LITHIUM LENS FOR POSITRON PRODUCTION SYSTEM*

A.Mikhailichenko#, Cornell University, LEPP, Ithaca, NY 14853, U.S.A.

Abstract

We represent optimized parameters for an undulator-based positron production scheme for ILC-type machine. In particular we describe details of Lithium lens design suggested for usage in collection optics.

INTRODUCTION

In ILC, the positrons are created by ~20MeV gamma beam in a spinning Titanium rim [1], (baseline). Usage of Ti allows for a significant reduction of power density deposition in a target. Some other possibilities for the target include a liquid metal target using Pb-Bi alloy or Hg. With reduced photon flux from the undulator, it becomes possible to use Tungsten here [2], [5].

After the positrons emerge from the target, they need to be collected (focused). There are few types of focusing systems used for positron collection: so called Adiabatic Matching Device (AMD) [3], Compact Solenoidal System (CSS) [6], Lithium Lens (LL) [4] and Horn Focuser System (HFS, Also called X-lens; used in BINP, Novosibirsk for positron collection at VEPP-2 complex replaced later by LL [4]). The last two represent devices making so called Quarter Wave Transformations (QWT), which means that the beam rays coming out of the target are at a wide angular spread, after passage through QWT are transformed into a parallel flow. Of course, such a transformation is chromatic sensitive.

Calculations show that optimal current for Li lens lies in margins 100-150*kA* [7]. The lens allows collection of >50% of positrons created in a target in a transverse phase volume $c\Delta p_{\perp}\cdot x\cong$5MeV-cm.

LITHIUM LENS ENERGETIC

The concept of a Lithium Lens represented in Fig.1, left.

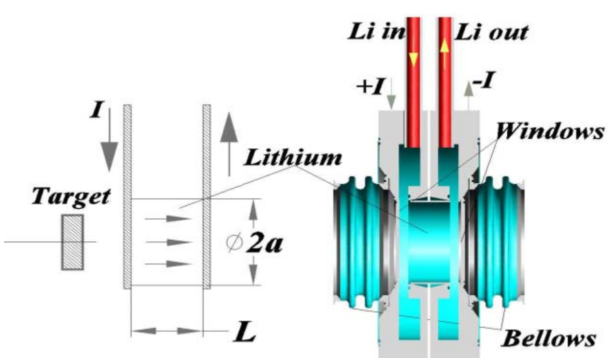

Figure 1: Lithium lens concept, left. At the right the transverse cut or suggested lens design is represented.

If a steady current *I Ampere* running co-directionally with positrons through the round conductor having radius *a cm*, magnetic field inside the rod is a focusing one with focal distance defined by $F\cong a^2\cdot(HR)/0.2LI$, where (HR) – is a magnet rigidity Gs-cm, pc=300(HR).

For ILC collection optics we suggest a system with *liquid* Li with flow rate ~1m/s. Lithium confined in Ti cylindrical container, see Fig.1, right. Windows made either from Beryllium, Titanium or Boron Nitride (BN). Resistance of the 0.5 cm long, 1*cm* in diameter Lithium rod could be estimated as $R=L/\pi a^2/\sigma\cong 0.9\cdot 10^{-5}$ Ohm, where $1/\sigma\cong 1.44\ 10^{-5}$ Ohm-cm taken as a specific resistance of Lithium. The instant power dissipation in the rod is as big as $P=I^2\cdot R\cong$202kW (150kA), which raises the temperature ~170°C. If the pulse lasts for τ seconds with repetition rate *f*, Hz, then the average power dissipation will be $<P>=I^2\cdot R\cdot f\tau$. For *f*=5Hz, $\tau\cong$4ms, the last goes to $<P>\cong 4$ kW only. The resistive voltage drop along the rod is as low as $U_2\cong I\cdot R\cong$1.5V. Inductance of the Li rod is $L_r\cong 5.3\cdot 10^{-9}$ H. Impedance, associated with this inductance goes to $Z\cong i8.3\cdot 10^{-6}$ Ohm, and the voltage associated will go to $|U_l|\cong$ 0.138 V. Together with voltage drop associated with inductance of line, calculated up to the cable transition connection, it becomes ~5 V. For direct feeding we suggest a transfer line with 120 coaxial cables, see Figs.2,4. Inductance, estimated for 50-m long transfer line goes to be $L_l\cong 1.25\cdot 10^{-7}$ H. Impedance, associated with this inductance goes to $Z\cong i2\cdot 10^{-4}$ Ohm, where we suggested frequency $\omega\cong 2\pi/4$ ms. The voltage drop along the all line will go to $|U_l|\cong I\cdot Z\cong 30$ *V*. So the PS must commutate >35 V at ~150 kA, in ~4ms time scale, what is not a problem for thyristor commutation, see below.

SCATTERING IN LITHIUM

Material of lens (Li) must scatter particles much less, than the angular spread of focused particles. This is always true for the collected particles after the target. Scattering of the positrons in a Lithium rod could be estimated as $\sqrt{<\theta^2>}\cong(13.6[MeV]/pc)\sqrt{t_{Xo}/X_{Li}}$, where X_{eff} –is an effective radiation length of the Lithium, $X_{Li}=83.3$ g/cm² (or 156 cm), t_{Xo} –is the length of the rod in g/cm². So for positrons with pc=15±5MeV, $\sqrt{<\theta^2>}\cong 0.04$ rad, i.e. ~13 times smaller, than the angular spread in the positron beam.

ENERGY DEPOSITION BY BEAM

Energy deposition in the material of windows is the main point of concern here. Taking into account that the energy deposition in the material is going by secondary particles

*Work supported by NSF
#mikhail@lns.cornell.edu

(positrons and electrons) at the level $\delta E \sim 2$ MeVcm^2/g, one can evaluate the energy deposited by each particle in a material of Be window as

$$\Delta E \cong \delta E \times \rho \times t / 1cm \cong 0.2 \text{ MeV},$$

where $\rho \cong$ 1.8 g/cm^3 is volume density of Be. So the total energy deposited by train of n_b bunches with population N each, comes to $E_{tot} \cong \Delta E \times N \times n_b \times e$ Joules, where e stands for the charge of electron. The last expression goes to be $E_{tot} \cong 1.8$ J. This amount must be multiplied by the factor reflecting spare particles, ~1.5-2 , also multiplied by factor two- reflecting equal amount of electrons and positrons and, finally, multiplied by factor reflecting efficiency of capturing (~30%). So the final number comes to $E_{tot} \cong 21$J. Temperature gain by heat capacity of Be $C_v \cong$ 1.82 J/g/^{o}C comes to

$$\Delta T \cong E_{tot} / mC_v \cong E_{tot} / \rho SlC_v \cong 83 \ ^oC.$$

Total temperature gain adds a resistive temperature gain by Litium ~170 ^{o}C, so the total temperature gain of windows comes to 250^{o}C. One needs to add the initial temperature which is above the melting point of Lithium (181^{o}C), coming to maximal temperature ~300 ^{o}C, brining total temperature jump~500^{o}C. Meanwhile the melting temperature of Be is 1278 ^{o}C, so it withstands. For Boron Nitride (BN) the melting temperature is ~2967^{o}C.

Windows kept cold by the contact with Li. For the one millisecond duty of the pulse, the liquid moving with ~1m/sec will pass ~1mm. To the next train which arrives in 1/5 sec i.e. in 200 *ms*, the Lithium will be refilled the volume of lens a few times. Boron Nitride is another candidate for the output window. Brazing of BN to the Titanium transition flange made with Ag/Cu/In alloy.

Axial pressure, generated by current comes to $P_0 = \frac{1}{2} H_{\max}^2 \cong 164$ atm, where $H_{\max} \cong 0.2I / a \cong 64$ kG is a magnetic field value at the surface of Li rod, while the pressure on the surface of the Li rod is zero.

LITHIUM LENS ENGINEERING

A lot of engineering work done for LL usage in VLEPP Linear Collider was done in BINP, Novosibirsk [4], [8] and for ILC at Cornell [7]. FERMILAB and CERN use

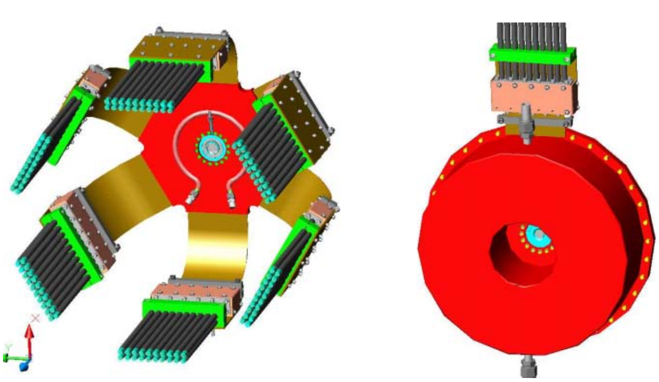

Figure 2: Lens feed directly, at the left; Lens feeding with transformer, at the right.

LL for antiproton collection. Lenses used here are much more powerful than is required for positron focusing. Dimensions of LL for positron production are typically *ten times smaller*, than the ones used in antiproton business.

Spherical aberrations of lens, associated with irregular current flow in transition to the leads, are small [4].

POWER SUPPLY

PS schematics represented in Fig.3. The pulser installed in service tunnel. Size of this installation could be $\sim 2 \times 1 \times 1$ m^3. Multilayer strip-line current duct is running through the penetration connecting service and main tunnels. If a transformer is used, it is installed in close vicinity of lens, Fig.3 (scheme rearranged so the recharge will be going through transformer). Area of laminated core estimated $S \cong 10^8 U_2 \tau / \Delta B \le 100$ cm^2, where $\Delta B \cong 15$kG stands for allowed induction in the core. Carefully designed transformer and ducts could provide negligible vibrations. At the moment we prefer direct high current feeding scheme. For commutation, broad variety of thyristors (Silicon Controlled Rectifiers; SCR's) could be used. New type of switches - Reverse Switch Dinistors (RSD) with 64, 76 and 100 mm in diameter in low profile housing are available now.

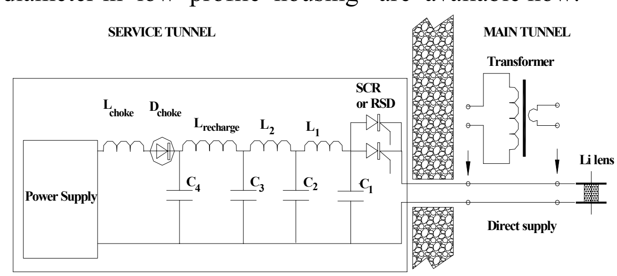

Figure 3: Power supply schematics.

In particular, a 100-mm RSD commutates the current up to 500 kA with blocking voltage of 2.4 kV. Single 76-mm and 63-mm RSD can commutate 380 kA and 250 kA respectively [9]. Low voltage, which is required in our case (<50V), makes usage of such devices guarantied. Capacitors C_1-C_3 and inductances L_1-L_2 on Fig.3 together with inductance of transferring line generate pulsed current of first, third and fifth harmonics close to trapezoidal shape with flat top ~1ms and <4ms base. C_4 and $L_{recharge}$ are elements of recharging circle; D_{choke} is protective diode.

LENS INSTALLATION

Lens installed right after the target, followed by acceleration structure, see Fig 4. The gear pump for liquid metal of target is shown on the left side. Similar pump could be used for pumping Lithium. RF structure is immersed in a solenoid, wound with an Aluminum conductor, generating field ~3T. Aluminum accumulates much less radioactivity, than the Copper one. The same is valid for the first section of *accelerator structure*. Technology for Al structure fabrication exists. RF power input arranged at far-entrance from the target, so the power input does not disturb the beam.

For the conversion system with Lithium lens the extension in tunnel diameter does not required. Total length occupied by undulator and magnets for creating offset chicane counted to be ~300 *m* total [7].

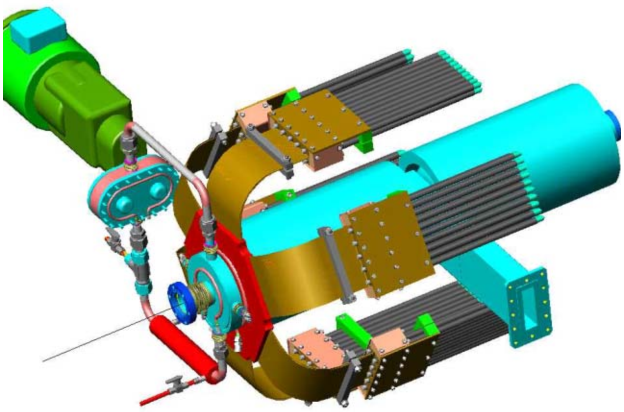

Figure 4: The lens is shown installed right after the liquid metal target [2] in front of accelerating structure. Ti rim could be used here as well.

Table 1: Parameters of conversion system with Lithium Lens recommended for the best polarization performance

General parameters	
Energy of primary beam	~150 GeV
Undulator period λ	10-12 mm
K factor, $K = eH\lambda/2\pi/mc^2$	≤ 0.4
Undulator length	$\leq$ 200 m
Efficiency , e^+/e^-	1.5
Polarization	$\geq$ 60%
Target	Tungsten 1.75 mm
Energy of quanta	~18 MeV
Distance to the target*	180 m
Lens	
Feeding current, I	<150 kA
Field at surface, H_m	43 kG
Gradient	$\leq$ 62kG/cm
Pulsed power	~200kW
Average power	~4kW
Pulsed duty , τ	<4msec
Lens diameter, 2a	1 cm
Length, L	0.5-1 cm**
Axial pressure, P_0	74atm (for L=0.5cm)
Temperature gain per pulse	$\leq$ 170°C at 150kA

*Calculated from the end of undulator,
**Under optimization for final λ and K.

CONCLUSIONS

AMD as an element of collecting positron optics becomes ineffective, while the target is a spinning rim. Eddy fields in moving target immersed in a magnetic field sweep the positron beam and make rotation difficult. In its turn, excessive photon flux (15% used for positron production only) and scattered positrons and electrons lost during collection, generates severe radiation activation in the nearby accelerating structure and elements of collection optics itself.

Utilization of Lithium lens allows strict limitation of the magnetic field, so the target becomes unaffected by the field and lens could be used with the spinning target as well. In turn, increased efficiency of collection optics allows reduction of photon flux required, so moderate K~0.3-0.4 becomes possible. Even more, Tungsten survival under conditions required by ILC with N_e~2x10^{10} becomes possible with LL. Thin W target allows better functionality of collection optics (less focusing depth as a result of thinner target). All this drastically reduces the radioactive background. Liquid targets as Pb-Bi alloy or even Hg allows further increase of positron yield.

Lithium lens is a well developed technique. Usage of LL allows for a drastic increase in accumulation rate, lowering K-factor. As the K factor could be made lower by at least 2.5-3 times, the photon flux goes down ~6-10 times. Usage of a conical shape of lens will allow for further reduction of feeding current and power down to 50%. Such calculations are under way with the help of FlexPDE code. As the power deposition in a LL by feeding current is P~1/L, but scattering $\sim\sqrt{L}$ so further optimization of length is possible.

One comment we would like to make here is that usage of Li lens in other than ILC beam format, say the CLIC one, allows for further simplifications for the lens and PS as the feeding current pulse becomes shorter.

Summing up, the technology of focusing elements with Li lens is the promising one and could be recommended for ILC positron source.

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