Lawrence Berkeley National Laboratory
Recent Work

Title
GENERATION OF MOMENTUM SPREAD WITH A CARBON GRATING

Permalink
https://escholarship.org/uc/item/57d8w9k0

Author
Lee, Edward P.

Publication Date
1981-08-01

eScholarship.org Powered by the California Digital Library
University of California

LBID-551
c 1

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

RECEIVED
LAWRENCE
BERKELEY LABORATORY
APR 21 1983
LIBRARY AND
DOCUMENTS SECTION

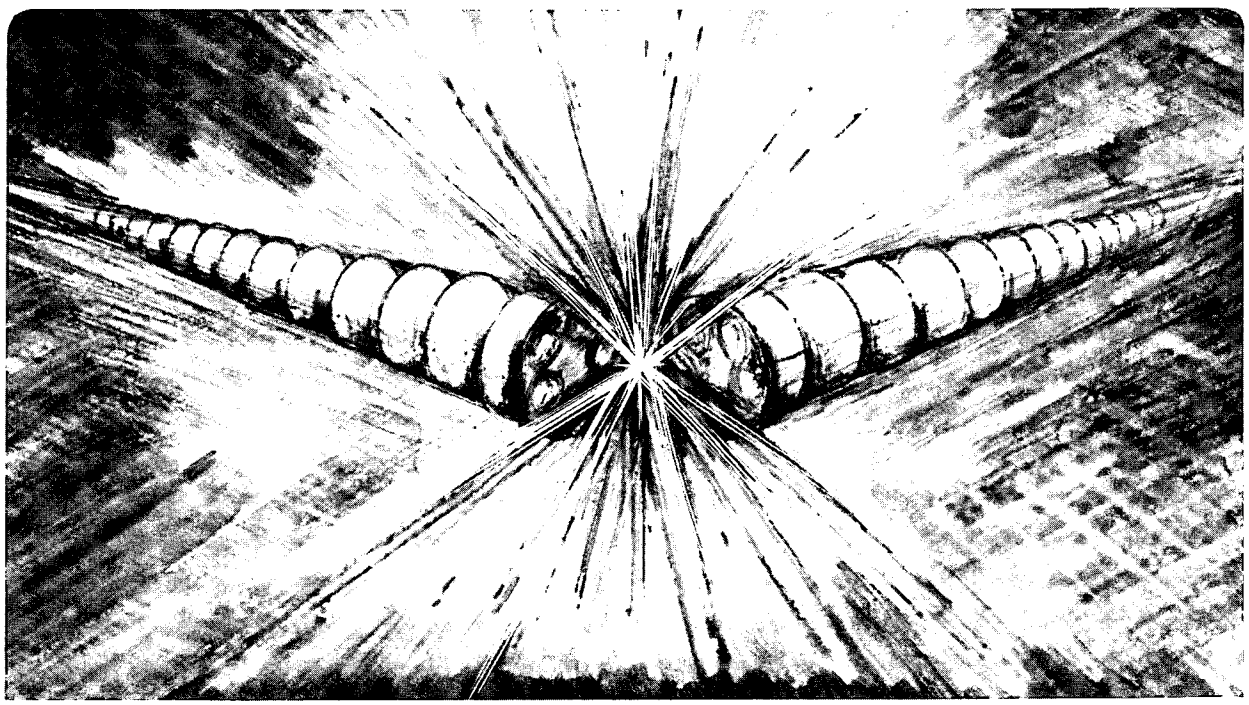
GENERATION OF MOMENTUM SPREAD WITH A CARBON GRATING

Edward P. Lee

August 1981

For Reference

Not to be taken from this room



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBID-551
1

LEGAL NOTICE

This book 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.

Lawrence Berkeley Laboratory is an equal opportunity employer.

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal 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 its 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, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBID-551
BETA-23

Lawrence Berkeley Laboratory

Technical Report of the Betatron Design Study

GENERATION OF MOMENTUM SPREAD WITH A CARBON GRATING*

Edward P. Lee

Lawrence Livermore National Laboratory
Livermore, California 94550

August 1981

in collaboration
with
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

*Sponsored by Defense Advance Research Projects Agency (DoD)
ARPA Order No. 3718, Amend. 37
Monitored by NSWC under Contract No. N60921-81-LT-W0031

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER BETA-23/LBID-551	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* GENERATION OF MOMENTUM SPREAD WITH A CARBON GRATING		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Edward P. Lee		8. CONTRACT OR GRANT NUMBER(s) N60921-81-LT-W0031
9. PERFORMING ORGANIZATION NAME AND ADDRESS Lawrence Livermore National Laboratory Livermore, California 94550		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61101E; 0; 0; 0R40AA
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency 1400 Wilson Boulevard, Arlington, Virginia 22209 Attn: Program Management/MIS		12. REPORT DATE August 1981 13. NUMBER OF PAGES 7
14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)* Naval Surface Weapons Center White Oak, Silver Spring, Maryland 20910 Attn: Code R401		15. SECURITY CLASS. *(of this report)* UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Betatron
negative-mass instability
momentum spread
emittance increase

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Momentum spread is produced in a relativistic electron beam by passing it through a carbon grating. At high power levels the beam radius must be kept large enough to avoid damage to the grating by heating. This requirement competes with the desire to keep emittance growth low.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

LBID 551
Beta 23
August 1981

Generation of Momentum Spread With a Carbon Grating

Edward P. Lee
Lawrence Livermore National Laboratory
Livermore, California

in collaboration
with
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Introduction

The negative mass instability is suppressed by sufficiently large momentum spread in the circulating beam. For electrons with I_b = 10 kA and E_o = 50 Mev the required spread has been estimated to be $\Delta P/P_o$ = 7.2 percent (full width - flat distribution), which considerably exceeds the intrinsic width expected from an induction linac injector. A simple method for introducing this spread is to pass the pulse through a grating prior to injection into the betatron (see figure), however, this produces a net energy loss, current loss and an emittance increase. There is also a possibility of breaking or melting the grating by the sudden deposition of heat.

The problem of heat deposition is reduced by increasing the beam's radius at the grating, but the emittance produced by scattering is thereby increased. It is found that there is a narrow window of beam radii within which these effects are tolerable for the contemplated injection parameters. We assume the grating is made of carbon (graphite), which is sturdy up to about 3000°C. Sequential pulses of a burst may pass through the grating at different transverse positions, so we only need to examine the effect of a single pulse.

It appears that there will be a severe problem of spallation if a single thick (~ .5 cm) grating is used, but this may be overcome with a more

complex design -- e.g., a series of thin gratings or construction from many separated fibers. The estimates given here are nearly independent of design details.

Thickness and Energy Loss

The stopping power and density of carbon are $E' = 1.90$ Mev cm^2/gm and $\rho = 2.25$ gm/cm^3. To achieve a $\pm$ 3.6 percent spread we use thickness

$$t_1 = \frac{3.6 \text{ Mev}}{E'\rho} = .84 \text{ cm},$$

and to hold the grating together we insert an extra thickness

$$t_o = t_1/20 = .042 \text{ cm}.$$

Energy and momentum are essentially equivalent since the electrons are highly relativistic, so the resulting spread is flat with

$$46.2 \text{ Mev} \lesssim E \lesssim 49.8 \text{ Mev},$$

$$\text{Mean Energy } \langle E \rangle = 48.0 \text{ Mev},$$

$$\text{Mean thickness } \langle t \rangle = (t_1 + 2t_o)/2 = .46 \text{ cm}$$

Bremsstrahlung and Current Loss

Scattering by carbon nuclei causes energy loss in the form of gamma rays. However, the dominant effect is loss of current because a beam particle which loses more than ~5 Mev will be lost in transport or will not be accepted by the betatron. To see this we note that the probability per electron for the emission of a photon of energy ε in the interval $d\varepsilon$ is

$$P(\epsilon)d\epsilon \approx \frac{<t>}{\lambda_R} \quad \frac{d\epsilon}{\epsilon} \quad ,$$

Where λ_R = 23.5 cm is the radiation length of 50 Mev electrons in carbon. This formula is valid for ϵ greater than a few hundred ev up to E_o, and the thin target distribution can be assumed since $<t><<\lambda_R$. Mean energy loss to photons is

$$- <\Delta E> \text{ rad} \approx \int_0^{E_o} \frac{d\epsilon}{\epsilon} \quad \frac{<t>\ \epsilon}{\lambda_R}$$

$$= \frac{<t>\ E_o}{\lambda_R} \quad = \frac{(.46)(50)}{(23.5)} = \ .98 \text{ Mev}$$

Since the energy loss spectrum [$\epsilon P\ (\epsilon)$] is independent of ϵ, 90 percent goes to photons with ϵ> 5 Mev. The electrons which suffer such a loss do not reach the betatron so we have current loss

$$-\left(\frac{\Delta I}{I}\right)_{\text{rad}} = \int_5^{50} \frac{d\epsilon}{\epsilon} \quad \frac{<t>}{\lambda_R} = \frac{<t>}{\lambda_R} \ln\ (10)$$

$$= \frac{(.46)\ln\ (10)}{(23.5)} = .045$$

This is a marginally significant value. The mean energy loss (to radiation) of the accepted particles is a negligible .098 Mev.

Temperature Rise

The specific heat of carbon rises from a value of .712 J/gm-°C at 25° C

to 2.08 J/gm-°C for T $\gtrsim$ 1500°C. We use the mean value C_v= 1.40 J/gm-°C. Then the temperature rise produced by a pulse of length τ_p is

$$\Delta T = \frac{I_b \tau_p E'}{\pi a^2 C_v} \quad ,$$

where (a) is the beam edge radius. Since the current density may be peaked on axis we allow a maximum increment ΔT_{max} = 1500°C [computed from this formula] instead of the actual limit of 3000°C. We therefore require

$$a \geq \left(\frac{I_B \tau_p E'}{\pi C_v (\Delta T)_{max}} \right)^{1/2}$$

$$= \left(\frac{10^4 \times 60 \times 10^{-9} \times 1.9 \times 10^6}{\pi \times 1.40 \times 1500} \right)^{1/2} = .416 \text{ cm}$$

The pulse is carefully focused down to this radius on the grating.

Emittance Increase

The pulse radius is made as small as possible to prevent an unacceptable increase of emittance by scattering. Factors of two are important here, so we must be careful with definitions. The usual 1-d emitance is

$$\pi Q = \pi x_{max} (dx/ds)_{max}$$

On passing through the grating the mean squared angle of the electron trajectories (total x-y projections) is increased by

$$\Delta\langle\theta^2\rangle = \Delta\langle(dx/ds)^2 + (dy/ds)^2\rangle =$$

$$= \sum \frac{|\delta P_\perp|^2}{P_o^2} = \frac{8\pi\rho\langle t\rangle Z(Z+1)r_e^2}{M\beta_o^4\gamma_o^2} \ln\left(\frac{\theta_{max}}{\theta_{min}}\right)$$

where $Z = 6$ and $M = 12.01$ amu are the nuclear charge and mass, $r_e = 2.82 \times 10^{-13}$ cm is the classical electron radius, and (β, γ) are the relativistic factors. The logarithmic factor is evaluated using the thin target formula:

$$\left(\frac{\theta_{max}}{\theta_{min}}\right) = \frac{Z^{2/3}(\rho\langle t\rangle/M)^{1/2}2\pi\hbar}{\sqrt{\pi}\, m\beta c} = 103.4$$

for the present case. We find

$$\Delta\langle\theta^2\rangle = 2.08 \times 10^{-3}(\text{rad})^2 \quad .$$

The relations between rms quantities and maximal (x, dx/ds) projections for a flat profile are

$$x^2_{max} = a^2 = 2\langle x^2 + y^2\rangle,$$

$$(dx/ds)^2_{max} = 2\langle\theta^2\rangle$$

The increment of Q^2 is therefore

$$(\Delta Q^2)\ \text{scat} = 2a^2 \Delta \langle \theta^2 \rangle$$

$$= 2 \times (.416)^2 \times (2.08 \times 10^{-13}) = .720 \times 10^{-3}\ (\text{r-cm})^2 \quad .$$

This (increment)^2 is to be added to the value Q^2 has before reaching the grating.

The induction linac ETA produces normalized emittance

$$\pi Q_N = \pi \beta \lambda Q = (.5)\pi \quad (\text{r-cm})$$

at 5 Mev, and this value will presumable be preserved in ATA up to 50 Mev. We thus expect

$$\text{initial } Q_N^2 \approx .25\ (\text{r-cm})^2 \ ,$$

which is smaller by more than two orders of magnitude than required. Scattering produces the increment

$$\beta_o^2 \gamma_o^2 (\Delta Q^2)\text{scat} \quad (98.8)^2\ (.720 \times 10^{-3}) = 7.027\ (\text{r-cm})^2 \quad .$$

This increment dominates over the initial value, but it is still somewhat less than the allowable value of 36 (r-cm)^2. This pulse radius could thus be increased by a factor of up to two at the grating if necessary.

Pinched Radius

It is of interest to caluclate here the achievable pinched radius which is consistent with the computed

$$Q_N^2 = \left(\begin{matrix}\text{Initial}\\ \text{value}\end{matrix}\right)^2 + \left(\begin{matrix}\text{scattered}\\ \text{part}\end{matrix}\right)^2$$

$$= .25 + 7.027 = 7.277\ (\text{r-cm})^2$$

The Bennett pinch condition for equilibrium between the azimuthal field and transverse thermal pressure is

$$\langle\theta^2\rangle = I/(17\beta\gamma kA).$$

We have

$$a = \frac{Q}{\sqrt{2\langle\theta^2\rangle}} = \frac{Q_N}{\beta\gamma}\sqrt{\frac{17\beta\gamma kA}{21}}$$

$$= (.250\text{cm})\left[\left(\frac{Q_N^2}{7.277}\right)\left(\frac{98.9}{\beta\gamma}\right)\left(\frac{10kA}{I}\right)\right]^{1/2}$$

A further ten-fold increase of energy would therefore allow sub-millimeter radii.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720