RECENT PROGRESS IN THE
EXPERIMENTAL STUDIES OF RELATIVISTIC ELECTRON
COILS

(ANNUAL PROGRESS REPORT)

(Sept. 1973 - Sept. 1974)

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PREPARED FOR THE U.S. ATOMIC ENERGY COMMISSION
UNDER CONTRACT NO. AT(11-1)-2319

MASTER

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Annual Progress Report
on the
EXPERIMENTAL STUDIES OF RELATIVISTIC ELECTRON COILS AT(11-1)2319

Since the writing of the last proposal, approximately one year ago, progress has been achieved in various areas. The various results have been and will be described in detail in various publications, a list of which is enclosed at the end of this report. This work progress can be summarized as follows:

1. The RECE-Berta measurements in which a vertical field gradient of up to about 1% was added to the existing mirror field and the respective detailed analysis were completed. Its results (published in LPS report #140) reconfirm the earlier suggestion that the observed changes in the ring position agree well with shifts in the equilibrium position of the rings, as they can be readily calculated theoretically. (Figure 1 shows the respective comparison for various cases.) Very clearly, no indications of instabilities induced by such field gradients have been found.

2. The measurements and the analysis on the changes in the average energy of the fast electrons were also completed. The final results (reported in LPS 139) are summarized in Table I. As it appeared from our preliminary results last year, these energy changes $(dE/dt)_{\text{expt}}$ are fully consistent with the theoretical values, $(dE/dt)_{\text{net}}$, calculated from the balance of the collisional energy loss rates, $(dE/dt)_{\text{gas}}$ and the energy gains $(dE/dt)_\beta$ from the betatron-type acceleration of the electrons in the decaying self-field of the rings.

3. During the vertical-gradient measurements described under 1, it was observed that a vertical field gradient of about 2.3×10^{-2}

FIGURE 1. Experimental (full lines) and theoretical (dashed) vertical displacement of electron rings.

SUMMARY OF RESULTS

<u>WIRE POSITION</u>	$\left(\frac{dE}{dt}\right)_{\text{GAS}}$	$\left(\frac{dB}{dt}\right)_{\text{PR.}}$	$\left(\frac{dE}{dt}\right)_{\beta}$	$\left(\frac{dE}{dt}\right)_{\text{NET}}$	$\left(\frac{dE}{dt}\right)_{\text{XPT'L}}$
EDGE	-7	-5	+3	-4.5 ± 1.5	-7 ± 3
CENTER	-7	-8	+5	-2.8 ± 1.5	-2 ± 3
	keV/ μ s	G/ μ s	keV/ μ s	keV/ μ s	keV/ μ s

Fig. I. Comparison of the theoretically expected rate-of-change of the average electron energy, $(dE/dt)_{\text{net}}$, with the experimentally measured values, $(dE/dt)_{\text{exp}}$.

Gauss/cm existed in the standard mirror field which had been used also in our earlier measurements of the decay rates of the magnetic probe signals. Therefore, the decay rate and the level at which the final dump occurred was determined as a function of the externally applied field gradient. Figure 2 shows the results. Both quantities exhibit a clear minimum around an external gradient of about $2 - 3 \times 10^{-2}$ Gauss/cm where the intrinsic field gradient of the machine just is canceled by the externally applied gradient. Both minimum values are smaller than the respective values without external field gradient by almost a factor 2. The minimum value of the decay rate now falls exactly on the value theoretically predicted earlier. Also, the minimum value of the dump level is now fully consistent with the one theoretically predicted, so that this dump now can be identified as due to the precessional mode already observed in the ~~Livermore-Astron~~ experiment. These results have been published in a report LPS 147.

4. As mentioned before, it could be shown that this precessional mode can be stabilized not only by a toroidal field B_0 (as in the Astron), but also in a minimum-B Ioffe mirror system. A theoretical model for this stabilization was developed, which gives excellent agreement with the measured dependence of the dump level on the strength of the quadrupole field (see Figure 3). Somewhat larger quadrupole fields were capable of suppressing the final dump of our rings even against field gradients of several 10^{-2} Gauss/cm (corresponding to magnetic field differences of about 1% across the rings). These results are presently being prepared for publication. Most recent observations indicate the occurrence of an instability of strong rings when too large Ioffe field components are used.

Fig. 1. Dependence of the dump level (a) and decay rate (b) on the relative external field gradient.

The experimental conditions are the same as in Fig. 2.

Fig. 1

EFFECT OF QUADRUPOLE FIELD ON DUMP LEVEL

Figure 3. Dependence of dump level on strength of Ioffe field.

This effect is presently under investigation.

5. In spite of the mentioned serious curtailment of our RECE-Christa effort due to the existing funding level, it was possible to extend the ring lifetime in this machine to about 250 μ sec (Figure 4) and to obtain a few rings which exhibited field reversal on the axis of the machine. Also, the construction of the pulsed B_θ -field (up to 1 K Gauss) has been completed, and first measurements using it are in progress.

6. As mentioned above, it was also possible to extend the ring lifetime in the small cusp experiment to over 80 μ sec using beam injection into a pulsed gas puff (see Figure 5).

7. For the analysis of various experiments, the radial image field indices for our rings were needed. Since these indices had been calculated so far only for axially long rings, new calculations had to be performed for the geometry of our rings. These calculations then were extended to investigate the dependence of the ring thickness and on the current distribution in the rings. These latter parameters do not appear to have a large influence. The calculations presently are being prepared for publication.

8. A systems analysis for fusion reactors based on plasma confinement in high-energy ion rings was completed. The results of this analysis are collected in the report LPS 148 which is included in the Appendix. This analysis indicates that significant power gains can be expected from an Astron-type reactor using rings of several hundred MeV protons or deuterons, if these ion rings are generated by adiabatic compression of low-energy ion rings. If feasible, this type of reactor may have a significant economic advantage over the more conventional fusion schemes.

INJECTOR CURRENT
17.4 KA/DIV

PROBE #2
28 G/DIV

200ns/DIV

PROBE #3
28 G/DIV
RC=300 μ s
PROBE #4
45 G/DIV
RC=955 μ s

PROBE #5
70 G/DIV
RC=300 μ s

50 μ s/DIV

Fig. 1. Ion jet-30 μ s pulse duration
and 10 μ s rise time.

8B PROBE SIGNALS

ST'D H_2
5/30/73

PULSED H_2
2/24/74

PULSED H_2
2/24/74

FI 5. Long-time trapping in the cusp with standard and pulsed H_2^- gas filling.

PUBLICATIONS AND PRESENTATIONS AT SCIENTIFIC MEETINGS

a) Scientific Reports Completed Since Last Proposal

1. "Observations of the Stable Equilibrium and Classical Diffusion of Field-Reversing Relativistic Electron Coils", D. A. Phelps, A. C. Smith, Jr., D. M. Woodall, R. A. Meger, and H. H. Fleischmann, (LPS 138) (accepted for publication in Phys. Fluids).
2. "Experiment and Theory on the Effects of Magnetic Field Gradients on Strong Relativistic Electron Rings", R. A. Meger, R. V. Lovelace, D. M. Woodall, and H. H. Fleischmann, LPS 140 (accepted for publication in Phys. Fluids).
3. "Increase of the Apparent Dump Level of Strong Electron Rings due to Magnetic Field Gradients", D. M. Woodall, and H. H. Fleischmann (submitted for publication in Phys. Fluids).
4. "Experiments on the Long-Time Interaction of Trapped Relativistic Electron Rings", A. C. Smith, Jr., C. E. Swannack, and H. H. Fleischmann (submitted for publication to Nucl. Fusion).
5. "On the Generation of High-Energy Ion Rings for Plasma Confinement", H. H. Fleischmann (submitted for publication on Nucl. Fusion).
6. "Stabilization of the Precessional Instability of E-Layers by Quadrupole Ioffe Fields", D. M. Woodall, H. H. Fleischmann, and A. Sleeper (in preparation).

b) Talks to be Presented at the Plasma Division Meeting at Albuquerque.

1. "Status of Relativistic Ring Experiments at Cornell", H. H. Fleischmann, Invited talk.
2. "Trapping of Strong Relativistic Rings in a Minimum-B Mirror Field Without Conducting Walls," S. Luckhardt, D. M. Woodall, and H. H. Fleischmann.
3. "Quadrupole Stabilization of the Precessional Mode of Trapped Relativistic Electron Rings", D. M. Woodall, and H. H. Fleischmann.
4. "Experiments on the Trapping Process in RICE-Berta", A. C. Smith, Jr. and H. H. Fleischmann.