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AN ADIABATIC MATCHING DEVICE FOR THE ORSAY LINEAR POSITRON ACCELERATOR

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Summary

An adiabatically tapered solenoidal magnetic field is used to match positron beam source emittance to accelerating section acceptance. Such a matching system improves the accepted energy band which has been accurately computed and compared with analytical determination. The tapered field is provided by stacked pancakes and solenoids of various radii ; total lens length is about 0.75m.

The adiabatic matching system took place of a quarter wave transformer system and has been in operation for two years. Positron conversion ratio is 3.3 % for a 1 GeV incident electron beam and presents a factor of nearly two of improvement for the positron yield. Energy bandwidth of positron beam has also been increased by a factor of nearly 2.5 ; the output positron beam energy is of 1.2 GeV.

1. Introduction

As well as positron sources have little transverse dimensions, large angle aperture and broad band energy the choice of the matching device between the source and the accelerator which has bigger geometrical acceptance and littler angular acceptance is important. Most of the linear positron accelerators having a final energy below one GeV make use of quarter wave transformer systems which seem well adapted for narrow band final energies. Improvement of positron yield by energy acceptance broadening has been carried out with the adiabatically tapered field of SLAC. [1] Such a broad band system obviously promising for multi-gev linear accelerators remains interesting for 1.3 GeV positron linac like Orsay's one. We studied an adiabatically tapered solenoid device which has been substituted to the former quarter wave system. Yield improvement has been calculated from energy acceptance enhancement taking into account positron distributions as given by Crawford and Messel tables. [2] The magnetic lens corresponding to the chosen adiabatic law is then described. Experimental results have been obtained with that system.

2. Behavior of a particle in a varying magnetic field

2.1 Adiabatic invariant

It is known that action integrals are adiabatic invariants for particles undergoing periodic motions : such quantities remain constants during a very slow variation of the external parameters of the system.

The action integral for the transverse motion of a particle in a constant magnetic field is given by

$$A = \oint \sum_i p_i dq_i = \frac{\pi p_\perp^2}{eB} \tag{1}$$

where (q_i, p_i) are the conjugate variables, $p_\perp$ the transverse momentum and B the longitudinal magnetic field strength.

2.2 Determination of the energy bandwidth

If the magnetic field changes slowly, so does the period of the motion and the adiabatic invariant $J = \frac{A}{\pi}$. That invariant J may be developed in terms of the parameter of smallness ϵ,

$$\epsilon = \frac{P}{eB^2} \cdot \frac{dB}{dz} \tag{2}$$

where P is the scalar momentum and $\frac{dB}{dz}$ the rate of variation of the magnetic field B on its axis.

An analytical approach using a canonical transformation of the usual conjugate coordinates and momenta $(x\ p_x\ y\ p_y)$ into a set of four variables of the action - angle type - one of which is precisely the half of the adiabatic invariant - gives a development $J(\epsilon)$ of the second order in ϵ. [3,4]

For a given magnetic field law

$$B = \frac{Bo}{1 + \alpha z} \tag{3}$$

where Bo is the initial value of B and α a constant, we put an upper bound on the growth of $J(\epsilon)$; that bound leads to an upper limit of ϵ and hence to a maximum value of the scalar momentum P. Such a method gives a realistic value for the energy bandwidth accepted by the optical system.

A more precise evaluation using numerical integration of the equations of motion by a *Runge-Kutta* method of the fourth-order has been applied to positrons randomly emitted between 4 and 40 MeV. That method led to positron spectrum which is given farther ; the lower bound of the spectrum is given by RF debunching considerations.

3. The adiabatic matching device

Positron focusing of the Orsay linear accelerator involves a long constant solenoidal field (30 meters) of 1.8 kilogauss which had to be used with the new matching device. So, the maximum value of the tapered field has been chosen to give the best yield improvement : a value of 12.5 kilogauss for the field at the converter exit has been kept. Lens length has been fitted to limit RF. debunching given by different velocities and trajectories of the particles ; tapered *field length is 0.72 m.* So the adiabatic magnetic field law is

$$B = \frac{12.5}{1 + 8.2z} \tag{4}$$

where z is expressed in meter and B in kilogauss.

3.1 Acceptance considerations

As pointed out by R. Helm, [1] the geometrical acceptance of the adiabatic system is given by

$$r_{max} = \sqrt{\frac{Bs}{Bo}} \cdot a$$

$$\text{and} \quad \theta_{max} = e\,\frac{\sqrt{BoBs}}{Po} \cdot a \tag{5}$$

where Bo and Bs represent respectively initial and final values of the adiabatic field, a the iris aperture and Po the scalar momentum corresponding to the lowest energy accepted.

Energy bandwidth has been calculated by numerical integration of the equations of motion. Fig. 1 and 2 *give geometrical and energy acceptances. We may* consider that captured positrons are laying in an interval of :

$$5 \leq E \leq 22 \text{ MeV}$$

Lower energies making particles more vulnerable to RF debunching. We may note that the analytical approach[3] using hamiltonian formalism led to 35 % increase of the adiabatic invariant with the magnetic law under consideration and for an energy of 22 MeV.

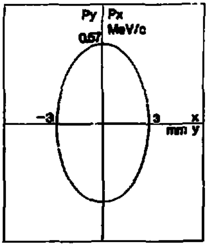

Fig. 1 Geometrical acceptance

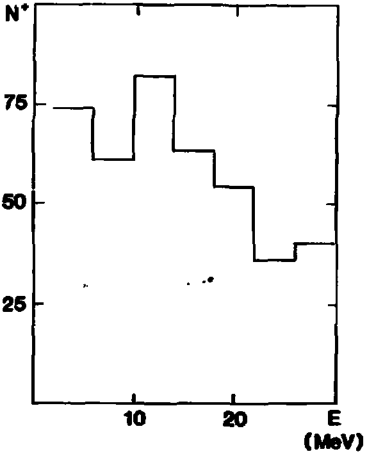

Fig. 2 Positron acceptance energy spectrum

3.2 Positron yield

With the preceding acceptance values, we have calculated the positron yield with geometrical and energy distributions derived from Crawford and Messel tables [2](Lead-3Xo- 1 GeV incident electron beam).

Theoretical yield is about 0.1 e^+/e^- GeV.

3.3 Solenoid design

We worked out a very simple device using the already existing power supply (120KW, 800A) of the former quarter wave matching device. Because of high radiation yield in the vicinity of the converter, the coil is shielded by an inner coaxial copper cylinder (30 mm thickness). Taking into account the converter mechanical positioning system, we took a coil inner diameter of 100 mm. Choosing one kind of conductor with constant current density for the whole lens, the outer diameter decreases from one border to the other. Magnetic concentration and shielding is ensured by low carbon steel return yoke. Numerical computation of the whole system was performed by a trial and error method using the POISSON program. Fig. 3 shows a plot of flux lines in the device (we omitted flux lines in the high radius part of the device, making the drawing clearer). Computed field is compared with analytical one on fig. 4 : both results agree within a few percents.

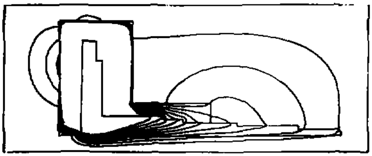

Fig. 3 Flux lines in the device

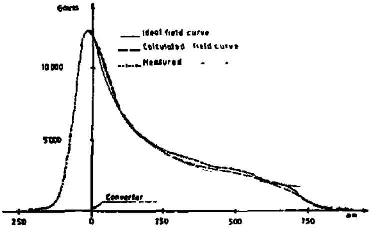

Fig. 4 Tapered field of the matching device

Figure 5 shows the coil with its external shielding (low carbon steel return voke and magnetic protection).

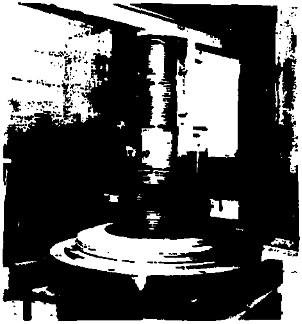

Fig. 5 Solenoid being assembled

We adopted a hollow copper conductor (8.5 x 8.5 mm^2 ; 6 mm diameter). Current density is about 16.5 A/mm^2 and total power consumption of 80 kW for a current of 725A. The coil is made with two double pancakes of 680 mm (outer diameter), one double pancake of 460 mm (outer diameter) and six solenoidal windings. In order to obtain two cooling circuits in a double pancake, two wires have been winded parallelly in the same pancake.

Axial magnetic field was measured and compared with computed one (Fig. 4). Agreement is quite good near the converter region.

4. Experimental results

4.1 Conversion yield

Beam intensity measurements made after the long constant solenoidal field showed conversion yield of 3.3×10^{-2} e^+/e^- for a one GeV incident electron beam. Such a conversion efficiency presents a factor of improvement of about two regarding the former matching system (a quarter wave transformer system having same initial and final values).

4.2 Energy bandwidth

Measurements made at energies above 1.1 GeV showed rather large spectra with an energy width at the half intensity points no less than 1.5 %. Positron yield in 1 % energy bin is of 10^9 e^+/pulse (20 nanosecond pulse width).

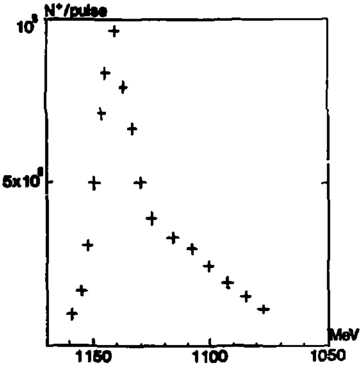

Fig. 6 Measured spectrum at the end of the linac

We are indebted to J.L. Saury for handling the adiabatic lens fabrication.

References

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