 mm in height and 25 μm in thickness. There is a certain distance (about 3 cm) between the converter and the first moderator assembly and also between each assembly, taking a width of a flange into account.

The overall slow positron yields were calculated with the following equations.

$$Y_p=\int y_pF_pdE_pd\theta_p \quad ; \quad Y_\gamma=\int y_\gamma F_\gamma dE_\gamma d\theta_\gamma \qquad (1)$$

The value Y_p is, for example, the ratio of the number of slow positrons emitted from each moderator assembly originated from energetic positrons from the converter, to that of incident electrons onto the converter. The result is shown in TABLE 1. The upper values in the table were estimated based on the energy and angular distribution of ejected particles from the converter, which were calculated at the position of "detector-1" indicated in Fig.5(b). The lower ones (in parenthesis) were obtained with "detector-2". The θ value, in the angular distribution of energetic particles ejected from the converter, was determined as an angle between the electron beam axis and a straight line from the electron injection point on the converter to the detected point of the ejected particle at the detector. The actual ejection angle is somewhat different from the θ value. The difference is smaller in the case of "detector-2", which is located far from the converter. With "detector-2", however, the θ values of some particles are estimated to be too large for the particles to be injected onto the first moderator foil in the first assembly, whereas the trajectories of the particles actually cross the foil. This results in underestimate of the overall yield. The real yield may be between the two values evaluated by "detector-1" and "detector-2".

TABLE 1
Overall Slow Positron Yield (Slow Positrons / Electrons) Calculated with EGS4-SPG for a 100 MeV Electron Beam Bombardment onto the Target System shown in Fig.5

	1st Assembly	2nd Assembly	3rd Assembly
Contribution by Energetic Positrons	6.3×10^{-6} (7.2×10^{-7})	1.1×10^{-7} (6.7×10^{-9})	6.8×10^{-9} (3.8×10^{-10})
Contribution by Energetic Photons	1.7×10^{-5} (2.3×10^{-6})	8.5×10^{-6} (8.8×10^{-7})	4.5×10^{-6} (4.9×10^{-8})

Upper: Estimated by Detector-1
Lower(in parenthesis): Estimated by Detector-2

The slow positron yield contributed by the energetic positrons ejected from the converter drastically decreased at the assemblies distant from the converter. From tracking of particles as shown in Fig.6, it was deduced that this is caused by spatial spread of the positron beam. On the contrary, there still were sufficient slow positron yields even at the rear assemblies, in the case of the energetic photon contribution. This is because the photons go almost straightforward and cause pair production reactions uniformly in every assembly. Thus produced positrons have comparatively lower energies, which results in higher probabilities to be thermalized in any moderator foil.

The above result suggests a possibility to extract multi-channel slow positron beams simultaneously from multiple moderator assemblies as shown in Fig.5, where photons play an important role in generating slow positrons especially at the rear assemblies.

A demonstrative experiment concerning the multi-channel slow positron beam extraction is in progress, using an electron linac. In the experiment, moderator assemblies with a structure as shown in Fig.5(c) are used. Each moderator foil is divided into several parts, electrically separated and biased to drift emitted slow positrons by sloping the electric field toward the extraction direction.

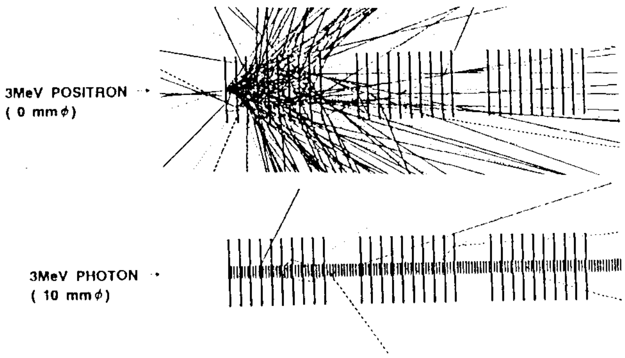


Fig.6 Sectional views of particles' trackings calculated with EGS4-SPG for 3 MeV positrons and 3 MeV photons injected perpendicularly onto the moderator assemblies shown in Fig.5.
solid line: positron, dotted line: photon,
broken line: electron

Conclusion

We performed a conceptual design of a state-of-the-art electron linac of 100 kW class with a beam energy of 100 to 150 MeV, which can produce an intense slow positron beam of more than 10^{10}/sec in intensity. The feasibility of a "self-driven rotating converter" suitable for the high power beam was confirmed by the performance tests and the thermal analysis. We evaluated slow positron yields from "multi-channel moderator assemblies" with a newly developed Monte Carlo simulation system, which suggests a possibility to extract multiple slow positron beams simultaneously.

References

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[2] W.R.Nelson, H.Hirayama, and D.W.O.Rogers, The EGS4 code system, SLAC report-265 (1985)