This is an informal report intended primarily for internal or limited external distribution. (The opinions and conclusions stated are those of the author and may or may not be those of the laboratory.) This report is not to be given additional external distribution or cited in external documents without the consent of the author or LLL Technical Information Department.

UCID - 16357

MASTER

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California

A RETURN TO BRUTE FORCE

G. W. Hamilton

J. E. Osher

September 26, 1973

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or 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.

Prepared for U. S. Atomic Energy Commission under contract no. W-7405-Eng-48

- i -

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Fig

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.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

A RETURN TO BRUTE FORCE

ABSTRACT

It now appears feasible to attempt to overcome instability losses by the brute force approach. Calculations show that the number of trapped ions can be increased by an order of magnitude and that trapping by ground-state ionization will become important under brute force conditions, because of recent improvements in beam, vacuum, and magnet technology. The key assumption is that the time constant for losses due to instabilities is constant.

INTRODUCTION

One of the readily available options in the Baseball II program is a return to the brute force approach which was considered at Culham and Livermore a few years ago. In this approach we attempt to use high-current injection to overcome losses due to instabilities, instead of trying to eliminate the instabilities before building up the plasma density. Brute force deserves new consideration at this time because of the significant advances during the past few years in increasing beam intensities, vacuums, and magnetic fields. The improved technologies and equipment are already available within the Baseball group. It may not be necessary to stabilize the Baseball plasma by clever techniques such as Coulomb scattering, feedback, and energy modulation.

The most relevant thinking on the brute force approach may be found in Refs. 1,2, and 3. The key assumption, based upon data from Culham,¹ is that the time constant τ_I for anomalous losses due to instabilities is fixed at about 0.2 sec and is independent of density. Therefore, if the vacuum is 10^{-8} Torr, losses due to charge exchange and scattering may be neglected and the steady-state density is

$$n = If\tau_I/V \quad \text{if} \quad \tau_I \ll \tau_{cx}, \tau_{sc}.$$

The instability-limited density in Baseball I² was found to be strongly dependent upon magnetic field, varying in proportion to $B^{4.5}$. Since the trapping fraction was

1. E. Thompson, Preliminary Results of High Current, Low-Energy Injection into Phoenix II, Culham Laboratory, Culham, England, Progress Report 1969-70).
2. C. C. Damm, et al., "Dependence of Ion Cyclotron Instabilities on Particle Distribution Functions in the ALICE Experiment," in Proceedings of the 1968 Novosibirsk Conference on Plasma Physics and Controlled Nuclear Fusion Research (IAEA, Vienna).
3. A. H. Futch and C. C. Damm, Consideration of a "Brute-Force Approach" to the Achievement of Higher Density in the Presence of Instability, "Lawrence Livermore Laboratory, Rept. UCID-15628 (1970).

proportional to $B^{1/2}$, we may infer that $\tau_I \propto B^4$. The conditions for maximum density in Baseball I were

$$nV = 6.4 \times 10^{12} \text{ trapped ions}$$

$$f = 2.8 \times 10^{-4}$$

$$W_i = 15 \text{ keV}$$

$$B = 6.5 \text{ kG}$$

$$I = 30 \text{ mA},$$

and therefore $\tau = nV/If = 0.12 \text{ sec}$, where $\frac{1}{\tau} = \frac{1}{\tau_I} + \frac{1}{\tau_{cx}}$.

Since $\tau_{cx} \geq 0.3 \text{ sec}$ for Baseball I, we may infer that $\tau_I = 0.2 \text{ sec}$. This is in excellent agreement with the Culham measurement under the conditions of maximum density and magnetic field.

DISCUSSION

Brute Force Possibilities with Baseball II

The improvements now available are high-intensity beams, better vacuum, cascade-trapping, and a stronger magnetic field. To be conservative we shall not assume any improvement in τ_I due to the stronger magnetic field. (More optimistically, we could hope to increase τ_I by an order of magnitude in proportion to B^4).

The background density in Baseball II during beam injection is now $10^8 \text{ molecules/cm}^3$, which is equivalent to $3 \times 10^{-9} \text{ Torr}$. Assuming the maximum charge-exchange cross section ($\sigma_{cx} = 10^{-15} \text{ cm}^2$), the charge-exchange time $\tau_{cx} = (n_o \sigma_{cx} v_{ion})^{-1} = 0.7 \text{ sec}$ for 20-keV H^+ . This is adequate for the brute force approach³; we can tolerate an additional beam-derived pressure rise of a factor of three or more.

An estimate of τ_I for the low-energy Baseball II plasma may be obtained from an analysis of particle trapping and loss rates in the current CTR Annual Progress Report (not yet published). The trapped-ion loss rates from a 2-keV plasma of 10^{13} trapped ions were estimated as follows:

Charge exchange loss	1.4 μA
classical scattering loss	0.1 μA
instability losses	
ends	2.3 μA
radial	0.5 μA
total losses	4.3 μA

We may therefore infer an instability loss time of

$$\tau_I = \frac{10^{13} \text{ ions} \times 1.6 \times 10^{-19}}{2.8 \times 10^{-6} \text{ A}} = 0.57 \text{ sec.}$$

This improvement in τ_I for Baseball II may be attributed to the improved vacuum and magnetic field or to the lower energy. At this time it is not known whether or not we can retain this improvement when the injected energy is increased to 15 to 20 keV for brute force injection. Therefore we shall continue to assume at this time that $\tau_I = 0.2 \text{ sec.}$

We shall base the following calculation on the existing MATS III beam ($I_{\text{total}} = 0.82 \text{ A}$ at 20 keV) and expect a neutral beam of 0.5 A within the $\pm 1.3^\circ$ Baseball acceptance angle. No allowance will be made for the enlarged acceptance angle nor for the improved beams now under development at Livermore and Berkeley.

The maximum trapped fraction by cascade trapping is³

$$f_{\text{max}} = \int_0^7 a/n^3 \, dn \approx 10^{-3} \text{ if } a = 0.1.$$

Therefore, neglecting charge exchange, the number of trapped ions now attainable by brute force is

$$\begin{aligned} nV &= If_{\text{max}} \tau_I \\ &= \frac{0.5}{1.6 \times 10^{-19}} \times 10^{-3} \times 0.2 \\ &= 6 \times 10^{14} \text{ trapped ions.} \end{aligned}$$

This is an order of magnitude above the nV of the existing low-energy Baseball plasma. The ranges of $If\tau$ and nV attained in Baseball I and Baseball II are compared with the ranges attainable by brute-force injection under the assumed conditions in Fig. 1.

Ground-State Ionization

Additional trapping by ionization of ground-state atoms will cease to be negligible when the density is increased to $6 \times 10^{10} \text{ cm}^{-3}$ by brute force injection. The beam fraction trapped by ground-state ionization is

$$\begin{aligned} f_{\text{GS}} &= (n_e \overline{\sigma v_e} + n_i \overline{\sigma v_i}) L/v_i \\ &= n \times 10^{-14} \text{ for 20 keV injection if the path length } L \text{ for collisional} \\ &\text{trapping is 30 cm.} \end{aligned}$$

Fig. 1. Comparison of attainable ranges of $If\tau$ and nV in the Baseball I and Baseball II experiments.

Under the assumed conditions, which are conservative, we can expect to reach a steady-state density above 6×10^{10} by the combination of cascade trapping and ground-state trapping. By brute force we expect to achieve an $I\tau$ of 0.1 A-sec even in the presence of instabilities. This may be only a factor of two below the value of $I\tau$ required for exponential buildup by ground-state trapping.

Source Availability

The MATS III source is now ready for use at 5 to 20 keV, but will be better optimized in the near future. It is compatible with the beam-line now being installed, which is designed for a high-power beam. A brute force experiment could be performed with very little delay.

The LBL 1-A source will be even more suitable for brute force injection, when it is available. Other LBL sources are not suitable because of the long pulse duration required for vacuum buildup.

DISTRIBUTION

LLL Internal Distribution

T. K. Fowler
R. F. Post
C. C. Damm
J. H. Foote
A. H. Futch
R. K. Goodman
F. J. Gordon
A. L. Hunt
G. W. Hamilton
J. E. Osher

G. D. Porter
TID File

30

External Distribution

E. Thompson
Culham Laboratory
Culham, England

Technical Information Center,
Oak Ridge

2

NOTICE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or 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."

HLI/lh