Association for Information and Image Management
1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

DOE/ER/54178--4

Technical Progress Report

Studies of Longitudinal Instability with an Electron Beam

DOE Grant No. DEFG02-92ER54178

for the Period

September 1, 1993 to February 28, 1994

Submitted to

Department of Energy

Submitted by

Electrical Engineering Department

and

Institute for Plasma Research

University of Maryland

College Park, MD 20742

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

UNIVERSITY OF MARYLAND

INSTITUTE FOR PLASMA RESEARCH

COLLEGE PARK, MARYLAND

20742-3511

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Technical Progress Report

Studies of Longitudinal Instability with an Electron Beam

DOE Grant No. DEFG02-92ER54178

for the Period
September 1, 1993 to February 28, 1994

Submitted to
Department of Energy

Submitted by
Electrical Engineering Department
and
Institute for Plasma Research
University of Maryland
College Park, MD 20742

TABLE OF CONTENTS

I. Introduction and Summary 1

II. Experiments on Space-Charge Waves 2

1. Generation of localized space-charge waves 2

2. Determination of the geometry factor g 3

3. Effect of beam edges on space-charge waves 3

4. Verification of smooth approximation theory 4

5. Beam diagnostics with localized space-charge waves 5

III. Resistive-Wall Instability Experiment 5

IV. Related Research 7

References 9

List of recent papers related to this research project 11

Appendix: Copies of relevant papers 14

Reprints & Preprints removed

1. Introduction and Summary

This progress report covers the research on the "Study of Longitudinal Instability with an Electron Beam" performed at the University of Maryland during the period from September 1, 1993 to February 28, 1994 of the two-year grant sponsored by the Department of Energy, under Grant No. DEFG02-92ER54178.

Our research is motivated by the issue of longitudinal instability in induction linacs as drivers for heavy ion inertial fusion [1,2]. The Fusion Policy Advisory Committee (FPAC) in its final report to DOE (September 1990) identified longitudinal instability as a key physics problem that needs to be solved if an induction linac is to be developed into a successful HIF driver. The FPAC report also stated that "in parallel" to the design and construction of ILSE "enhanced theoretical and experimental efforts are required for an improved understanding of potentially serious longitudinal beam instability issues". Our experiment with electron beams in this area is a low-cost way to gain a thorough understanding of the instability and to test computer codes in collaboration with LBL, LLNL, and I. Haber at NRL.

We stated in the Proposal that our primary goal for the revised first year (August 1, 1992 to August 31, 1993) program would be to study the evolution of a small perturbation in the current pulse (introduced via the grid voltage on the electron gun) when the beam propagated through our 5-m long periodic solenoid channel. Specifically, we wanted to see if the perturbation was reflected from the rear end of the pulse. For the second year program (September 1, 1993 to August 31, 1994), we wanted to perform the resistive-wall instability experiment in the 1-m long solenoid channel, as described in Section 4a of the proposal.

The last six months saw the transition of the research activities from phase 1 to phase 2. By the end of last September, the experiments on space-charge waves had been completed. This had fulfilled our first year's goal of this two-year grant. Though the completion of the experiments was one month later than that scheduled and the data analysis still continues up to now, we have done much more than we originally proposed.

The study on space-charge waves has produced very interesting, unexpected results which concern the fundamental beam physics and new applications. A paper reporting the generation of localized space-charge waves was published in Physical Review Letters last September. The study of the evolution of small perturbations in the beam current pulse

resulted in a paper on the determination of the geometry factor g under longitudinal perturbations in a space-charge dominated beam, which was submitted to Physical Review Letters for publication. The experimental results of the effect of bunched beam edges on space-charge waves are still in analysis and a paper on this subject will be submitted to Physical Review Letters for publication in the near future.

Besides the g-factor measurement, other by-products of the experiments on space-charge waves include a paper on the experimental verification of the smooth-approximation theory in a periodic solenoid focusing channel, which was submitted to Applied Physics Letters for publication, and a paper describing the new method of beam diagnostics with localized space-charge waves, submitted for publication to Review of Scientific Instruments. In addition, an invited review paper on the "Localized Space-Charge Waves in a Space-Charge Dominated Beam" will be submitted for publication to the International Journal of Modern Physics B.

For the resistive-wall instability experiment, we have made a significant effort to test the uniformity of the second glass tube with resistive-film coating, manufactured by the Chinese Vacuum Institute in Beijing. Both the optical and electrical uniformity tests have revealed some problems with the tube. The Institute now agrees to replace this tube without charge and two more tubes have also been ordered. We have already started to assemble the resistive-wall instability experiment, which is the major goal of our proposal for the second year of the grant. We expect to start taking experimental data by the late spring, 1994.

A brief report on our activities under this grant during this period is given below.

II. Experiments on Space-Charge Waves

1. Generation of localized space-charge waves

Our results on this subject were reported in the last progress report. What we have discovered was the first experimental evidence that a single fast wave, or a single slow wave, or any combination in amplitudes and polarities of these two waves can be generated. A time-domain approach was developed for the theoretical analysis of this phenomenon. The dependence of space-charge waves on initial perturbation conditions (velocity, density and current) was examined. The analysis yielded the conditions for degeneracy of two waves, indicating that this is a phenomenon in space-charge dominated

beams. A paper entitled "Generation of space-charge waves due to localized perturbations in a space-charge dominated beam" was published in Physical Review Letters last September and is included in the Appendix. The technique developed from this experiment will be employed to the resistive-wall instability experiment.

2. Determination of the geometry factor g

The preliminary measurement of the g-factor was reported in the last progress report. Since then, further experiments were performed during last September to refine the measurement. The purpose of this experiment was to accurately measure the g-factor in a wide parameter range by the localized space-charge wave method [3], and at the same time independently to measure the corresponding beam radius by the phosphor screen plus CCD camera technique [4]. This should provide the parametric dependence of the g-factor on the beam radius, and verify the correct g-factor formula, about which there has been some confusion in the beam physics community [5]. In addition to the experimental work, a new theoretical model has been developed to compare with the measurement. A satisfactory agreement between the experiment and theory has been achieved. The issue of the g-factor not only concerns the numerical value of this parameter, but also, more importantly, concerns some fundamental beam physics, such as surface wave or body wave, density bunching or beam radius rippling, etc. [6]. A paper summarizing this study has been submitted to Physical Review Letters for publication. A copy of the paper is included in this report in the Appendix. The topic is also discussed in the book by M. Reiser [7] to be published in Spring 1994.

3. Effect of beam edges on space-charge waves

The study of the beam edge effect on space-charge waves was a major goal in our first year's research proposal. The issue of the edge reflection and/or transmission of space-charge waves in bunched beams concerns how to correctly estimate the overall growth of the longitudinal instability in accelerators. The previous studies on this subject included computer simulations [8] and theoretical work [9].

We performed the experimental study on this topic before last summer. The preliminary results were reported in the last progress report and presented at the HIF Conference in Frascati, Italy, June 1993 [10]. In that experiment we produced two space-charge waves and placed the initial perturbation close to the beam rear edge. Both reflection and transmission of the slow wave at the rear edge were observed. The speed of

the reflected wave and transmitted wave were measured. The problem with that experiment was that the perturbation signals on the beam were rather small, not significantly above the noise level.

More experiments on the edge effect were performed last September to study the phenomena on the beam front edge. A single fast wave with rather large amplitude was employed and initially placed very close to the beam front edge. The splitting of the fast wave into two waves, namely, the reflected wave and transmitted wave, was observed. The perturbation signals were well above the noise level. The speed of the reflected and transmitted waves were carefully measured with respect to the beam center. The results showed that the reflected wave, co-moving with the beam edge towards the beam pulse center, has the same speed as the beam edge erosion speed [11]. The transmitted wave also has approximately the same speed, moving down to the beam edge. This may be caused by a larger g-factor there, though the beam current, as well as the line-charge density, is getting smaller on the edge.

Computer simulation on this experiment is in progress with the help of Dr. Haber of NRL. So far the phenomenon of transmission and reflection has not been seen conclusively in the simulation. A technical report entitled "Experiment on beam edge effect on space-charge waves in a bunched electron beam" summarizes this research and is included in the Appendix.

4. Verification of smooth approximation theory

This is a by-product of our experiments on space-charge waves. During the experiment on the g-factor measurement by the method of space-charge waves, we compared the beam radii measured by the phosphor screen plus CCD camera technique with the analytical results from the smooth approximation theory, and found some very interesting results.

The smooth approximation theory for intense beams was developed by M. Reiser long ago [12] and is widely used in the design and analysis of intense beams to predict the average beam radius and maximum ripples in a periodic focusing channel. There was no experiment previous to verify the theory for axially symmetric, periodic focusing channels. The prediction of the theory for the radius of a space-charge dominated electron beam in a periodic solenoidal focusing channel was this time checked experimentally over a wide range of beam parameters and focusing conditions. The phase advance without space-

charge, σ_0, was varied from σ_0=45° to σ_0=90°, and the tune depression due to space-charge, σ/σ_0, was in the range of 0.2 to 0.3 in the experiment.

We have found that the experiment and theory agreed very well when the magnetic focusing was not too weak. But, for σ_0 approaching 45°, the discrepancies between the experiment and theory increased. This was caused by a spherical lens aberration existing in the experiment, but not included in the theory. By taking the third order term of the magnetic field expansion into account in the hard-edge approximation of the focusing magnetic field, this non-linear effect can be included in the original theory. Finally, the smooth-approximation results were found to agree with the experimental data to better than 5%. A paper entitled "Experimental Verification of the Smooth-Approximation Theory for a Space-Charge Dominated Beam in a Periodic Focusing Channel" summarizes this study and has been submitted to Applied Physics Letters for publication.

5. Beam diagnostics with localized space-charge waves

Through the study of space-charge waves, we have developed a new method for beam diagnostics by employing the localized space-charge waves. The traditional applications of space-charge waves are always with sinusoidal signals [13]. The advantage of the localized space-charge waves is that the beam current or energy signal contains individual slow and fast waves. The propagation speed of the two waves can be easily and accurately measured from the beam current waveforms or energy signals. This results in a number of beam parameters such as the g-factor, the beam radius, the longitudinal wave impedance, the growth rate in a resistive channel, etc. In addition, some measurements such as the reflection and transmission of waves on beam edges may not be possible with sinusoidal signals. A paper entitled in "Beam Diagnostics with Localized Space-Charge Waves" summarizes this study and has been submitted for publication to Review of Scientific Instruments.

III. Resistive-Wall Instability Experiment

The resistive-wall instability experiment is the second phase of this research project. After the successful completion of the first phase, i.e. the experiments on the generation, propagation and edge effect of space-charge waves, we are ready to run the resistive-wall instability experiment soon. The short-pulse electron beam injector is now available, and the resistive-wall channel and the diagnostics are complete. The installation of the whole

experimental system is in progress. We expect to have the first results from this experiment by late spring or early summer of 1994.

The experimental goals are twofold First, we will measure the growth rate of the slow wave due to localized perturbations in a coasting beam as well as the decay rate of the fast wave produced in the same way. This will provide the information to compare the existing theory and experiment. Second, we will study experimentally the beam quality deterioration due to the instability, especially the longitudinal energy spread or emittance growth in this process. The longitudinal energy spread or the emittance growth due to the resistive-wall instability in a space-charge dominated beam is a very important issue to heavy ion inertial fusion drivers and other advanced accelerator applications. This has not been experimentally studied before in the microwave or accelerator research community, as far as we know.

The beam parameters for the resistive-wall experiment are determined as follows [14, 15]. The spatial growth rate k_i of the slow wave in a non-relativistic electron beam traveling in a resistive-wall channel is proportional to the wall resistance R^* per unit length, the square root of the beam current I, and inversely proportional to the fourth root of the beam voltage V, as shown in the relation

$$k_i = \left(\frac{1}{2}\frac{q}{m}\pi^2\varepsilon_0^2\right)^{1/4}\left(\frac{I}{g\,V^{1/2}}\right)^{1/2} R^* .$$

Here q/m denotes the ratio of charge to mass of the particles, ε_0 is the permittivity of free space, and g=2ln(b/a) is the geometry factor discussed in Section II(2). Due to the mass dependence, the instability growth rate is significantly enhanced if electrons are used in place of heavy ions. Furthermore, to observe the instability in a reasonably short distance, a beam with large current and low energy is desirable. Most importantly, the wall resistance should be substantially greater than the 100-200 Ω/m expected for a heavy-ion system. Nevertheless, the wall resistance is limited by the condition that the space charge force is dominant, and by the external distributive capacitance. Though a larger beam current will result in a higher growth rate, the beam power loss in the wall is also higher. Decreasing the beam voltage only increases the growth rate mildly, but reduces the initial beam power drastically. A trade-off has to be made for a useful experiment. For example, an electron beam of 100 mA current and 5 keV energy can yield a spatial growth rate of 0.38 in a one-meter channel of a 5 kΩ resistance. In practice, the distributive capacitance always reduces the growth rate. Assuming a distributive capacitance C of 30 pF/m, the

spatial growth rate would be reduced to k_i=0.32/m at a perturbed wave frequency of 100 MHz. This corresponds to a 38% increase in the slow wave amplitude and the same amount of decrease in the fast wave amplitude. We should be able to observe these amplitude changes in the experiment. The beam power loss in such a channel is 50 W in comparison with the initial beam power of 500 W. These parameters will be verified in the experiment.

We have ordered two 1-meter long glass tubes with very thin resistive material coating of about 5 kΩ/m, manufactured by the Chinese Vacuum Institute in Beijing. Unfortunately, the first tube was broken during the early installation. After rejoining the remaining two pieces, the first tube has a length of 71.5 cm and a total resistance of 1.77 kΩ. The second tube was received with a severe defect, non-uniformity of the resistive coating. A lot of effort was made to prove the problem. Both optical and electric measurements revealed the non-uniformity of the tube. After negotiation with the manufacturer, the Chinese Institute has agreed to replace this tube at no charge. We have also ordered two more tubes for future use. We expect to receive them by this April.

The installation of the resistive-wall experiment with the existing tubes is now in progress. Due to the short length and small resistance of the first tube and the non-uniformity of the second one, we do not expect good results from this setup. But, we believe this is an important step to start with, to get us familiarized with the system and equipment. The new tubes will be installed for data-taking after their arrival. A conducting tube with the same dimension will also be employed for comparison study. We hope that we will have interesting experimental results to present for the next progress report, due August 31, 1994.

IV. Related Research not Directly Sponsored by This Contract

Besides the experiments on space-charge waves, the last six months also saw the research activities in other projects which were closely related to the Heavy Ion Fusion program, but funded by the High Energy Physics Office of the Department of Energy. The data analysis of the longitudinal compression experiments, completed last summer, still continues. We have written a paper entitled in "Restoration of Rectangular Pulse Shape after Edge Erosion for a Space-Charge Dominated Electron Bunch" and submitted it to Physical Review Letters for publication. This concerns a novel method to deal with the longitudinal dynamics of rectangular bunches in high current machines. It is very likely we

can apply this technique to our proposed electron ring to achieve a space-charge dominated beam. The comparison of the parabolic bunch compression experiment with computer simulation is undertaken by I. Haber. The results will be submitted for publication.

There has also been a significant amount of theoretical work related to heavy ion inertial fusion, but not in the main directly sponsored by this contract. Two studies should be mentioned in this context. One was a collaborative effort between Ingo Hofmann and R. W. Hasse at GSI Darmstadt and M. Reiser on intensity effects in final focusing for heavy ions [16]. Its main conclusion is that the outer beamlets in a bundle must be injected into the target chamber with a convergence that is greater than the geometrical angle to overcome the space-charge repulsion and to hit the target spot. The effect is particularly worrisome for the charge state $Z>1$, is very sensitive to the beam current, and requires fast beam steering in the final focusing system.

The second study, involving graduate students C. Allen and N. Brown under M. Reiser's supervision, was concerned with a very extensive calculation of image effects in bunched beams propagating through a cylindrical pipe. Its main results are the numerical calculation, graphical display and tabulation of the effective longitudinal g-factor as a function of the bunch eccentricity Z_m/a and radius a. This work has been submitted for publication in Particle Accelerators [17] and the results are also presented in the book scheduled for publication in Spring 1994 (Ref. [7], Section 5.4.7).

References:

[1] E. P. Lee and L. Smith, in Conf. Record of the 1991 IEEE Particle Accelerator Conference, San Francisco, CA, (IEEE 91CH3038-7, Piscataway, NJ, 1991), Vol. 3, p. 1737.

[2] E. P. Lee, IL Nuovo Cimento A, **106** (11-12), 1993.

[3] J. G. Wang and M. Reiser, to be submitted for publication to Rev. Sci. Instr..

[4] D. Kehne, K. Low, M. Reiser, T. Shea, C. R. Chang, and Y. Chen, Nucl. Instr. & Meth. in Phys. Res. A**278**, pp. 194-197, 1989.

[5] J. D. Lawson, The Physics of Charged-Particle Beams, (Oxford University Press, New York, 1988), second edition, Section 6.3.

[6] A. W. Trivelpiece and R. W. Gould, J. of Appl. Phys., **30** (11), 1784 (1959).

[7] M. Reiser, Theory and Design of Charged Particle Beams, (John Wiley & Sons, Inc., to be published in Spring, 1994.), Section 6.3.2.

[8] D. A. Callahan, A. B. Langdon, A. Friedman, and I. Haber, in the Proceedings of the 1993 Particle Accelerator Conference, Vol. 1, p. 730, Washington, D. C., May 17-20, 1993.

[9] M. Lampe, unpublished.

[10] J. G. Wang, D. X. Wang, D. Kehne, M. Reiser, and H. Suk, IL Nuovo Cimento A, **106** (11-12), 1993.

[11] A. Faltens, E. P. Lee, and S. S. Rosenblum, J. Appl. Phys., **61**(12), 5219 (1987).

[12] M. Reiser, Particle Accelerators, **8**, 167 (1978)

[13] A. H. W. Beck, Space-Charge Waves and Slow Electromagnetic Waves, (Pergamon Press, New York, 1958).

[14] J. G. Wang, M. Reiser, W. M. Guo, and D. X. Wang, Particle Accelerators, vols. **37-38**, pp. 181-189, 1992.

[15] J. G. Wang and M. Reiser, Physics Fluids B, 5(7), July 1993.

[16] I. Hofmann, R. W. Hasse, and M. Reiser, J. Appl. Phys. **73**, 7061 (1993).

[17] C. Allen, N. Brown, and M. Reiser, "Image Effect of Bunched Beams in Axisymmetric Systems", CPB Tech. Report #93-045, Aug. 10, 1993; to be published in Part. Accel.

List of Recent Papers and Presentations Related to This Research Project

I. Invited and Contributed Presentations

1. M. Reiser, "High Intensity Beams: Stability and Halo Formation", invited talk given in the workshop on Accelerators for Future Spallation Neutron Sources, Santa Fe, NW, February 15-21, 1993.

2. M. Reiser, "Simulation of Heavy Ion Beam Dynamics with Electrons', invited talk given in the International Symposium on Heavy Ion Inertial Fusion, Frascati, Itaiy, May 25-28, 1993.

3. J. G. Wang, "Experimental study of longitudinal dynamics of space-charge dominated beams", invited talk given in the Department of Nuclear Engineering, The University of Michigan, Ann Arbor, MI, October 8, 1993.

4. J. G. Wang, D. X. Wang, D. Kehne, and M. Reiser, "Experimental and Theoretical Studies of Space-Charge Waves in a Bunched Electron Beam", presented at the 1993 International Symposium on Heavy Ion Inertial Fusion, Frascati, Italy, May 25-28, 1993.

5. D. X. Wang, J. G. Wang, M. Reiser, and I. Haber, "Longitudinal Compression and Expansion of Electron Bunches with Parabolic and Rectangular Density Profiles", presented at the 1993 International Symposium on Heavy Ion Inertial Fusion, Frascati, Italy, May 25-28, 1993.

6. J. G. Wang, D. X. Wang, M. Reiser, and H. Suk, "Experiments on Space-Charge Waves due to Localized Perturbations in a Space-Charge Dominated Electron Bunch", presented at the 35th Annual Meeting, APS Division of Plasma Physics, St. Louis, Mo., 1-5 November, 1993.

7. M. Reiser, J. G. Wang, H. Suk, and D. X. Wang, "Determination of the Geometry Factor for Longitudinal Perturbations in Space-Charge Dominated Coasting Beams", submitted to the 1994 Annual Meeting of the Division of Physics of Beams, APS Spring Meeting, Washington, D. C., April 18-22, 1994.

8. J. G. Wang, D. X. Wang, H. Suk, and M. Reiser, "Study of the Edge Effect of Bunched Beams on Space-Charge Waves", submitted to the 1994 Annual Meeting of the Division of Physics of Beams, APS Spring Meeting, Washington, D. C., April 18-22, 1994.

9. D. X. Wang, J. G. Wang, and M. Reiser, "Reconstruction of Rectangular Pulse Shape for a Space-Charge Dominated Beam", submitted to the 1994 Annual Meeting of the Division of Physics of Beams, APS Spring Meeting, Washington, D. C., April 18-22, 1994.

10. H. Suk, M. Reiser, J. G. Wang, and D. X. Wang, "Experimental Verification of the Smooth Approximation Theory for a Space-Charge Dominated Beam in a Periodic Focusing Channel", submitted to the 1994 Annual Meeting of the Division of Physics of Beams, APS Spring Meeting, Washington, D. C., April 18-22, 1994.

II. Publications in Refereed Journals and Conference Proceedings

1. I. Hofmann, R. W. Hasse, and M. Reiser, "Intensity effects in final focusing for heavy-ion inertial fusion", J. Appl. Phys. **73** (11), June 1, 1993.

* 2. J. G. Wang, D. X. Wang, and M. Reiser, "Generation of Space-Charge Waves due to Localized Perturbations in a Space-Charge Dominated Beam", Phys. Rev. Lett., **71**(12), pp. 1836-1839, September 20, 1993.

3. J. G. Wang, D. X. Wang, D. Kehne, M. Reiser, and H. Suk, "Studies of Space-Charge Waves due to Localized Perturbations in an Electron Beam", IL Nuovo Cimento A, **106** (11-12), 1993.

4. D. X. Wang, J. G. Wang, D. Kehne, M. Reiser, and I. Haber, "Longitudinal Expansion and Compression of Electron Bunches with Rectangular Line Charge Profiles", IL Nuovo Cimento A, **106** (11-12), 1993.

5. C. Allen, N. Brown, and M. Reiser, "Image Effects for Bunched Beams in Axisymmetric Systems", to be published in Part. Accel.

* 6. J. G. Wang, H. Suk, D. X. Wang, and M. Reiser, "Determination of the Geometry Factor for Longitudinal Perturbations in Space-Charge Dominated Coasting Beams", submitted for publication to Phys. Rev. Lett..

* 7. H. Suk, M. Reiser, J. G. Wang, and D. X. Wang, "Experimental Verification of the Smooth-Approximation Theory for a Space-Charge Dominated Beam in a Periodic Focusing Channel", submitted to APL for publication.

* 8. D. X. Wang, J. G. Wang, and M. Reiser, "Restoration of Rectangular Pulse Shape after Edge Erosion for a Space-Charge Dominated Electron Bunch", submitted for publication to Phys. Rev. Lett..

9. J. G. Wang and M. Reiser, "Beam Diagnostics with Localized Space-Charge Waves", submitted for publication to RSI.

10. J. G. Wang, D. X. Wang, H. Suk, and M. Reiser, "Reflection and Transmission of Space-Charge Waves at the Edges of a Space-Charge Dominated Electron Bunch", to be submitted for publication to Phys. Rev. Lett..

11. J. G. Wang and M. Reiser, "Localized Space-Charge Waves in a Space-Charge Dominated Beam", invited review paper to be submitted to the International Journal of Modern Physics B.

12. D. X. Wang, J. G. Wang, D. Kehne, M. Reiser, and I. Haber, "Experimental Study of Longitudinal Dynamics of Space-Charge Dominated Parabolic Bunches", in the Proceedings of the 1993 Particle Accelerator Conference, Vol. 5, pp. 3627-3629, Washington, D. C., May 17-20, 1993.

13. J. G. Wang, D. X. Wang, D. Kehne, and M. Reiser, "Generation of Space-Charge Waves due to Localized Perturbations ", in the Proceedings of the 1993 Particle Accelerator Conference, Vol. 5, pp. 3282-3284, Washington, D. C., May 17-20, 1993.

14. N. Brown, M. Reiser, D. Kehne, D. X. Wang, and J. G. Wang, "Longitudinal Kinetic Energy Spread from Focusing in Charged Particle Beams", in the Proceedings of the 1993 Particle Accelerator Conference, Vol. 1, pp. 62-64, Washington, D. C., May 17-20, 1993.

15. I. Haber, D. A. Callahan, A. B. Langdon, M. Reiser, D. X. Wang, and J. G. Wang, "Computer Simulation of the Maryland Transport Experiment", in the Proceedings of the 1993 Particle Accelerator Conference, Vol. 5, pp. 3660-3662, Washington, D. C., May 17-20, 1993.

16. J. G. Wang, M. Reiser, H. Suk, and D. X. Wang, "Study of Space-Charge Waves in the Form of Localized Perturbations in a Space-Charge Dominated Beam", submitted to the 10th International Conference on High-Power Particle Beams, June 21-25, San Diego, CA.

17. N. Brown, M. Reiser, H. Suk, and J. G. Wang, "Effects of Beam and Channel Parameters on Energy Spread in Periodically Focused Electron Beams", submitted to the 10th International Conference on High-Power Particle Beams, June 21-25, San Diego, CA.

18. J. G. Wang and M. Reiser, "Studies of Localized Space-Charge Waves in Space-Charge Dominated Beams", submitted to the 17th International Linac Conference, August 21-26, Tsukuba, Japan.

III. Technical Report

1. J. G. Wang, D. X. Wang, and M. Reiser, "Analysis of Generation and Propagation of Space-Charge Waves due to Localized Perturbations in a Space-Charge Dominated Beam", CPB Technical Report #93-042, LPR, University of Maryland, College Park, July 1993.

2. C. Allen, N. Brown, and M. Reiser, "Image Effect of Bunched Beams in Axisymmetric Systems", CPB Tech. Report #93-045, Aug. 10, 1993.

3. J. G. Wang, H. Suk, D. X. Wang, and M. Reiser, "Determination of the Geometry Factor for Longitudinal Perturbations in Space-Charge Dominated Coasting Beams", CPB Technical Report #93-055, LPR, University of Maryland, College Park, October 1993.

4. H. Suk, M. Reiser, J. G. Wang, and D. X. Wang, "Experimental Verification of the Smooth-Approximation Theory for a Space-Charge Dominated Beam in a Periodic Focusing Channel", CPB Technical Report #94-001, IPR, University of Maryland, College Park, January 1994.

5. D. X. Wang, J. G. Wang, and M. Reiser, "Restoration of Rectangular Pulse Shape after Edge Erosion for a Space-Charge Dominated Electron Bunch", CPB Technical Report #94-003, IPR, University of Maryland, College Park, February 1994.

* 6. J. G. Wang, D. X. Wang, H. Suk, and M. Reiser, "Experimental Investigation of the Behavior of Space-Charge Waves at the Edges of Bunched Electron Beams", CPB Technical Report #94-004, IPR, University of Maryland, College Park, February 1994.

* Included in the Appendix.

DATE
FILMED
10/5/94

END