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Slow Positron Target Concepts for the Advanced Photon Source (APS) Linear Accelerator

M. White and E. Lessner
Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439-4800 USA

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Abstract The APS linear accelerator (linac) system [1,2] consists of a 200-MeV, 2856-MHz S-band electron linac, followed by a 450-MeV positron linac. The linac is available for other uses upon completion of the storage ring injection cycle. Nominal linac beam power is 480 W but the power can be increased substantially, making it suitable for production of slow positrons. Simulation studies for the design of a slow-positron target-moderator system that is optimized for operation with the APS linac are presented. Results of simulations of various target configurations indicate that a suitably designed multilayer target can result in a higher positron yield than a single-block target. Use of an integrated, multilayer target moderator is suggested. Some possibilities for extracting slow positrons between target layers by means of electromagnetic fields are discussed. First results from recent accelerator studies aimed at increasing the linac beam power are also presented.

1 Introduction

Slow positrons are valuable tools in atomic physics, materials science, and solid state physics research. They can be used to probe defects in metals, to study Fermi surfaces and material surfaces and interfaces, and to obtain detailed information about the electronic structure of materials. Positrons can be used to obtain information complementary to that obtained by other means. Slow positrons are emitted by some radioactive sources and can also be obtained by moderating the positrons produced by bremsstrahlung when an accelerator beam hits a high-Z target. In our case, an intense electron beam impinges on a tungsten target. The fast positrons are then moderated by a series of foils with a negative work-function for positrons. Positrons emitted from the moderator are captured and transported to an experimental area by electromagnetic fields. The number of positrons that can be delivered to an experiment is a function of the incident accelerator beam power, the target material and geometry, moderator efficiency, and the capture and transport efficiency.

Some initial concepts for the design of a target that is optimized for slow-positron production are discussed, and simulation results are presented. We compare the positron yield obtained from simulations of various target configurations for a fixed beam power and energy. Our integrated target-moderator concept, when combined with an efficient extraction and transport system, can result in a high-intensity slow positron source.

The APS linac beam could be used to produce slow positrons during the hours between storage ring injection cycles or top-up operations. The linac as well as results of the first beam tests aimed at increasing the beam power are briefly described.

2 Simulations

Computer simulations of several target configurations were performed using the electromagnetic shower code EGS4 [3], in order to optimize the target-moderator design parameters. In the simulations, a pencil beam of electrons was incident perpendicular to the basis of a tungsten cylinder. The beam power was fixed at 800 W and the incident electron energy was 400 MeV. We

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examined the positron yield from single-layer targets and multiple-layer targets of varying layer thicknesses. Energy distributions and divergences of all shower products were analyzed in each case.

Simulations of single-layer target geometries indicate that a tungsten target that is three radiation lengths (Xo) thick (10.5 mm thick) results in the highest positron yield. However, for the same incident beam power and energy, the total positron yield from segmented targets can be significantly higher. The total yield of positrons with energies up to 6 MeV is shown in Figure 1(a). The yields in the figure are calculated per incident electron and are shown for the optimized single-layer, 3-Xo-thick target and for the optimized five-layer target.

In Figure 1(b) we show positron production by each segment of the five-layer target. The yield per incoming 400-MeV electron increases from 0.14 positrons per electron after the first segment to 0.30 after the fourth segment and decreases slightly to 0.24 after the last segment. Contributions from backscattered positrons are negligible and are not included in this estimate. Using the numbers above and assuming an average moderator reemission efficiency of 10^{-2} [4], we estimate a total slow positron yield from the target of roughly 10^{10} positrons per second. The final slow positron current at the experiment will be much less due to capture and transport inefficiencies.

The efficiency of slow positron production depends strongly on the target-moderator geometry. We are developing an integrated tungsten-based target-moderator concept in which the moderator "foils" are an integral part of the target. Our concept uses the electrical discharge machining (EDM) process to machine foils into the target in a simple and straightforward way, thus reducing the manufacturing and handling difficulties. We demonstrated that foil thicknesses ≥ 100 μm can be achieved, and we are refining our techniques. The reemission percentage of low-energy positrons would be higher if we used thinner foils, but very thin foils are difficult to produce and to handle.

The separation between foils must be optimized for maximum efficiency while still allowing penetration of the electromagnetic extraction fields. We incorporated effects of the electrical extraction fields into our computer simulation, and preliminary tests of the code have been performed. We are also considering extraction by a pulsed septum-magnet-type device that permits on-line energy selection. We have not yet simulated the actual moderating process.

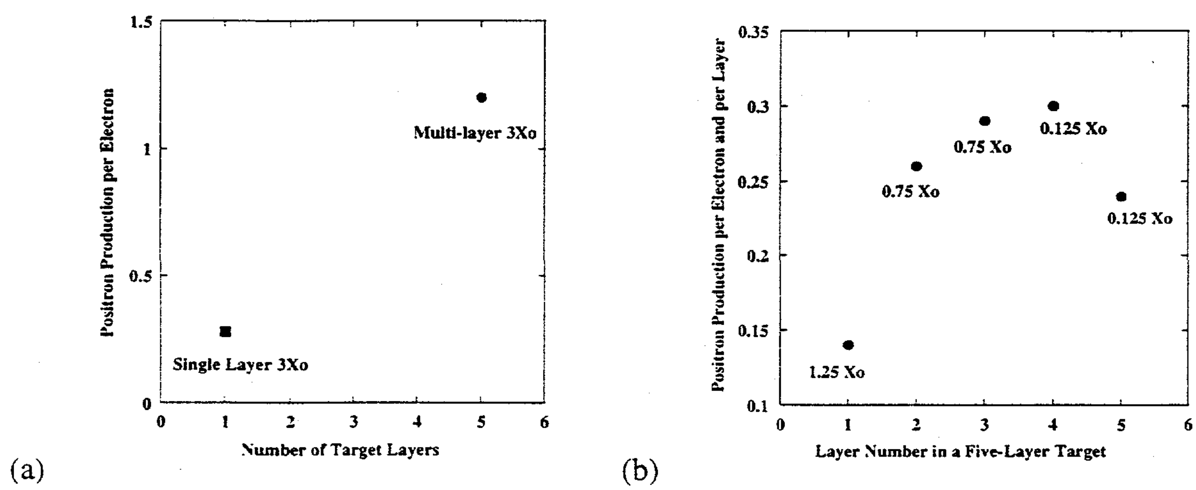

Figure 1: (a) Production, per 400-MeV e^-, of e^+ in the energy range $0 < E_{e^+} \leq 6$ MeV, by a single-segment 3-Xo-thick target and by a five-segment target of the same total effective length and (b) Positron production downstream of each target segment of the optimized five-layer target.

3 Beam Measurements

The APS electron linac normally accelerates 30-ns-long pulses containing 50 nC of charge to an energy of 220 MeV with a total beam power of about 500 W. The nominal beam power can be increased for slow positron production purposes by increasing the pulse length and the effective repetition rate. A special pulser card, capable of producing several-μs-long pulses, was used in preliminary tests. The 4-μs-long gun pulse droops, as can be seen in Figure 2(a), thus pulse flattening is planned. Figure 2(b) shows the 4-μs-long accelerated pulse as measured by a bandwidth-limited current monitor designed for measurement of short pulses. Beam loading from a 1-A peak current, 4-μs-long pulse is shown in Figure 3. The 4-μs-long beam pulse can be accelerated within the 5-μs-long radiofrequency (rf) pulse. The beam was accelerated to about 40 MeV using only the first accelerating structure in the linac. We estimate that a linac beam power of 25-50kW is achievable, but accelerator studies are ongoing and the estimates will be refined.

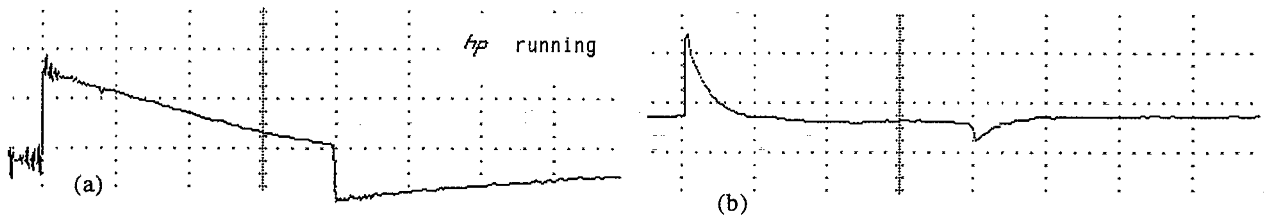

Figure 2: (a) The 1-A peak, 4-μs-long, gun pulse. Pulse flattening is planned. (b) The start and end of the 4-μs-long, 40-MeV accelerated beam pulse is shown using a bandwidth-limited current monitor designed only for short beam pulses.

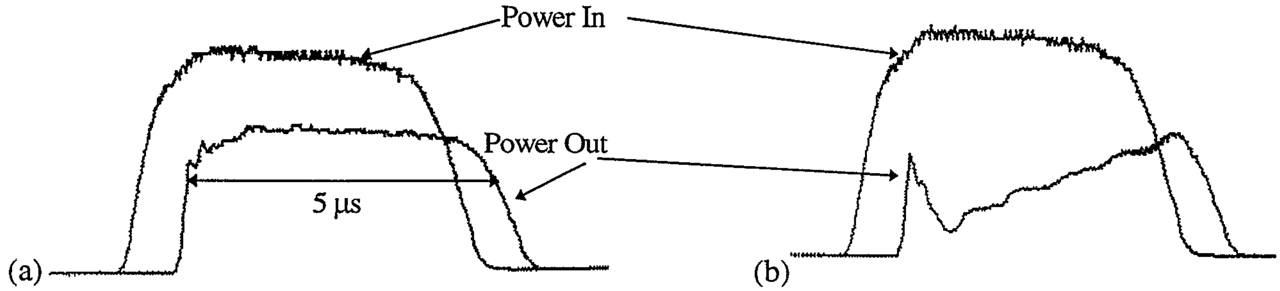

Figure 3: The upper trace is the 5-μs-long rf input to the accelerating structure. The lower trace is the 5-μs-long output power with (a) no beam current and (b) loaded by the 1-A peak, 4-μs-long beam.

4 Conclusions

Our studies indicate that the APS linac can be used to produce slow positrons. An integrated target-moderator concept is now being optimized by simulation studies, and concepts for the extraction and transport systems are being developed. Accelerator studies are in progress to determine the maximum achievable beam power, to optimize machine performance and beam properties. Accelerator simulations are also being carried out.

5 Acknowledgments

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6 References

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