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GYRO-ELECTRON GHOST IMAGES DUE TO MICROCHANNEL
PLATE OPERATION IN TRANSVERSE MAGNETIC FIELDS

By

A.L. Roquemore and S.S. Medley

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**GYRO-ELECTRON GHOST IMAGES DUE TO MICROCHANNEL
PLATE OPERATION IN TRANSVERSE MAGNETIC FIELDS**

A. L. Roquemore and S. S. Medley

Plasma Physics Laboratory, Princeton University
Princeton, New Jersey 08544

ABSTRACT

A multi-anode microchannel plate (MCP) detector was operated in a transverse magnetic field. When a collimated ion beam of ~ 4 -mm diameter impinged on one area of the plate, ghost images were observed elsewhere on the plate at anodes up to several centimeters from the beam spot. This effect is due to secondary electrons which are emitted from the interstitial surfaces around the MCP pores and returned to the surface of the plate under the influence of $\tilde{\mathbf{E}} \times \tilde{\mathbf{B}}$ fields, where $\tilde{\mathbf{E}}$ is the electric field perpendicular to the plate due to the MCP bias potential and $\tilde{\mathbf{B}}$ is the externally applied transverse magnetic field. A regenerative process is observed in which the secondary electrons traverse the surface of the plate in the $\tilde{\mathbf{E}} \times \tilde{\mathbf{B}}$ direction by successive gyro-orbit steps. A method for suppressing the ghost images is discussed.

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Introduction

In recent years, the application of microchannel plate (MCP) electron multipliers¹ to the detection of particles and photons has expanded in many areas of science and technology. One of the advantages of MCP detectors compared with conventional electron multiplier tubes is a relatively high insensitivity to operation in a magnetic field environment. Sufficiently strong magnetic fields ($\gtrsim 100$ Gauss) such as encountered for diagnostics in the vicinity of magnetic confinement fusion experiments, however, can affect the performance characteristics of MCP detectors.

Several studies have been reported concerning modification of the MCP gain characteristics under magnetic fields both transverse and parallel to the pores of the microchannel plate.²⁻⁴ All of these investigations employed single anode MCP detectors. In general, the MCP gain decreased in strong magnetic fields and the drop was more rapid for fields parallel to the microchannel pores compared with transverse fields.

In this paper, we report a new effect of magnetic fields on the operation of MCP detectors. Using a multi-anode microchannel plate operated in a transverse magnetic field, we observed that excitation of one area of the MCP detector by a collimated ion beam produced ghost images of the beam at anodes several centimeters removed from the ~ 4 -mm diameter impact region. The ghost images are created by secondary electrons which are produced at the surface of the microchannel plate and returned to another location on the surface under the

influence of $\tilde{E} \times \tilde{B}$ fields, where $\tilde{E}$ is the electric field perpendicular to the plate due to the MCP bias potential and $\tilde{B}$ is the ambient transverse magnetic field. It should be noted that this effect could be responsible for some details of the variation in the gain and detection efficiency reported for MCP operation in a transverse magnetic field.

I. Apparatus

Microchannel plates are used for particle as well as photon detection. A wafer-thin, leaded-glass plate supports a matrix of 10-100 μ m diameter closely spaced parallel pores whose walls have good secondary electron emission characteristics (Fig. 1). The open pores account for about 50% of the total surface area while the surrounding interstitial glass accounts for the remainder. A bias applied between the opposite surfaces of the plate drives cascading electrons down the pore structure producing the desired electron gain. A detailed explanation of MCP operation is given in the literature.¹

A large area MCP was designed at the Princeton Plasma Physics Laboratory to be used as an ion detector in the $E \parallel B$ spectrometer for determination of the mass-resolved energy distributions of the charge-exchange neutrals (H, D, T) emanating from the Tokamak Fusion Test Reactor (TFTR). The spectrometer, shown by the schematic in Fig. 2, has been described elsewhere.⁵ The MCP, shown at the top of Fig. 3, is a large-area, chevron configuration with the multi-anode array arranged to provide three columns of 4-mm x 10-mm anodes with 25 anodes per column. The mass columns are separated by 5-mm wide "dead" strips while

adjacent anodes within the mass column are separated by 1-mm. The biasing arrangement (Fig. 1) consists of a -2100 volt potential applied to the front particle impact surface with a -1100 volt bias between the two plates and a -100 volt bias at the exit of the last plate. The general characteristics of this plate are displayed in Table I.

II. Experiment

The experimental arrangement was as follows. The parallel magnetic and electric fields within a dee-shaped region inside the spectrometer provide energy and mass resolution of incoming particles, respectively. The MCP is located in the fringe-field area (Fig. 2) where the field strengths are decreased by at least a factor of 12 relative to the central values. The analyzer was calibrated using a monoenergetic ion beam of either H_1^+ , H_2^+ , or H_3^+ which was stepwise variable in energy from 0.5 - 150 keV with the minimum energy increment of about 50 eV. The beam size is determined by limiting entrance apertures which were chosen to keep the beam diameter at the detector less than the width of a single anode. For fixed spectrometer fields, small increments in beam energy cause the beam to stepwise traverse the front surface of the plate along a given anode column. Automatic data acquisition from a total of 25 data channels is provided at the end of each increment in beam energy. Up to 20 increments in beam energy were typically used to scan across a single anode. Computer-generated profiles of the anode count rate as a function of beam energy are obtained. For a given charge to mass ratio, q/A , the energy of the beam, $E(kV)$

that is incident on an anode located a distance of $Z(\text{cm})$ away from the entrance aperture is given by

$$\alpha \cdot Z \cdot B = 9.8(A \cdot E)^{1/2} \quad (1)$$

where B is the central magnetic field in kG and A is the particle mass in AMU. An anomaly arose whenever the beam was swept along the lower anode column as illustrated in Fig. 3. In this case an examination of the data from a selected anode displayed multiple image profiles in addition to the principal ion beam profile produced when the beam was stepped across the selected anode. An example of the data given at the bottom of Fig. 3 shows the principal peak at 7.5 keV and four additional peaks progressively displaced in beam energy by ~ 1 keV. Using measured values of the beam energy and central magnetic field, we calculate that the impact point of the calibration beam has advanced 4 cm from the selected anode when the last profile is produced.

III. Interpretation

The spurious peaks were deduced to arise from secondary electrons emitted at the interstitial spaces of the MCP due to particle impact. The applied -2100 volt MCP bias and the transverse component of the spectrometer magnetic fringe field create an $\tilde{E} \times \tilde{B}$ field⁶ region that causes the particles to execute semicircular gyro orbits and return to the plate one orbit diameter away from the production point. The orbit diameter depends on the strength of the transverse magnetic field at the face of the MCP. On returning to the MCP surface, a portion of the secondary electrons will enter the pores of the plate and generate an output pulse, while the remainder will impact

on the interstitial spaces creating a new generation of secondary electrons with trajectories similar to the first generation. This regeneration process is illustrated in Fig. 4 which shows the secondary electrons gyro-stepping down the plate, and has been observed to repeat itself up to seven times before the gyro peak amplitude approaches zero. If we assume that each electron that enters a pore produces a pulse and that the open area ratio of the plate is 50%, then the diminishing amplitudes can be closely predicted by having a secondary emission coefficient of slightly less than two. To predict accurately the gyro peak amplitude, one would need to know the detection efficiency of the plates which may be somewhat greater than the open area ratio^{1,7} as well as the precise secondary emission coefficient of the Inconel electrode material and the impact energy of the electrons. In addition, the beam footprint on the MCP should be much less than the size of the anodes in order to assure the capture of electrons that are spatially spread out due to the angular distribution of the emitted secondary electrons.⁸

Several other observations are given in support of the gyro-orbit interpretation. The $\tilde{E} \times \tilde{B}$ field was altered to examine the effect on the peak location. First, a soft iron shield with ~6-mm-thick walls was constructed around the MCP to reduce the magnetic field, $\tilde{B}$, at the surface of the plate by a factor of four. It was observed that the gyro step size was correspondingly increased by a factor of almost four. Second, the magnetic shield was removed and a negatively biased, 95%

transparency screen was placed 1 cm in front of the MCP. It was found that the spacing between peaks could be controlled by varying the screen bias and hence the electric field, $\tilde{E}$. These tests confirmed that the spurious peaks were indeed electron effects. When the calibration beam was swept along either of the other two anode columns, however, a single near-Gaussian-shaped profile was obtained as the beam traversed each anode. This raises the question of why only the lower column produced the observed gyro peaks. An examination of the plate location yields the answer. The lower anode column was located on the center line of the magnetic pole gap so that the fringe magnetic field component, $\tilde{B}$, was almost totally transverse (i.e., parallel to the surface of the microchannel plate), whereas the top two anode columns were in a region where the magnetic field curved away from the plate as depicted by the insert in Fig. 3. The electrons leaving the upper anode columns are confined to the magnetic field lines which guide them away from the plate.

IV. Discussion

Spurious counts in any of the anodes due to the gyro-electron effect would obviously cause large errors in the experimental data. Numerous tactics were tried to eliminate the gyro peaks. The problem with most schemes was that if they eliminated the peaks in the lower anode column, the secondary electrons would then drift up to the middle mass column. The various schemes tried, excluding details, included small tilts to the plate, blades placed between the anode columns to block electron motion

from one column to another, and various trials with a biasing screen in front of the MCP.

The final configuration adopted to suppress the gyro-electron effects is illustrated in Fig. 6. A double-walled soft iron shield was placed around the MCP with a window cutout to admit the particles. In addition, the window is covered by a grounded, high transparency screen as indicated by the dashed line. The measured magnetic field inside the shield is approximately 10 G for the highest field case (5 kG central field). In this low field, secondary electrons are accelerated straight away from the MCP plate surface, through the grounded grid, and are deflected by the distorted fringe fields outside the shield box.

Another possible method that would eliminate the gyro peaks would be to reverse bias the plate by placing a +2100 volt bias at the exit of the plate and grounding the front surface. This has the disadvantage of having to couple capacitively the signal processing electronics to each individual anode.

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Table I

MCP GENERAL CHARACTERISTICS

Pore Diameter	25 μm
Pore Length/Pore Diameter	80
Pore Bias Angles	8°/8°
Strip Current	100 μA
Plate Resistance	20 M Ω
Dark Count	1 CPS/cm ²
Maximum Pulse Count Rate	10 ⁶ CPS Random
Open Area Ratio	50%
Electrode Plating	Inconel

FIGURE CAPTIONS

1. Schematic of the chevron style microchannel plate and the associated biasing arrangement.
2. Schematic of the $\mathbf{E} \parallel \mathbf{B}$ charge-exchange analyzer and microchannel plate detector.
3. Top: Anode arrangement for microchannel plate.
Bottom: Single anode output signal showing the principal ion beam peak and the spurious gyro-electron-generated peaks.
4. Illustration of secondary electrons gyro-stepping down the MCP in the $\tilde{\mathbf{E}} \times \tilde{\mathbf{B}}$ fields.
5. Final configuration used to suppress gyro-electron effects using a double-walled magnetic shield and a grounded high transparency screen covering the entrance window of the magnetic shield box.

Fig. 1

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Fig. 2

Fig. 3

Fig. 4

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Fig. 5

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