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NEUTRAL PARTICLE TIME-OF-FLIGHT ANALYZER FOR THE TANDEM MIRROR EXPERIMENT UPGRADE (TMX-U)

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NEUTRAL PARTICLE TIME-OF-FLIGHT ANALYZER FOR THE TANDEM MIRROR EXPERIMENT UPGRADE*

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Abstract

We describe the design and performance of a time-of-flight (ToF) analyzer being built for installation on the east end cell of the Tandem Mirror Experiment Upgrade (TMX-U). Its primary purpose is to measure the velocity distribution of escaping charge exchange neutral particles having energies between 20 and 5000 electron volts (eV). It also enables direct determination of the thermal barrier potential when used in conjunction with the plasma potential diagnostic and the end loss ion spectrometer. In addition, it can measure the velocity distribution of passing ions leaving the central cell and of ions trapped in the thermal barrier.

Individual pulses will be separated from the stream of neutral particles by an optomechanical chopper. The particles in these pulses will be temporally dispersed according to their characteristic velocities as they traverse a long flight tube. At the end of their free flight, the particles will strike a secondary emitter, which ejects electrons into an electron multiplier. The resulting signal will be collected and processed by a dedicated data acquisition system employing a microcomputer. The detector can be remotely recalibrated using an ion source mounted on a pneumatically-driven shuttle.

Introduction

An important diagnostic technique for the investigation of hot plasmas is the analysis of energetic neutral particles that escape the plasma. These neutrals result from charge exchange reactions between plasma ions and background gas or energetic neutral beams. The velocity dependence of the neutral emission is useful in determining the temperature of the confined ions and various plasma potentials.

A standard technique we considered for measuring the velocity dependence of the neutral flux uses a gas stripping cell followed by magnetic and electrostatic analysis of the resulting charged particles. The sensitivity of this type of instrument makes it impractical at energies less than about 1,000 eV. Ions are confined in TMX-U at about 1,000 eV, and to study them we must measure neutral particles with kinetic energy less than the confining potential. Therefore we have instead chosen a secondary emission type of particle detector, which efficiently detects these particles without the losses inherent in a gas stripping cell.

In the instrument we have designed for TMX-U, the particle stream will leave the geometric center of the east end cell at a departure angle of 22.6 degrees and enter the ToF analyzer (Fig. 1) through a vacuum isolation valve on the east end dome. Within the analyzer, it will first pass through a beam shaping collimator. Then in the chopper, two slits, one stationary and one moving at high speed, separate very short pulses from the continuous particle flux. These bursts of particles then travel along a 7-m-long flight tube and enter a detector section, where they cause a negatively-biased beryllium-copper plate to eject secondary electrons. These are finally directed into a multistage electron multiplier. The overall length of the instrument is just under 8 m, the longest available path between machine and vault wall that is also within the particle loss cone. The flight path length from chopper to detector is 7.0 m. On one side of the flight path and just ahead of the detector section will be a high-vacuum pump. On the other side will be a calibration station consisting of a shuttling ion source and an energy analyzer.

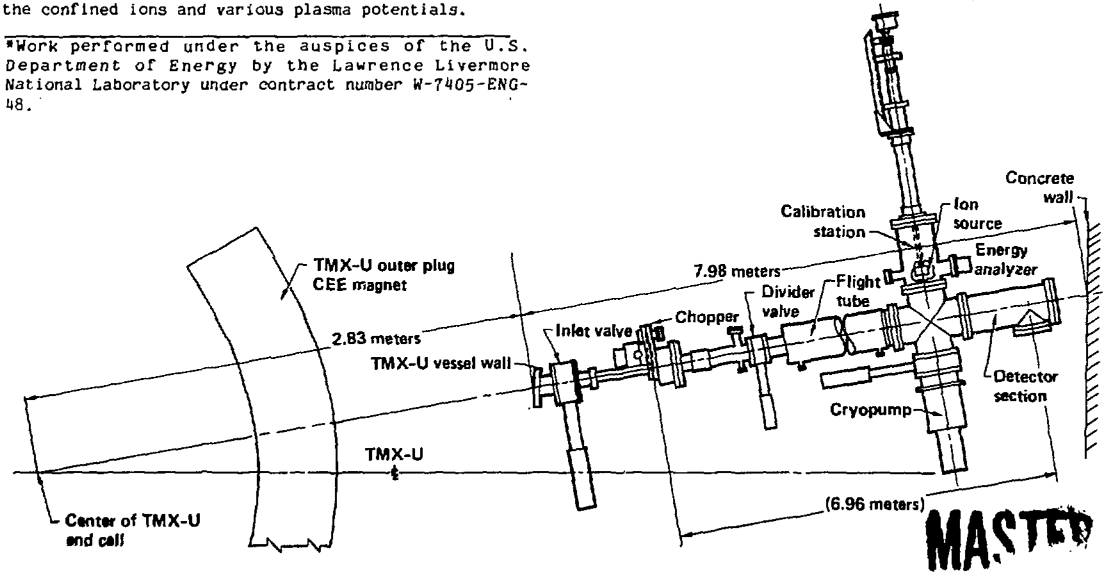

Figure 1. The greatest possible particle velocity separation will be achieved by making the ToF analyzer as long as space allows.

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All components of the ToF analyzer itself have been built or purchased. The support frame is being designed and will be built and installed, together with the analyzer itself, in the near future.

Areas of technical interest are discussed in detail below.

Chopper System

Short pulses will be separated or "chopped" from the neutral particle beam as it first encounters a narrow slit crossing the beam at high speed, and then immediately afterward an identical but stationary slit. The moving slit will actually be one of fourteen radial slits positioned near the periphery of an aluminum alloy disk spinning at high speed. The single stationary slit will be positioned parallel and as close as possible to the spinning disk. Operating parameters for this chopper system are given in Table 1, and it is pictured in Fig. 2. It will be similar to one used by Munson [1] in a ToF analyzer installed on the ZT-40 experiment at Los Alamos National Laboratory.

Pfeiffer GmbH is modifying an otherwise standard TPU-170 turbomolecular vacuum pump so that its three low-pressure stages are replaced by the spinning chopper disk. Its rotational speed is steplessly variable, allowing the analyzer to be used in studying deuterium neutrals between 20 and 5,000 eV. Heavy flanges form a containment ring around the spinning disk.

The single stationary slit will be cut in a foil mounted in a commercially available adjustable rotary stage. To replace this slit or adjust its position, a short section of the flight tube adjacent to the chopper will be removed. A bellows lets this be done without mechanically disturbing the rest of the ToF analyzer. This removable section prevents the instrument from being self-supporting without an external frame.

Table 1.
Chopper System Design and Operation Parameters

Slits (both moving and stationary)	40 mm long; width tapering from 0.16 mm to 0.25 mm
Outside radius of disk	113.5 mm
Radius at tips of slits	110 mm
Speed at tips of slits	50,000 mm/sec, maximum
Rotor speed	Continuously variable from 50 to 725 rev/sec
Beamlet pulse shape	Triangular with 1.0 μs duration

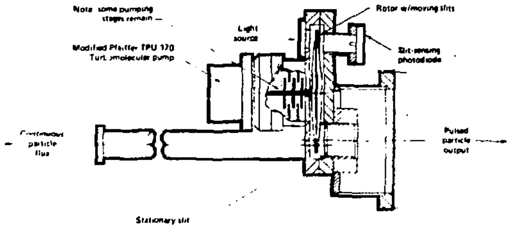

Figure 2. The optomechanical chopper separates 1-μs wide pulses from a continuous particle stream.

Detector Section

The time-resolved pulses of neutral particles enter the detector section through a collimating aperture, pass a short distance through a shielding cylinder, and finally strike a tilted beryllium copper plate biased at about -3700 V (Fig. 3). Secondary electrons ejected from the plate pass out through a hole in the side of the shielding cylinder to a multistage mesh electron multiplier (Fig. 3). The cylinder is biased -2 V with respect to the secondary emitter, and prevents the secondary electrons from reaching the grounded wall instead of the electron multiplier.

Our detector assembly will be similar in its construction to that developed by Voss and Cohen [2] at Princeton, and will be made so that all its internal elements are easily replaced. This will enable us to experiment inexpensively with alternative configurations and materials.

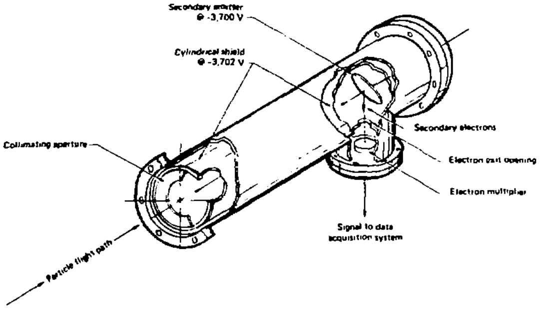

Figure 3. The secondary-emission type detector.

Vacuum System

The detector requires an operating pressure of 10^{-8} T. A maximum pressure of 10^{-6} T is required everywhere else in the ToF analyzer, and it is especially important to avoid hydrocarbon contamination of the secondary emitter and detector surfaces.

Bellows seals and metal-gasketed, demountable flanges will be used throughout, but cost control requires the compromise of o-ring gate seals in the vacuum valves. The 8-inch flight tube diameter will afford sufficient gas conductance over its full 7-m length and avoid attenuation of the stream of neutral particle pulses.

An in-line gate valve divides the flight path into two vacuum regions so that the detector section can be kept under continuous high vacuum while the chopper section is open to the atmosphere for adjustment or repair. Instead of an oil-sealed mechanical pump, a zeolite absorber will rough-pump the detector side. A gaseous-helium cryopump sustains high vacuum. We expect to rough-pump the chopper side more often and it is quite distant from the detector, so an oil-sealed mechanical pump is used, but with the protection of both a cryogenic and a catalytic trap. The remaining stages of the chopper pump are expected to have a high-vacuum pumping speed of 90 l/s, which is sufficient for this section of the instrument. Gas will simply pass through the turbomolecular pump during roughing, so no external crossover is needed.

The vacuum control system is designed around conventional ion gauges and thermocouple pressure transducers (Fig. 5). The interlocking of valves and pump controls is achieved using conventional dedicated programmable controllers.

Calibration System

A saddle-field ion source with Einzel focusing lens will be mounted on the end of a hollow shaft (Fig. 4) that passes through the hollow piston rod of a pneumatic cylinder. Remote actuation of the cylinder moves the source so that it can be placed either in front of the detector (coincident with the path of the neutral particles) or in front of a repelling-grid energy analyzer, allowing the detector to be recalibrated as often as desired without interrupting TMX-U operation. A concentric manual adjustment allows the position of the calibration source to be biased either coincident with the centerline of the neutral particle beam or up to 20 mm off-axis. The high-voltage cables and gas supply for the source pass through the hollow shaft. The vacuum boundary and feedthroughs are at the end of the shaft near the source itself. We expect smooth, repeatable travel because there is no eccentric mechanical loading. A bellows vacuum seal assures leak-free motion and rotational indexing of the source about the shaft centerline.

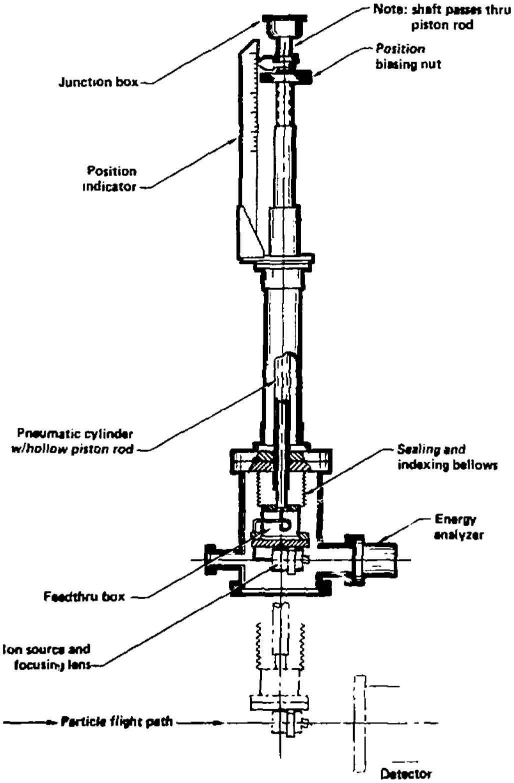

Figure 4. The calibration station with its ion source mounted on a pneumatically-powered shuttle.

Data Acquisition

The data acquisition system for the ToF analyzer (Fig. 5) will be assembled from commercial power supplies and CAMAC data acquisition hardware. Signals collected on the electron multiplier's anode will be input to a 2-MHz twelve-bit transient digitizer for which a 256K word memory will provide real-time data storage.

A photodiode and light source installed on opposite sides of the chopper disk will detect the passage of the moving slits from which the launch times of the particle pulses can be inferred. A delay generator and a CAMAC programmable clock will process its signal to initiate the detector sampling period and synchronize the data recorder.

After each TMX-U plasma cycle, data stored in the digitizer's memory will be transferred to a 32-bit minicomputer for processing, analysis, and display. The data is archived on a 64-MByte hard disc and backup tape.

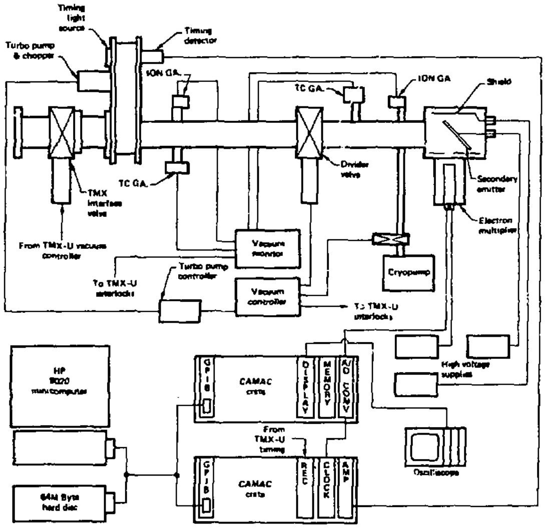

Figure 5. The electronic systems will process and store data while controlling the analyzer's vacuum system.

References

[1] C. Munson, Private Communication, February, 1984.

[2] D. E. Voss and S. A. Cohen, Rev. Sci. Inst., Vol 53, No. 11, November, 1982, p. 1696.