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SLC POSITRON SOURCE PULSED FLUX CONCENTRATOR

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Abstract

SLC positron beams produced by a high energy electron beam, impinging on a high Z target, have initially small transverse size but large divergence, a situation ill matched to the following S-band accelerator. The flux concentrator is an adiabatic matching device placed between the target and this accelerator, which trades divergence versus size. It produces a magnetic field with a sharp rise over less than 5 mm to its peak value, and then falling off adiabatically over 10 cm. It is a 12 turn, 10 cm long copper coil with a cylindrical outside radius of 4 cm and a conical inside radius growing from 3.5 mm to 2.6 cm. The 0.2 mm gaps between the individual windings were manufactured by electric discharge machining out of one copper block. Excitation current and water cooling is provided by a hollow rectangular copper conductor brazed to the outside of the coil (also 12 turns). The pulsed magnetic field has a maximum strength of 58 kG at 16 kA. At the terminals, the coil has an inductance of 0.8 μH. Current shape is a half sinusoidal wave with a bottom width of 5 μs, and the system operates at a repetition rate of 120 Hz. The coil has only one supporting ceramic insulator at the low voltage front end. The flux concentrator has improved the positron yield approximately 2 times and had no failure in operation during several years.

I. INTRODUCTION

The design and operation of the SLC positron source has been described.[1] Recent improvements include the installation of a moving target.[2] The overall performance of the source is discussed in reference [3].

Integral to the design of the source is the use of a large bandwidth phase-space transformer as in SLAC's original positron source.[4] Such a device utilizes a longitudinal magnetic field whose strength decreases slowly with longitudinal distance from the target.[5] It can be shown that this transforms the phase-space radii by the square root of the magnetic field ratio, *i.e.*, Ba^2 is a constant proportional to beam emittance, where B is the magnetic field and a the beam radius. The final field value, away from the target, must be large enough to keep the beam inside the accelerator aperture. The initial value then needs to be high to achieve a useful transformation of the phase-space aspect ratio.

II. DESIGN PRINCIPLES

The specifications for the SLC positron system require a high positron yield[6], achievable only if the peak longitudinal field at the target is at least 7 T. Since such a high field is not practical in the high radiation environment of the target with a simple tapered field solenoid (TFS), a 5.8 T (peak) field produced by a pulsed flux concentrator (FC) has been added to a 1.2 T TFS DC field as shown in Fig. 1. Beginning with an existing concept for a pulsed device[7], a vacuum insulated, physically robust, mechanically simple, highly reliable, pulsed FC has been designed and will be described below.

The field concentration is achieved by a pulsed coil having an internal conical shape. A sharp rise of the magnetic field to its peak value over less than 5 mm distance is achieved by limiting the smallest radius of the cone to 3.5 mm and locating it 2.5 mm from the moving target exit-surface. The strength of the longitudinal field along the axis of the cone is to first approximation simply inversely proportional to the cross-sectional area as indicated above. The dimensions of the cone are: minimum radius, 3.5 mm; maximum radius, 2.6 cm; length of cone along its axis, 10 cm. Twelve turns were chosen for the coil as a compromise between efficiency[8] and the maximum required current. More turns would require less peak current, but because of increased flux leakage would decrease the efficiency, requiring more power from the modulator. It should be noted that the flux leakage determines the exact shape of the longitudinal field. The loss of efficiency for a give number of turns can be limited by reducing the width of the gap between turns. Since 2 skin depths are present at each gap, the practical limit for the gap is about 1 skin depth. In this case, the skin depth is 0.2 mm.

III. FABRICATION TECHNIQUE

The FC is machined from a single block of OFHC Cu with internal cone and external groves for a rectangular water-cooled conductor as shown in Fig. 2 (a). The conductor is next brazed into the groves, after which a spiral gap of 0.2 mm is cut through by electric discharge machining (EDM) to form the 12-turn coil as shown in Fig. 2(b). No insulator between the turns is necessary—a significant achievement in this design. However, if there is a discharge between 2 turns, the resulting force from adjacent turns will push the 2 shorted turns together. This is a problem only if the Cu is annealed, such as is common when cleaning for vacuum. Thus, to insure the coil will spring back to its original position following a discharge, it must be work-hardened. Work-hardening is easily accomplished by mechanically collapsing then reopening the gaps a number of times.

The coils require only a single supporting insulator, chosen here to be at the low voltage end of the coils and also to be a vacuum-clean ceramic. The mechanical stability of the coils is ensured by choosing a short pulse width and a sufficiently large mass for the coils. On the other hand, to avoid excessive voltage requirements, the pulse width should not be too small. In this case, a half-sinusoidal wave with bottom width of 5 μs was chosen. (The positron pulse is <<1 ns long.)

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Because this is a mechanically stiff structure with a complex shape, many mechanical resonances can be excited during operation. For this design, the highest frequence resonance observed was 49 Hz. Thus to avoid exciting any resonance, the coil repetition rate is restricted to be ≥60 Hz.

The assembly of the FC in the source vacuum system is shown in Fig. 3. The supporting insulator attaches the FC to the front end magnet yoke. The current and water cooling leads are carried through the vacuum wall with no water joints exposed to the vacuum system. The modulator design is discussed elsewhere.[9]

IV. PERFORMANCE

ETRANS[10], a computer simulation code that traces particles in electric and solenoidal magnetic fields, has been used with the measured magnetic fields to compute the effect of the FC on the positron phase space. The results for the transverse phase space are shown in Fig. 4(a) and (b). The longitudinal phase space of the positrons exiting the FC are shown in Fig. 4(c). Note that particles with <1 MeV/c are reflected by the rising magnetic field. Particles with small energy and relatively large transverse momentum are delayed because of the spiral trajectories in the strong field of the FC.

The performance of the FC can be judged by the effect on the yield. The first positron intensity monitor is after capture and acceleration to about 120 MeV. The yield here is improved by a factor of 2 as shown in Fig. 5.

The FC has been in operation in the SLC positron source for 3 years without a failure.

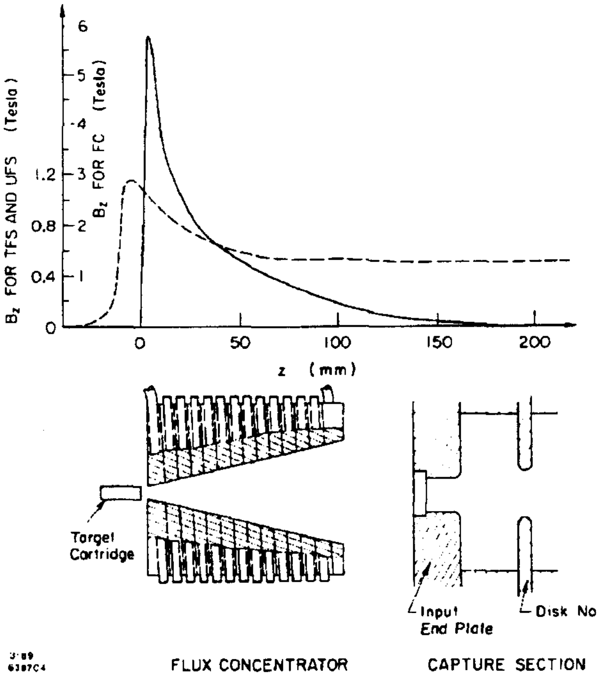

Figure 1. The positron source adiabatic system. The devices shown in cross section at bottom are to scale. The computed solenoidal fields and measured FC pulsed field are shown above with the same z-scale as for the devices.

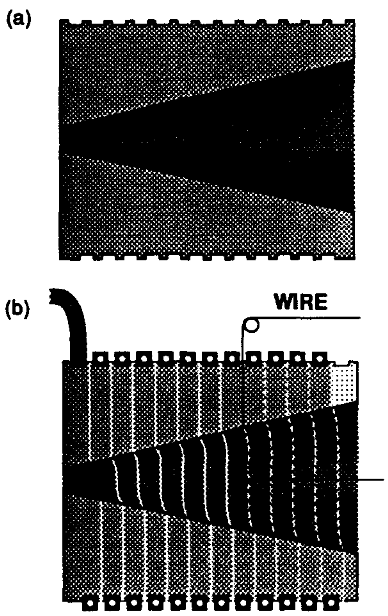

Figure 2. FC body cross section: (a) Showing internal cone and grooves fro rectangular conductor; (b) Showing EDM wire cuts after conductor is brazed into grooves.

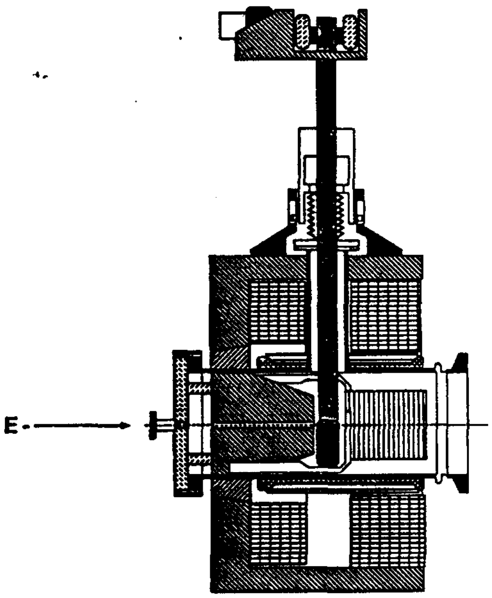

Figure 3. Complete target module assembly showing trolling target driven from above, TFS surrounding both the target (solid black) and FC, and the FC itself supported by the TFS yoke (hashed) on the upstream end.

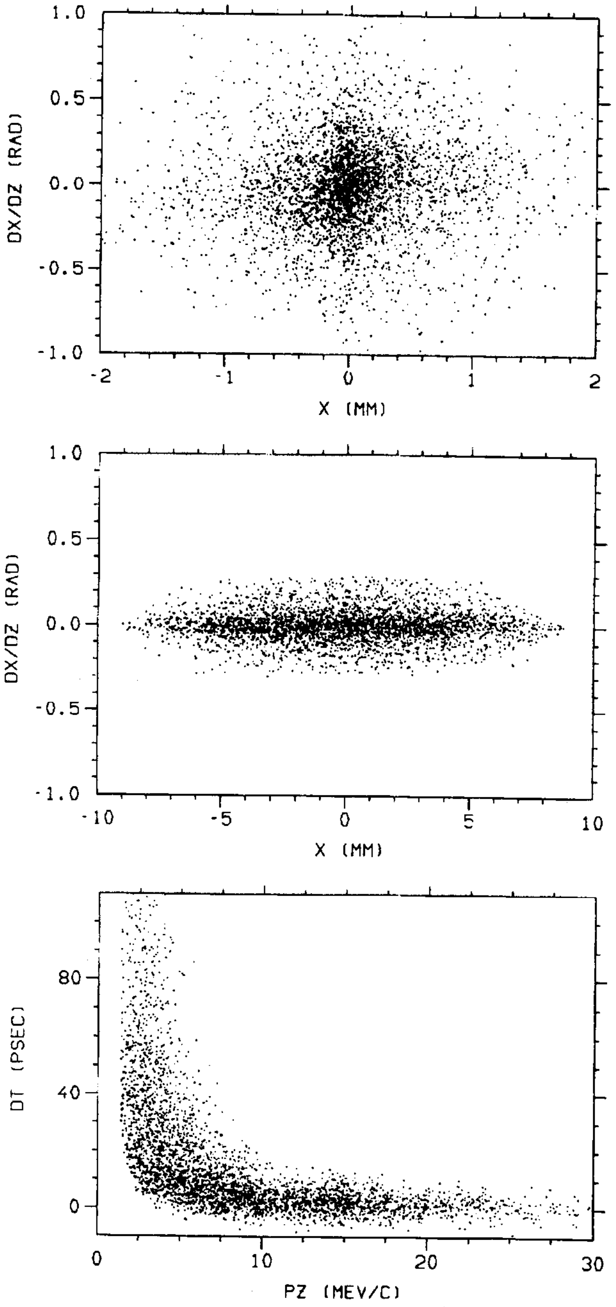

Figure 4. Phase space transformations. (a) EGS simulated phase space at target exit; (b) Transverse phase space at exit of FC (z = 140 mm) as simulated by ETRANS; (c) Longitudinal phase space at exit of FC, also ETRANS.

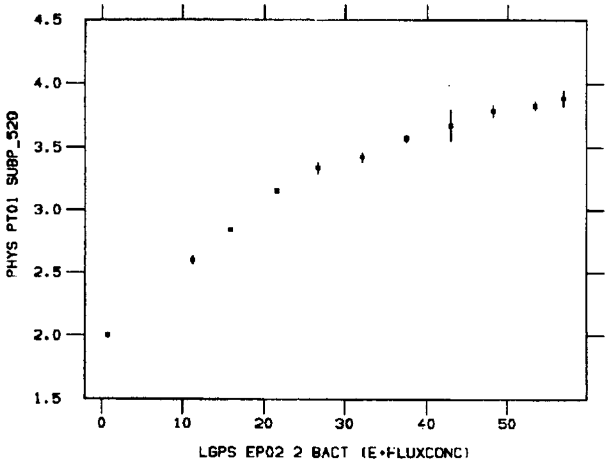

Figure 5. Positron yield at first intensity monitor (at 120 MeV location) as function of peak FC field in kG.

V. REFERENCES

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[2] E. Reuter, *et al.*, "Mechanical Design and Development of a High Power Target System for the SLC Positron Source," this conference.

[3] R. Pitthan, *et al.*, "SLC Positron Source--Simulation and Performance," this conference.

[4] H. Brechna, *et al.*, in R. B. Neal, ed., *The Stanford Two-Mile Accelerator*, Benjamin (1968), section 16.

[5] R. H. Helm, SLAC-4 (1962).

[6] The positron yield at a give location is defined as the ratio of the number of positrons at that location to the number of electrons impinging on the conversion target.

[7] M. N. Wilson and K. D. Srivastava, *RSI* **36** (1965) 1096.

[8] The efficiency is defined as the ratio of the stored energy in the useful magnetic field to the total stored energy.

[9] A. Kulikov, *et al.*, "SLC Positron Source Flux Concentrator Modulator," this conference.

[10] The program ETRANS was written by H. Lynch (SLAC).