A NOVEL CONCEPT FOR A LITHIUM LENS EXCITER

G.G. Karady
Department of Electrical Engineering
Arizona State University
Tempe, AZ 85287-5706

H.A. Thiessen
Los Alamos National Laboratories
Los Alamos, NM

ABSTRACT

A particle beam is focused by the magnetic field of a lithium lens which collects particles produced in a small target. The major components are a short lithium rod and an exciter. This paper presents a new circuit concept for the exciter to produce a 100 kA current pulse with a 1 msec flat top. In every half-cycle a capacitor generates a current pulse. A thyristor-controlled rectifier charges the capacitor to the supply voltage, and a thyristor switch discharges it through a pulse transformer which supplies the lens. A zinc-oxide surge arrester, connected in parallel with the pulse transformer, produces the current flat-top. The control of a larger current pulse with a non-linear component is a new concept which improves the lens performance. The exciter can be built with commercially available components.

INTRODUCTION

The lithium lens was used in the last decade to focus particle beams on a small target. The lens consists of a lithium bar, which is supplied by a 100-150 kA current pulse. The magnetic field generated by the current pulse focuses the beam on a very small area. The dimensions of the lithium rod are, length = 10-30 cm and diameter = 0.5-2 cm. The current pulse is a half sine wave with a peak amplitude of 100-150 kA, a duration of 60-100 msec, and a repetition frequency of about 3 Hz.

Los Alamos National Laboratory investigated the feasibility of a lens with a significantly increased duty cycle. The desired current wave form is shown in Figure 1.

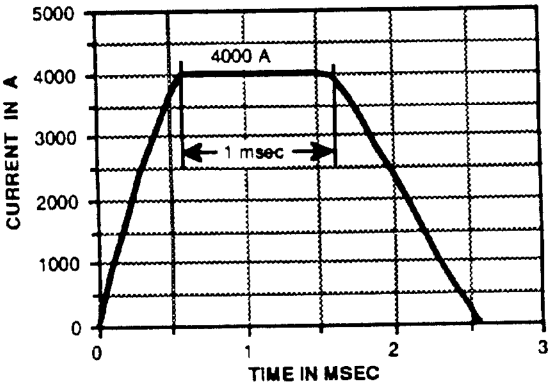


Figure 1: Current pulse for lithium lens

It can be seen that the major difference between the Los Alamos requirement and the previous designs is in the wave shape and the higher repetition frequency. The generation of the pulse with a flat top is more complicated than with a sine shape.

The purpose of this investigation is to develop a new circuit which generates a 100 kA pulse with a flat top.

BACKGROUND

The literature regarding lithium lenses was reviewed. The survey shows that the lithium lens is connected to the power supply through pulse transformers, and the current pulse is generated by a capacitor discharge. A typical system described by Bayanov et al. [1] utilizes a 100 μF low-inductance capacitor. This capacitor is charged by a rectifier and discharged by a thyristor switch through a pulse transformer having a turn ratio of 1:4. The secondary of this transformer is connected to a 50 m long co-axial cable, which is terminated by a second pulse transformer with a turns ratio of 1:6. The secondary of this transformer supplies a low-inductance strip line with a length of 6 m. The strip line is terminated by a third pulse transformer, again with a turns ratio of 1:6. The water-cooled lithium bar is mounted directly to the secondary of the last pulse transformer. The lithium bar resistance is 0.7 mohm, and its inductance is 0.05 μH. The strip line inductance is about 0.7 μH, and the co-axial cable inductance is 2 μH. The system operates at a frequency of 3 Hz and generates a sinusoidal pulse with an amplitude of 130 kA and a duration of 60 μsec. The overheating of the lithium bar limited the operation frequency and lifetime.

Sieveres et. al. [2] describe a lens using liquid lithium, supplied by a sinusoidal of 320kA current pulses. The operation frequency is 2-3 pulses per second. The lens accumulated more than 10^4 pulses in CERN.

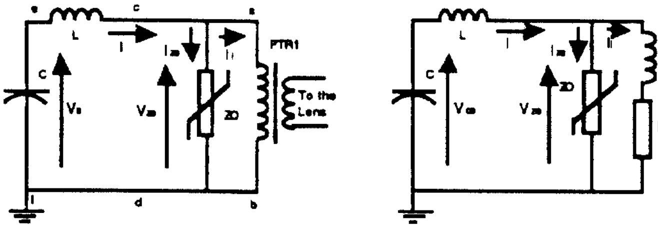
Hojvat and Lennox [3] presented a new lens design for Fermi Laboratory. The lens was tested at CERN and survived more than 1.4 M 290-320 kA pulses.

The analysis of the results shows that: (1) all systems generate sinusiodal wave forms with no reference to a flat top; (2) the efficiency of the energy transfer is about 60% because of the losses in the pulse transformers; (3) the reduction of the number of pulse transformers is desirable; and, (4) the deterioration of the lithium bar limits the lifetime of the lens.

0-7803-0135-8/91$01.00 ©IEEE

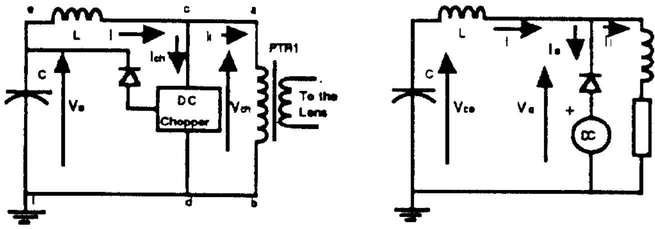
CURRENT PULSE GENERATON WITH FLAT TOP

The standard method of generating a high-current pulse is the discharge of a charged capacitor by a thyristor switch through low-inductance line and a pulse transformer. The latter supplies the load, in our case the lens. This circuit produces a current pulse with a half sine wave shape. The generated wave shape can be modified by diverting the current, above a certain limit, to a parallel path with constant voltage in order to a produce flat top. Figure 2 shows the possible realization of this circuit.



a) Flat top generation by ZO arrester

b) Equivalent circuit with for ZO surge arrester assisted system



c) Flat top generation by chopper

d) Equivalent circuit for chopper assisted system

Figure 2: Current pulse forming circuit

Figure 2a diverts the current into a zinc-oxide surge arrester, which has a very non-linear current-voltage characteristic. The equivalent circuit of this system is shown in Figure 2b, where the pulse transformer and the load is represented by an equivalent impedance. The surge arrester is represented by a non-linear resistance described by equation 1:

$$V_{zo} = C_{zo}\ I_{zo}^{\alpha} \quad \text{where} \qquad (1)$$

C_{ZO} and α are constants determined by the zinc-oxide material. V_{ZO} and I_{ZO} are the zinc-oxide device voltage and current.

This circuit was used for analytical studies and system simulation. The current and voltage wave shapes and zinc-oxide characteristics are shown in Figure 3. This figure demonstrates that this circuit generates the proper wave shape, but the zinc-oxide arrester has to absorb large amounts of energy during conduction. This requires the connection of several arresters in parallel.

Figure 2c shows another circuit realization, where a constant-voltage dc-to-dc converter is connected in parallel with the load. The equivalent circuit is shown in Figure 2d. The voltage and current wave shapes are similar to that shown in Figure 3. The converter in this circuit operates as a high-frequency chopper, produces a flat current pulse, and returns the energy to the capacitor bank during conduction.

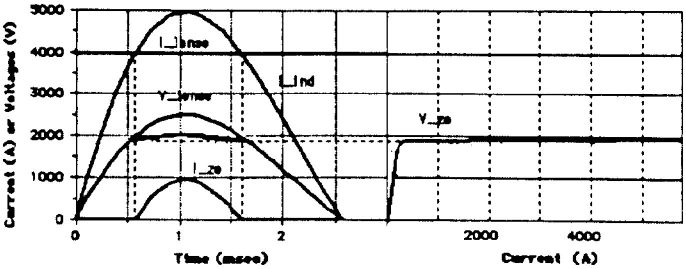


Figure 3. Current wave forming by zinc-oxide arrester

SYSTEM CONCEPT

Using the current shaping method of Figure 2a, the one-line diagram of the lens' power supply is developed and shown in Figure 4.

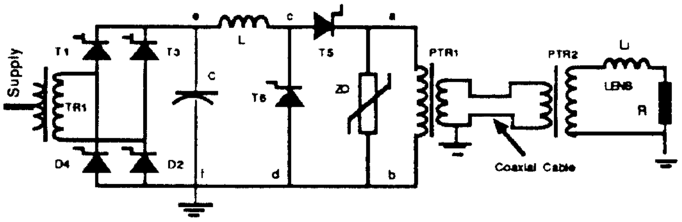
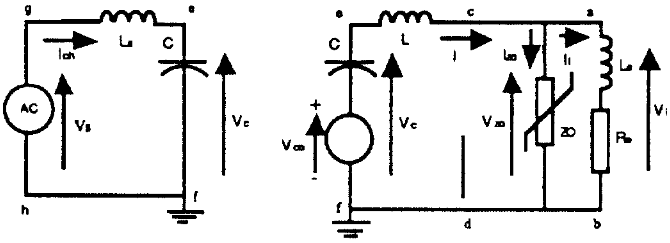


Figure 4: One-line diagram of the lithium lens power supply

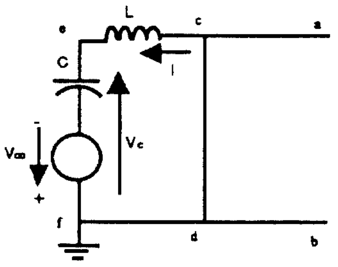
The pulse transformers and lens can be replaced by an equivalent impedance.

The system operation is divided into three states. The equivalent circuit in each state is shown in Figure 5.



a) Equivalent Circuit for STATE 1

b) Equivalent Circuit for STATE 2



c) Equivalent Circuit for STATE 3

Figure 5: Equivalent circuits

State 1 - Charging (Figure 5a)

The voltage wave form is shown in Figure 6. The single-phase rectifier charges the capacitor during both the positive and negative cycles. In the positive cycle, when the source voltage becomes equal to the capacitor voltage (point a), thyristor T_5 is fired and the transformer charges the capacitor to the peak voltage (TR, D6, T5 path in Figure 4). In the negative cycle, T3 is fired and the capacitor is charged through T3, D4. When the source voltage reaches its peak value (point b), the charging is completed and the capacitor is ready for pulse generation.

State 2 - Discharge and pulse generation (Figure 5b)

Thyristor T1 is fired at any time after point b in Figure 6. This discharges the capacitor, which then generates a sinusoidal current wave as shown in Figure 7. The wave is modified by the zinc-oxide arrestor and a pulse with flat top is generated. The current of the arrestor is shown in Figure 7. This pulse is transferred to the lens through the two pulse transformers. In this process the peak current is increased from 4 kA to 100 kA. The polarity of the capacitor voltage is reversed. At the end of the discharge period, the capacitor is charged to a negative voltage (point c) which is considerably less than the peak supply voltage (point b). Nevertheless, significant energy remains in the capacitor.

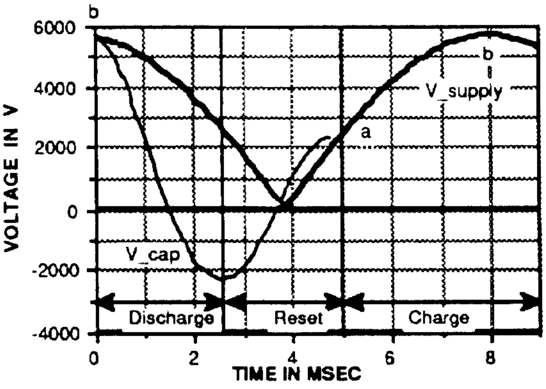


Figure 6: Voltage wave forms

State 3 - Reset period (Figure 5c)

The remaining energy is recovered by firing T_2 at point c just after T1 is turned off. The discharge of the capacitor through T2 and L reverses the capacitor voltage (point d) and recovers the energy. After that, the capacitor voltage remains constant until the charging period starts at point a.

OPERATION ANALYSIS

The system was simulated using the MICROCAP transient analysis program. For the simulation study, the system equivalent circuit was developed and shown in Figure 5. The results prove the feasibility of the circuit as shown in Figure 4. Furthermore, the results of these studies permit the selection of components and the practical design of the system.

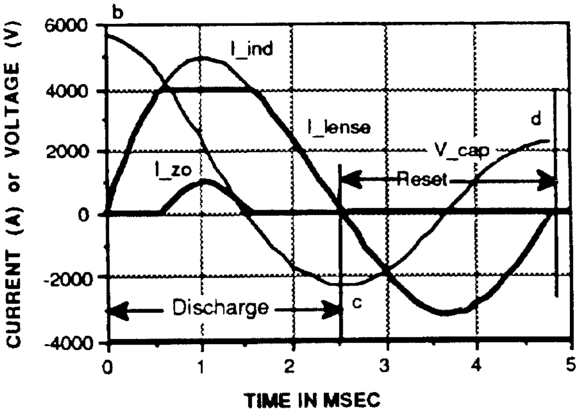


Figure 7: Current and voltage wave forms during discharge and reset

SYSTEM DESIGN

The result of the system operation analysis permits the selection of components' ratings and the determination of major requirements. Based upon the results of our preliminary analyses, the components may be selected for a future exciter. The approximate power consumption of this exciter would be 1.6 MW.

CONCLUSION

The concept of a high-power lithium lens power supply is developed. The major components are selected. The system operation analysis and computer simulation proved the feasibility of the proposed system.

REFERENCES

1. B.F. Bayanov, J.N. Petrov, G.I. Silvestrov, J.A. MacLanchlan, G.I. Nicholls, "A Lithium Lens for Axially Symmetric Focusing of High Energy Particle Beams" Nuclear Instruments and Methods, I90 (1981), pp. 9-14.
2. P. Sievers, R. Bellone, A. Ijspeert, P. Zanasco, "Development of Lithium Lenses at CERN", IEEE Trans. of Nuclear Science, Vol. NS-32, No. 5., Oct. 1985, pp. 3066-3668.
3. D.C. Fiander, C.D. Johnson, S. Murry, T.S. Sherwood, G. Dugan, C. Hojrat, A. Lennox, "Bean Test of a 2 cm Diameter Lithium Lens", IEEE Trans. Nucl. Sci., Vol. NS-32, No. 5, Oct. 1985, pp. 3063-3065.
4. G. Dugan, C. Hojvat, A.J. Lennox, G. Biallis, F. Cilio, M. Leininger, J. McCarthy, W. Sax and S. Snowdon, Mechanical and Electrical Design of the Fermilab Lithium Lens and Transformer System, IEEE Trans. Nucl. Sci, NS-30, p. 3660, 1983.