27
8-7-78
25
HTIS

MASTER

UCID- 17806

Lawrence Livermore Laboratory

A MULTICHANNEL MAGNETIC ANALYZER FOR PULSED PLASMA SOURCES

J. E. Osher and W. J. Stroh

May 18, 1978

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MAJOR CONTRACTOR'S RECOMMENDATION FOR
DISPOSITION OF SCIENTIFIC AND TECHNICAL DOCUMENT

See Instructions on Reverse

1. ERDA Report No. UCID-17806

3. Title A MULTICHANNEL MAGNETIC ANALYZER FOR PULSED
PLASMA SOURCES

2. Subject Category No.

4. Type of Document ("X" one)

- ☒ a. Scientific and Technical Report
☐ b. Conference Paper
 Title of conference
 Date of conference
 Exact location of conference
☐ c. Other (Specify, Thesis, Translation, etc.)

5. Copies Transmitted ("X" one or more)

- ☐ a. Copies being transmitted for standard distribution by ERDA-TIC.
☐ b. Copies being transmitted for special distribution per attached complete address list.
☒ c. 27 completely legible, reproducible copies being transmitted to ERDA-TIC.

6. Recommended Distribution ("X" one)

- ☒ a. Normal handling (after patent clearance) no restraint on distribution except as may be required by the security classification.
☐ b. Make available only to U.S. Government agencies and their contractors.
☐ c. Make available only within ERDA and to ERDA contractors.
☐ d. Make available only within ERDA.
☐ e. Make available only to those listed in item 12 below.
☐ f. Other (Specify)

7. Recommended Announcement ("X" one)

- ☒ a. Normal procedure may be followed.
☐ b. Recommended following announcement limitations

8. Reason for Restrictions Recommended in 6 or 7 above.

- ☐ a. Preliminary information.
☐ b. Prepared primarily for internal use.
☐ c. Other (Explain)

9. Patent Clearance ("X" one)

- ☒ a. ERDA patent clearance has been granted by responsible ERDA patent group.
☐ b. Document has been sent to responsible ERDA patent group for clearance.

10. National Security Information (For classified document only: "X" one)

- ☐ a. Document does contain national security information other than restricted data.
☐ b. Document does not contain national security information other than restricted data.

11. Copy Reproduction and Distribution

- a. Total number of copies reproduced
b. Number of copies distributed outside originating organization

12. Additional Information or Remarks (Continue on separate sheet, if necessary)

13. Submitted by (Name and Position) (Please print or type)

Jack L. King, Technical Information Department

14. Organization

Livermore Livermore Laboratory, Livermore, California 94550

15. Signature

Tam Smith

16. Date

8-1

A MULTICHANNEL MAGNETIC ANALYZER
FOR PULSED PLASMA SOURCES*

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, 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.

ABSTRACT

We constructed, calibrated, and used a simple multichannel magnetic analyzer for pulsed plasma-target production studies. With time-of-flight resolution of velocity, the channel signals unfolded to yield a measurement of each of the present ion-energy-distribution functions. Measurements made with a narrow-slit, high-gain electron multiplier detector allowed clearly resolved identification of each major ion species. However, because of the uncertainty of secondary-emission detection efficiency for high- q ions, we made all absolute signal measurements with a wider entrance slit and an array of Faraday-cup detectors. The latter arrangement was calibrated with an H^+ beam of known adjustable energy. We describe how this instrument can determine N^+ to N^{7+} and H^+ ion-distribution functions for a CO_2 laser pulse incident on an NH_3 pellet.

INTRODUCTION

Analysis of the ion-energy distribution from an intense pulsed plasma source can raise a number of diagnostic problems. Electrostatic, retarding grid-type analyzers are relatively simple to construct, but they are limited to designs and placement yielding an instantaneous ion flux $\leq$ the appropriate space-charge-limited current density.¹ If used other than as a simple detector they are normally limited to relatively low analyzer voltages (or hence low $mv^2/2q$). A magnetic analyzer is a more involved diagnostic, but with a narrow entrance slit it is relatively insensitive to space-charge problems and is generally capable of analyzing a higher range of mv/q . For

*
This report is based on a poster talk given at the 2nd Topical Conference on High-Temperature Diagnostics, Santa Fe, New Mexico, March 1-3, 1978 (sponsored by the American Physical Society). It correlates with a previous version, UCRL-80525 Abstract.

pulsed plasma sources the velocity can conveniently be determined through time-of-flight (TOF) for either type of instrument. For a shot-to-shot, variable-pulsed plasma source or one involving multiple-ion species it is also important to build a multichannel analyzer with some direct means of calibration.

The solution described here is a magnetic analyzer designed with six useful channels. This analyzer uses Faraday-cup ion-current detection to avoid problems of differences in secondary electron emission with ion energy or with various high ion-charge states. Such a simple instrument is not new,² but at Lawrence Livermore Laboratory our work includes details of calibration with a 2-to-20-keV H^+ beam and application to the measurement of H^+ and N^+ through N^{+7} ion-energy distributions for plasma produced by a 50-ns, 300-J FWHM CO_2 laser pulse split to impinge on both sides of a 150- μm -diam NH_3 pellet. The purpose of this laser-pellet application was to produce an initial startup target plasma for neutral-beam buildup in Baseball-II experiments.³

Experimental Arrangement

The basic structure of an eight-channel version of the magnetic analyzer appears in Fig. 1. Calibration and test use indicated some analyzer-structure scattered beam problems in the last two (7,8) channels, so use was generally limited to the first six channels. The magnetic-pole tips for this instrument were of simple circular shape and external to the vacuum chamber, making possible further refinement by pole-tip shaping for partial ion focusing. Here, effects of the fringing field and pole tip shape were accommodated by calibrating the instrument with the available 2-to-20-keV H^+ beam in the arrangement shown in Fig. 2.

The expected magnetic analyzer calibrated for an ion of mass M and charge state q has the form

$$\frac{\tau_{\mu sec}}{L_{cm}} \approx \frac{1}{V_{cm/\mu sec}} \approx K_1 \frac{M_{(amu)}}{qI_{(A)}} \phi_k^0, \quad (1)$$

where τ is the TOF for a distance L and ϕ_k^0 is the angle in degrees for deflection into the k^{th} Faraday cup. For the particular instrument described here, with $L = 252$ cm and $B_g \sim 200$ T, this yields $K_1 \sim 1.32$

Fig. 1. Eight-channel magnetic analyzer with Faraday-cup detectors.

Fig. 2. H^+ beam calibration arrangement for the multichannel analyzer.

$\times 10^{-3}$. Because of the fringing-field differences between channels and an oversimplified definition of the angle of deflection, K_1 is only an approximate constant here ($\sim 20\%$ variation between channels 1 and 6).

A typical calibration curve for the first six useful channels is shown in Fig. 3 for H^+ ($M/q = 1$) and the Baseball-II spacing ($D = 252$ cm). The experimental H^+ calibration points are indicated by the symbols $\otimes$ for the centers of the appropriate channels. The simultaneous extension to include other M/q values causes a variable-species overlap problem, particularly for small M/q changes such as those between N^{7+} to N^{5+} in Channel 1. This problem is seen in Fig. 4, with calculated TOF for the mixed species of H^+ and C^+ to C^{6+} for a $D = 223$ cm for just the first four channels.

Signal Detection

Initial plans included use of an electron-multiplier structure detector for each channel. Figure 5 shows typical data taken with a narrow-entrance slit and only a single-channel electron-multiplier detector for a 30-J, 50-ns FWHM CO_2 laser pulse incident on one side of a glass-stalk-mounted 100- μ m-diam polystyrene pellet. Figure 6 shows the experimental arrangement for this case. The data clearly resolved the various carbon C^{3+} -to- C^{6+} ion states (as well as H^+). However, use of this type of detector introduces the need to unfold a secondary-emission coefficient expected to vary both with energy and specific ion-charge states.

Thus all multiple-channel data were taken with a somewhat wider entrance slit, Faraday-cup detectors, and high-gain amplifiers. This avoided the secondary-emission variation problem, though at the price of limited resolution and much poorer signal-to-noise ratios.

Typical Faraday-cup data are in Fig. 7. Note that the use of low-level Faraday-cup signals with relatively long distributed-capacitance leads tends to act somewhat like an integrator; i.e., it reduces the frequency response of the system. This made analysis of the sharply spiked H^+ signals particularly difficult. Attempts to use local line drivers or high-gain amplifiers near the detectors were not completely satisfactory during our limited setup time.

Signal Reduction for Multichannel Analyzer

The voltage signal V from a Faraday-cup detector of area A across terminating resistor R is unfolded to yield a measure of $\partial n/\partial W$ vs energy

Fig. 3. A typical calibration chart of TOF (τ) vs magnetic-analyzer magnet current for H^+ in the six useful Paraday-cup channels for this particular instrument, with $L = 252$ cm.

Fig. 4. A display of expected TOF for various m/q states (for a polystyrene target with $L = 223$ cm) for the first four Faraday-cup channels for $I \approx 1$ A. Note that the wider slits used with the Faraday cup gave high q species overlap problems for channels 1 and 2. Data did not clearly resolve some states and was handled by readout at mid-channel TOF for the indicated species. Thus identification could be in error by roughly one charge state in some cases.

Fig. 5. Typical single-channel data with narrow slits. Also an electron-multiplier detector to illustrate the resolution possible and the problem of unfolding signal response for different q-ion species of different energies.

Fig. 6. A typical experimental analyzer arrangement with a laser-pellet test chamber.

Fig. 7. Typical Faraday-cup data taken with the large (300 J) CO_2 laser pulse incident on a free-flight NH_3^+ pellet in Baseball-II. The lack of species resolution and the difficulty of analyzing the H^+ signal from this limited high-frequency response system is evident.

W for each ion species. For a signal $V_k(t)$ from the k^{th} channel of width $\Delta W_{1,k}$:

$$V_k(t) = j_k(t)AR, \quad (2)$$

and

$$\left(\frac{\partial n_i}{\partial W_i} \right)_{W_k} \Delta W_{ik} A \approx \frac{A}{q} \int_{\Delta W_{i,k}} j_k dt, \quad (3)$$

thus

$$\left(\frac{\partial n_i}{\partial W_i} \right)_{W_k} = \frac{\bar{V}_k(t)}{qRA_k} \frac{\Delta \tau_k}{\Delta W_{1,k}} \left(\frac{\bar{V}_{kT_1}}{qW_1} \right)_{W_k}. \quad (4)$$

For Baseball II-T, when used with NH_3 pellets, the signal from each channel was measured at the mean channel TOF as required for either mass 1 or mass 14 ions, with q adjusted to fit the calibration. Figure 8 provides examples of such reduced data, produced by use of a 300-J CO_2 laser pulse incident on two sides of a 150- μm -diam NH_3 pellet. These ion distributions show relatively large populations of N^{3+} and N^{4+} as predicted by LASNEX code calculations. The detailed structure vs energy in these and other similar data suggest considerable charge exchange from one specific charge state to an adjacent state at certain energies. No further analysis was made, but this suggests a velocity-resonant charge-exchange process. Another factor from these examples is the apparent dearth of H^+ ions. Instead of a 3:1 ratio, as expected with ammonia, we observed a ratio more like 0.2:1. The experiment was terminated before this dilemma was completely resolved, but a brief test for energetic H^0 indicated that the equivalent flux of H^0 was the H^+ flux. Also, some of this loss may have been due to poor signal response to sharply peaked signals.

ACKNOWLEDGMENTS

The authors acknowledge the encouragement and support of C. C. Damm and others of the Baseball group in developing and calibrating this instrument.

Fig. 8. Reduced data for a single shot, with species identification from channel center TOF. Identification of N^{7+} is subject to possible error because of the signal-overlap problem. The N^+ signal was too low to be observed above the noise (but had relatively large error limits). The H^+ signal magnitude shown is likely a lower limit due to detector sensitivity roll-off for short signal pulses.

REFERENCES

1. J. E. Osher and G. D. Porter, "Limitations and Calibration of Gridded Ion Detectors," *Bull. Am. Phys. Soc.* 21, 851 (1976).
2. J. E. Osher, "Particle Measurements," *Plasma Diagnostic Techniques*, R. H. Huddleston and S. L. Leonard, Eds. (Academic Press, New York, 1965), p. 527.
3. C. C. Damm, J. H. Foote, A. H. Futch, R. K. Goodman, R. S. Hornady, J. E. Osher, and G. D. Porter, *Target-Plasma Production by Laser Irradiation of a Pellet in the Baseball II-T Experiment*, Lawrence Livermore Laboratory, UCRL-52363 (1977).

LG