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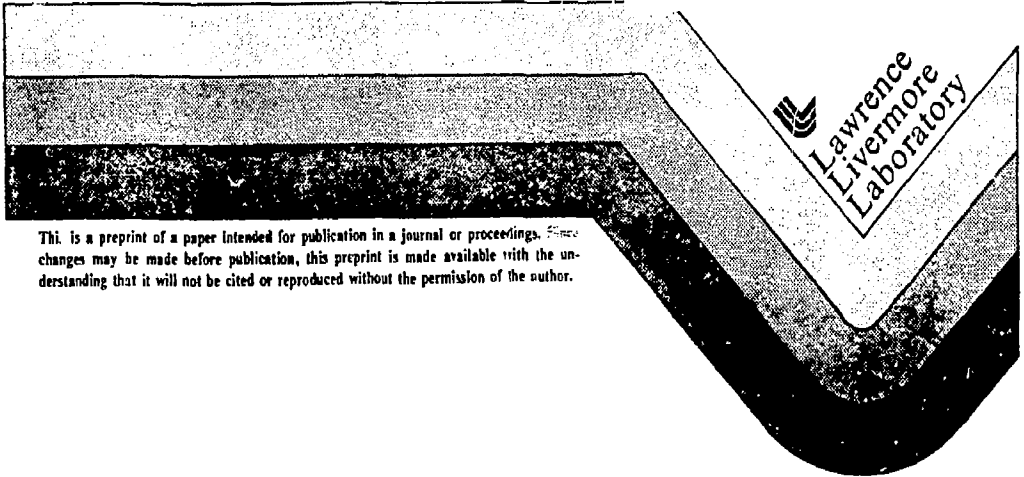
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ACCELERATION OF MAGNETIZED PLASMA RINGS*
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Introduction

In an earlier publication¹ we considered acceleration of plasma rings (Compact Torus). Several possible accelerator configurations were suggested and the possibility of focussing the accelerated rings was discussed. In this paper we consider one scheme, acceleration of a ring between coaxial electrodes by a B_0 field as in a coaxial rail-gun. If the electrodes are conical, a ring accelerated towards the apex of the cone undergoes self-similar compression (focussing) during acceleration. Because the allowable acceleration force¹ $F_a = \kappa U_m / R$ ($\kappa < 1$) increases as R^{-2} , the accelerating distance for conical electrodes is considerably shortened over that required for coaxial electrodes. In either case however, since the accelerating flux can expand as the ring moves, most of the accelerating field energy can be converted into kinetic energy of the ring leading to high efficiency.

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** Consultant S. Levy Inc., Campbell, California.

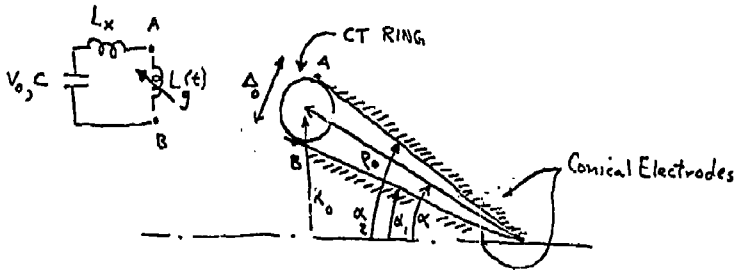


FIGURE 1: Geometry and Circuit. Here $L_g = \frac{\mu_0}{2\pi} \ln \left[\frac{\tan \frac{\alpha_2}{2}}{\tan \frac{\alpha_1}{2}} \right] (\rho_0 - \rho)$.

Equations of Motion

We consider a ring between electrodes as shown in Fig. 1. Since the ring approximately conserves flux ψ_p, ψ_T during acceleration, and since $p \ll B^2/2 \mu_0$, so that $B_T \simeq B_p$, it is readily seen that the aspect ratio a/R remains constant as R changes. We note that the net accelerating force on the ring is due to the B_y field behind the ring, $F_{By} = (dL_g/d\rho) (I^2/2)$ and the component of the equilibrium force along the cone, $\bar{F}_{eq} \cdot \hat{\rho} \simeq U_m/\rho$. The ring motion is given by,

$$M_r \ddot{\rho} - F_{drag} = U_m/\rho - L'_g I^2/2 \quad (1)$$

where U_m and M_r are the ring's magnetic energy and mass respectively. F_{drag} is computed from the eddy current dissipation in the electrode surfaces. Approximately, $F_{drag} = (2\delta/\Delta^2) U_m$ where δ is the skin depth allowing for velocity-dependent and diffusive penetration of the ring fields. The electrode resistivity η used to compute δ is corrected for nonlinear diffusion.²

Equation (1), the driving circuit equation,

$$V_0 - \int \frac{I dt}{c} = \frac{d}{dt} [(L_x + L_g) I] \quad (2)$$

and the energy equation,

$$U_m = \dot{U}_m \Big|_{\text{compression}} - \dot{U}_m \Big|_{\text{skin loss}} - \dot{U}_m \Big|_{\text{plasma resistance}}$$

are solved numerically for the ring motion.

Results and Summary

A number of problems have been studied using parameters approximating CT rings which have been produced by plasma guns, and using parameters appropriate to various high-energy, high power electromagnetic pulse sources (Python, SHIVA-STAR, etc.). Here we summarize one case, a ring accelerated in two phases by the SHIVA STAR capacitor bank.³ Phase I consists of adiabatically compressing the ring in an $\alpha = 90^\circ$ cone. Phase II allows the compressed ring to turn the corner and accelerate along an attached small-angle cone thus converting the stored magnetic energy into ring kinetic energy. The results are given in the table.

If the ring at the maximum kinetic energy (4.4 MJ) were allowed to strike a target, the deposition power would be roughly 1.2×10^{16} watts ($\tau \approx .3$ nsec) with a power density of 5.3×10^{15} watts/cm². Only the ring mass is specified here, the choice of ion species being left to further optimization.

TABLE
Phase I Initial State

t = 0							
L_x	Δ_0	R_0	M_r	U_{m0}	T_e	B_{ave}	U_{cap}
nH	cm	cm	gm	10^5 joules	eV	MG	10^5 J
40	15	50	1(-4)	0.4	10	1.3(-2)	93.3

Phase I Final State

t = 10.0 μ sec							
R	L	I	U_{cap}	U_L	U_m	U_{mlost}	B_{ave}
cm	nH	DMA= 10^7 A	10^5 J	10^5 J	10^5 J	10^5 J	MG
5.7	66.7	1.4	19.5	69.2	1.9	1.2	0.77

Phase II Maximum Kinetic Energy State

t = 10.58 μ sec							
R	U_m	U_k	V_{ring}	E_k	Δ	B_{ave}	L_{acc}
cm	10^5 J	10^5 J	cm/ μ sec	eV/nucleon	cm	MG	cm
1.1	9.2	44.0	930.0	4.4×10^6	0.33	20.0	400

References

1. P.R. Lett., V. 48, No. 14, April 5, 1982, p. 929.
2. "Pulsed High Magnetic Fields", H. Knoepfel, N. Holland Pub. Co. 1970, p. 73.
3. SHIVA-STAR is a 9.3 MJ Upgrade of SHIVA-II see; W. Baker, et al., paper ID5-6 Proc. 1982 IEEE Int. Conf. on Plasma Science, May 1982, Ottawa, Canada.