POSITRON ACCELERATION IN THE FRASCATI 450 MeV LINEAR ACCELERATOR

F. Amman, R. Andreani
Laboratori Nazionali del CNEN, Frascati, Italy

and

J. Haimson, C. Nunan
Varian Associates, Palo Alto, California, USA

(presented by R. Andreani)

The Frascati Linear Accelerator built for the Consiglio Nazionale delle Ricerche by Varian Associates, Palo Alto, has been undergoing beam tests during the last four months in Frascati CNEN Laboratories.

This is a progress report which presents the first results achieved in the acceleration of positrons through the entire machine.

The Linac is made up of twelve sections: four low energy sections capable of accelerating 420 mA of electron beam to 65 MeV, and eight high energy sections capable of accelerating, together with the low energy ones, 100 mA of electron beam to 375 MeV.

The system for the positron production has already been described in detail (1, 2, 3).

It includes:

1) The target made of pure tungsten, one radiation length thick, ring shaped, water cooled and rotated at a speed of 120 rpm.

2) The short solenoid, extending 6.2 cm from the immersed target and run at 17,770 Gauss. The half cyclotron period for 10 MeV positrons is 6.2 cm.

3) The eight high energy sections. Each section is equipped with a full length solenoid producing a magnetic field of 2400 Gauss.

The positron beam produced by the machine is going to be used for "injection" into the Frascati Storage Ring - ADONE and for nuclear physics experiments. Useful beam current is then limited to an energy spread of $\pm$ 0.5% and an emittance of π x 1 mrad x cm.

Expected Results

The expected positron yield has been computed in Frascati using a Montecarlo method (4, 5). The calculation was based on some simplifying assumptions on the parameters of the positrons produced at the target.

1) Energy distribution: constant intensity within the range of interest of $\pm$ 2.5 MeV around the outer energy of 10 MeV.

2) Angular distribution: $\frac{dN}{d\Omega}$ = const.

3) Space distribution: Gaussian with an rms radius of 1.0 mm corresponding to an electron beam having an rms radius of 0.6 mm (98% of the current in 1 mm radius) on the target.

For computation purposes, the emitting area, considered on the target, was limited to 3 mm radius around the target centerline.

The electron beam bunch width was considered 8°.

The minimum iris radius is about 1 cm.

The positrons were considered ultra-relativistic; no bunching in section 5 was supposed to occur.

The positron yield was derived from the experimental results (6) obtained at Orsay, which give the positron density for small values of θ : $dN/dE d\Omega$ per $\theta = 0$. From the Orsay results, the following formula can be derived: assuming a uniform distribution in angles for the solid angle considered.

$$i_+ = 240 \left(1 - \frac{25}{V_-}\right) \times \Delta V_+ \times \Omega \times P \ (\mu A) \quad (1)$$

where: P - peak electron beam power on the Converter - Mw.

Ω - positron solid angle, sterad, accepted for acceleration.

ΔV_+ - positron energy spread accepted for acceleration.

This is valid for an electron energy range from 50 to 220 MeV, for a positron energy range from 10 to 15 MeV, converter thickness between 1 and 1.5 radiation length and for small Ω.

Of the current coming from the converter, only a certain fraction can be accepted by section 5 and accelerated, and a small percentage of this is within the useful limits of energy and angle at the end of the machine.

At 420 mA electron beam at 65 MeV on the target and 1 mm rms radius positron source, the total computed positron current at the accelerator output was 1250 μA, of which 610 μA was within π mrad x cm and $\pm$ 0.5% energy spread.

Later measurements performed at Stanford by H. De Staebler (7) with electrons at 1 BeV, positrons at energies between 6 and 14 MeV and a lead target 2.9 radiation length thick, give for the angular distribution a dependance of this kind:

$$\frac{dN}{d\Omega} = \left.\frac{dN}{d\Omega}\right|_{\theta = o} \times e^{-\frac{\theta}{\theta_o}}$$

with θ = 0.35 rad.

This would give a reduction factor of about 0.75 in our case if the same distribution applied for our lower energy and thinner target. Certainly a correction of some sort should be applied and we would expect it to be between 0.75 and 1.0.

The computation was done considering the case of a solenoid along the entire length of the machine. Therefore no loss of particles occurred in between sections. However, for simplicity in initial adjustment of the Linac, bridge coils were not installed between sections. Therefore, another correction factor has to be introduced in this calculation, due to the drift spaces free of magnetic field existing between sections. The percentage loss of particles due to each drift space decreases with increasing energy of the particles. Considering a positron energy of 320 MeV at the end of the machine (40 MeV per section), the loss has been calculated to amount to about 20% of the total positron current accelerated.

Summarizing these corrections, we would expect between 640 and 850 μA total current and between 310 and 415 μA useful current, depending on the angular distribution correction factor used at 320 MeV for 260 mA electron beam at 80 MeV at the target.

Experimental Results

First tests on positron production were performed at Varian's facility in March, 1965. Only one section after the converter was installed at that time. Using an electron beam of 260 mA at 80 MeV, the total positron current over the entire measurable energy spectrum was 1900 μA peak.

Tests in Frascati were performed on the entire machine. The problem of solenoid misalignment with respect to the sections was solved by mounting soft iron plates at the beginning and at the end of each section, concentric with it. The plates are centered on the Linac axis. This affects the fringing field configuration which tends to become centered with respect to the beam. The transverse magnetic field component, due to the solenoid being tilted with reference to the section centerline, is compensated using two steering fields per section.

Electron beam peak current used for conversion was 260 mA at 80 MeV.

The total current obtained at the end of Sect. 12 integrated over the range 291-333 MeV but within an acceptance of $\pi \times 10^{-3}$ rad x cm resulted in a peak of 930 μA over 3.2 μsec pulse width.

Positron current within 1% energy bin was 380 μA at 321 Mev.

The positron energy spectrum is given in Figure 1. The positron beam current was collected on a Faraday Cup and measured with an integrator. The beam pulse width was determined using a ferrite monitor and scope.

Comparison of Experimental Results and Computed Values

Table 1 presents normalised values of the theoretical computations and experimental results both in Palo Alto and in Frascati.

The computed values presented in the table have been subjected to corrections due to the field free spaces and angular distribution.

In order to compare Palo Alto results with Frascati, we have extrapolated the 1300 μA obtained at the end of Section #5 to the end of Section #12 using a factor 0.8 to account for the field free spaces.

We have then an expected current of 1520 μA at the end of the machine.

Both Palo Alto and Frascati total accelerated currents appear higher than the computed values and the Palo Alto current is larger than Frascati current by 64%.

Part of the difference between measured and computed positron currents may be due to capture and acceleration of particles emitted at energies below the 7.5 to 12.5 MeV range used in the computations.

For example, positrons emitted at 3 MeV make three half cyclotron revolutions in the short solenoid length and can be accepted within the accelerator aperture over an emission solid angle 9 times the design solid angle for 10 MeV positrons.

Such particles have a maximum phase delay of 58 degrees with respect to positrons at 10 MeV emitted along the axis. A good part of them can still be captured and accelerated.

This was noticed in Palo Alto where we could obtain a double peak on the current energy curve. The current in the lower energy peak was about 25% of the current in the higher energy peak.

We were able to vary the distance in energy of the two peaks and to eliminate either of them by adjusting the phase of the radiofrequency power supplied to the section. This clearly accounts for the bunching and capture process taking place in Section 5.

The remaining difference between Palo Alto measured current and computed current may be due to the yield being understated in eq. (1). If this were true, the constant of 240 in this equation would have to be increased by between 40% and 90% and improvement of as much as 64% in total current through the entire machine might be expected by further tuning of the machine.

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DISCUSSION

R. ANDREANI, Frascati

VOGEL, ANL: In your calculations it seems to matter what target materials you use in your comparison, how many collision lengths your target was measuring, and what the acceptance angle was of the focusing system you used, if you used such a system. Where does this formula apply? At the slit, I suppose.

ANDREANI: I didn't quite get the first part of your question. Can you give the first part?

VOGEL: What was the target material?

ANDREANI: The target material was tungsten.

VOGEL: How long was your target?

ANDREANI: One radiation length.

VOGEL: Did this formula apply at the slit, or where?

ANDREANI: No, this formula only gives the possible yield out of the target.

VOGEL: What are the units?

ANDREANI: The energy is in MeV. E-minus is the energy of the electron beam incident on the target. P is the peak power of the electron incident beam. ΔV-plus is the energy spread of the positrons. Omega is the solid angle which is accepted by the high-energy section of the accelerator. Using megawatts for P and MeV for the energy and ΔV plus, and Ω in steradians, this formula gives the current in μA.

BURNOD, Orsay: Do you have any experimental results, moving the incident electron beam off the axis of the accelerator?

ANDREANI: You loose current, of course.

BURNOD: By what factor?

ANDREANI: That is very difficult to say, because, generally, when we try to produce positrons, we try to get the electron beam right in the center and in a small spot. We have not done any experiments, but I think that if you go off axis, you loose a good part of the beam. For example, suppose your electron beam is 4 mm in diameter, and you have it just off the axis, you lose about half of the current or something like that, but this is just a guess.

LOEW, SLAC: Have you been able to observe accurately the phase of the klystrons necessary to attain the best positron capture and energy as compared to the phase necessary for electrons. Is it 180, 175, or what?

ANDREANI: We haven't done accurate measurements. These results I presented have just been obtained. As I said before, I have the impression that there are two possible phases or a certain range of phases that you can use. What we generally do is to reverse the phase of the sections from the fifth to the twelfth section, and you must treat them as a block. Then you vary the phase of No. 5 section; and by varying that phase, it appears that you can tune up the positron current.

MILLER, SLAC: Do you have some idea how large the range of tuning is which you do in the vicinity of π out of phase with the electrons?

ANDREANI: No. It certainly is not more than 10°.

HAIMSON, MIT: Computer runs on the phase orbits of the positrons in the 7- to 10-MeV range, injected into the fifth section, indicated that a shift of about 185° from the electron mode of operation is optimum. But it is also possible to accept positrons down to about 2 MeV in the fifth section, and this requires an additional 15 to 20° phase shift.

ANDREANI: Well, these are computed values. As I said, we have not made exact measurements. We obtained these results in only two runs so we have not really looked carefully at this problem.

Table I

	Total Current*	Useful Current*
Computed values with correction for field free spaces	850 μA	415 μA
Computed values with corrections for field free spaces and angular distribution (+)	640 μA	310 μA
Palo Alto test at sect. #5	1900 μA	
Palo Alto test at sect. #5 extrapolated at the end of the machine with correction for field free spaces	1520 μA	
Frascati test	930 μA	380 μA

(*) Electron incident beam: 260 A at 80 MeV.
(+) Correction factor for angular distribution 0.75.

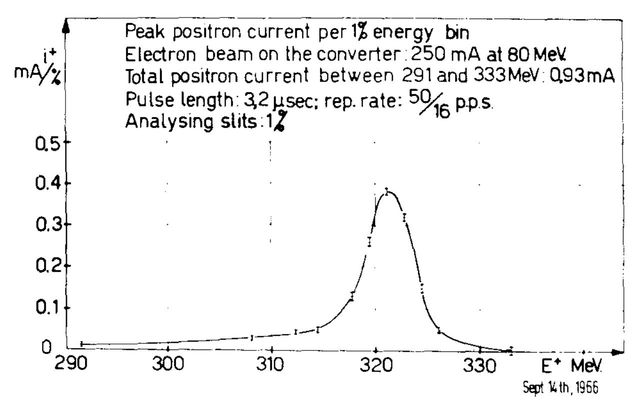

Figure 1.