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Abstract

We have installed a new diagnostic instrument to investigate ions emanating along magnetic-field lines of the TMX-U tandem-mirror experiment. This analyzer contains parallel electric and magnetic fields, which yield ion mass and energy spatial separation. A dual array of 128 copper collector plates detects particles in the ion flux that is first collimated and then focused through the 180-degree bending magnetic field. An electric field applied transverse to the bending particle path then separates the ion masses in the direction perpendicular to the magnetic-pole faces while the magnetic field spreads out the different energies of each mass in a plane parallel to the magnetic-pole tips. The CAMAC-based data recorders are fiber-optically coupled to the system controller for data acquisition, analysis, and display. A commercial CAMAC data recorder was modified for current input. We expect to measure higher particle energies than the present gridded end-loss analyzers as well as to more accurately determine the energy spectra.

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Introduction

The tandem-mirror machine (TMX-U) at Lawrence Livermore National Laboratory is an open-ended design using the tandem-mirror magnetic-field configuration and thermal barriers. By open ended we mean that ions and electrons can escape from the plasma region along magnetic field lines. The end-loss-ion spectrometer (ELIS) is designed to determine the energy spectra of ions with different masses, usually deuterons and protons, escaping from the end region.

Apparatus

TMX-U

The current TMX-U configuration with magnets and neutral-beams is depicted in Fig. 1.

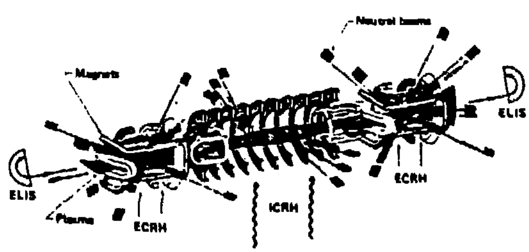

Figure 1. TMX-U.

As indicated, the two ELIS instruments are located at each end of the machine. The plasma is confined within the magnetic-field lines and fans out toward the end of the ELIS instruments.

E||B Analyzer

The major components of the ELIS diagnostic instrument are detailed in Fig. 2.

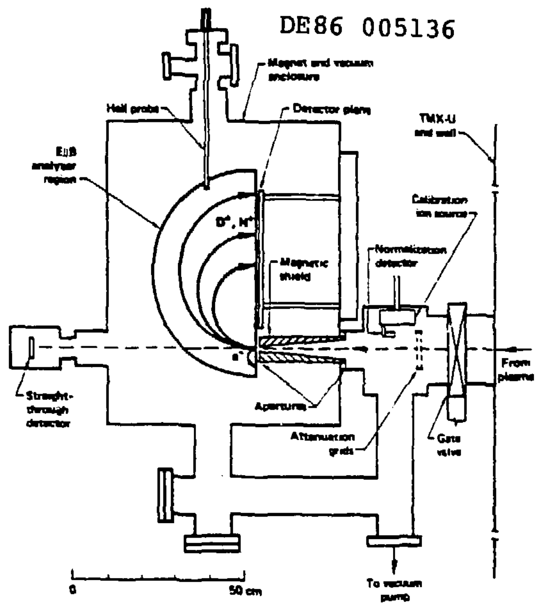

Figure 2. E||B analyzer.

The E||B analyzer (of Tokamak Fusion Test Reactor design) has electric and magnetic fields perpendicular to the plane of the figure [Ref. 1]. This analyzer will spatially separate particles with different masses and energies. The opposing magnetic-pole faces determine the E||B analyzer region, indicated by the shaded area of the figure. A large flat electrode similar in shape and size to the E||B analyzer region is attached to one of the magnetic-pole faces and insulated from it. A high voltage applied to this electrode will establish the desired electric field between the electrode and the opposite grounded magnetic-pole face. The electric field separates the ion masses in the direction perpendicular to the magnetic-pole faces. Meanwhile, the magnetic field spreads ion energies of each mass to different path radii, as indicated by the curved path lines in the figure.

Attenuation grids are used to reduce ion flux from the plasma and to prevent space-charge blowup of ion beamlets within the E||B analyzer region. A normalization detector is provided to monitor the total ion flux from the plasma. During testing and calibration the ion source is moved into the spectrometer field of view to simulate a plasma ion flux of known energy, mass, and spatial definition.

The straight-through detector is used to set up the calibration ion source for energy, aiming, and focus.

The two apertures, a slit, and then a circular hole, define the field of view for the instrument. Located between the apertures is a magnetic shield that terminates the magnetic-field lines from TMX-U, protects the ions from the fringe fields of the E||B analyzer, and provides a field-free drift region in which the ions can move in straight lines to define their direction and incident positions.

Detector Array

The detector array consists of two sets of 60 small-area current collectors with eight large-area border collectors, as shown in Figs. 3 and 4.

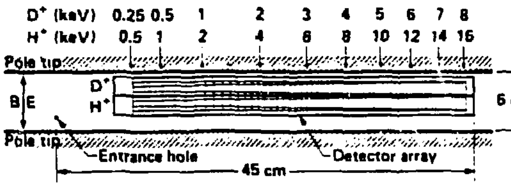

Figure 3. ELIS detector array.

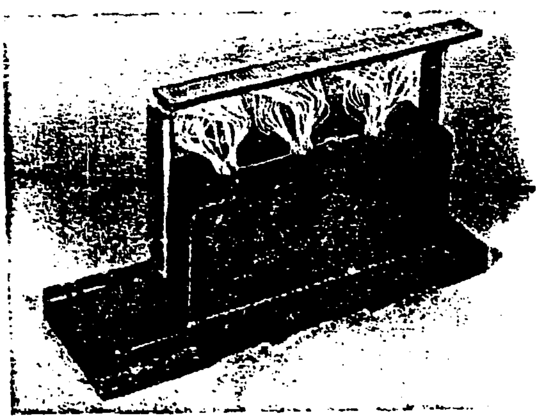

Figure 4. ELIS detector and re-entrant box.

In Fig. 3 the gradually widening pairs of lines across the upper and lower arrays illustrate the vertical extent of the ions at the detector. The width of each active collector is sized to equal energy steps across the full width of the array, excluding the end border collectors. Two logical groups are included, one for D^+ ions and the other for H^+ ions. The array was fabricated from 1/4-inch-thick G10 epoxy fiberglass with 2-oz. copper plating. Electrical connections to the collectors are by way of plated-thru holes to vacuum-compatible 55-pin hermetic connectors installed in a re-entrant box that provides the support and alignment of the detector array.

Data Recorders

Commercial data recorders (LeCroy Model 8212A) were modified for current input by replacing the resistor packs of the input buffer amplifiers with a 5 MΩ feedback resistor, as shown in Fig. 5.

With three feet of shielded, twisted-pair cable connected to the vacuum feed-thru connectors of the detector array, the measured frequency response was 3 dB loss at 2-kHz frequency. It has not been necessary

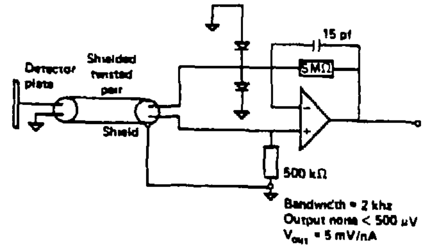

Figure 5. Schematic of ELIS 8212 I/V amplifier.

to make further changes or adjustments to the modified data recorders; the noise floor is normally 2.4 nA at a sample rate of 5 kHz.

CAMAC System

The CAMAC system, shown in Fig. 6, consists of three crates interfaced together by way of a fiber-optic serial link running at 5-Mhz data byte rate.

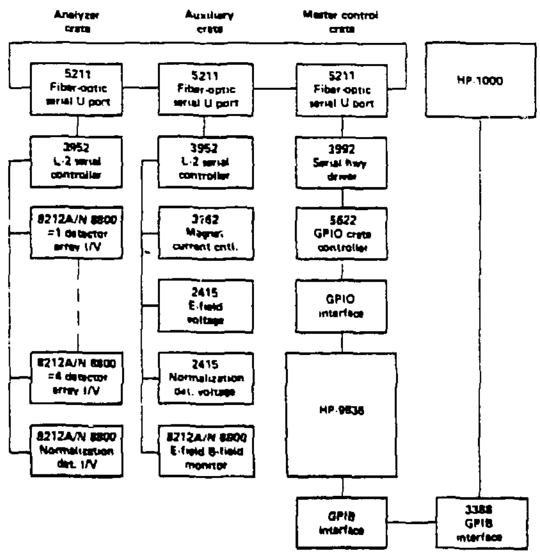

Figure 6. ELIS CAMAC system.

Analyzer Crate: The analyzer crate is mounted to the ELIS analyzer at the machine-end location. It contains the modified LeCroy data recorders, Kinetic Systems 3952 serial crate controller, LeCroy 5211 fiber-optic U-Port adapter, and in-house-built clock trigger module. We currently use four I/V data recorders to monitor the 128 detector-array data lines with master timing provided by the clock trigger module. The crate is positioned such that interconnect lines from the data recorders to the vacuum feed-thru connectors need not be longer than three feet. By mounting the analyzer crate on the E||B analyzer the task of grounding and shielding is reduced, because the fiber-optic link isolates the data recorders from any ac ground-loop problems.

Auxiliary Crate: The auxiliary control crate is located in a supplemental equipment rack outside the

TMX-U pit, approximately 50 feet from the east end of the machine. This location was chosen to permit manual control of the analyzer-magnet power supply and E-field voltage. This location is also convenient for installing the Hall probe monitor, magnetic power supply, and high-voltage power supplies required for calibration. The auxiliary crate contains a Kinetic Systems 3952 serial crate controller; a LeCroy 5211 fiber-optic U-Port adapter; a LeCroy 2415 hv programmable power supply for the E-field voltage source; a Kinetic Systems 3162 power supply controller for future control of the ELIS magnet power supply; a LeCroy 8212 data recorder for E-field, B-field, and ELIS-magnet-current monitoring; and a clock trigger module for master timing.

Master Control Crate: The master control crate is located in the diagnostic area on the second floor of the TMX-U building, approximately 200 feet from the auxiliary equipment rack location. Installed in the master control crate is a LeCroy 5211 fiber-optic U-Port adapter, a Kinetic Systems 3992 serial highway driver, and an Aeon 5622 GPIO Crate controller. This equipment provides an interface between the local control computer and the fiber-optic data link that is connected to the remote analyzer and auxiliary crates. The data link runs at 5-MHz byte rate and transfers 128 K words of data in 300 ms. The reliability of the data has been very good.

Magnet Control

The ELIS magnet power supply is located at the auxiliary equipment rack and connected to the E||B analyzer by way of cables run in conduit. The E||B analyzer magnetic field is manually adjusted by monitoring an F.W. Bell 620 Hall-probe instrument. The E-field voltage for the E||B analyzer is also manually set on the LeCroy 2415 hv power supply. Provisions for computer control and monitoring of both the magnetic field and E-field have been made in the present system although not yet in the computer software.

Vacuum System

Vacuum control and monitoring is done by an independent system based on the Granville-Phillips 303 vacuum controller, depicted in Fig. 7.

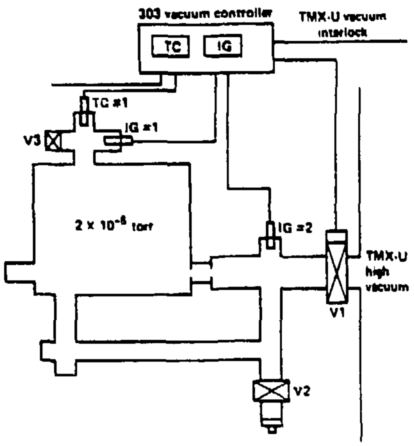

Figure 7. ELIS vacuum system.

A 6-in. valve, separating the E||B analyzer from TMX-U, is operated through the TMX-U vacuum interlock system by the local vacuum controller. For leak-hunting, the TMX-U vacuum system can override local control to open or close the valve, provided that the local vacuum controller directs the valve to open. No action can be taken by TMX-U vacuum system for a condition where the local controller directs the valve to remain closed. The intent of the system is to protect TMX-U should a vacuum failure develop within the E||B analyzer. Acceptable vacuum levels can be programmed in the 303 vacuum controller and are retained by battery backup in the event of power loss. This system is easy to use and has been trouble free.

Computer System

The ELIS computer system represented in Fig. 8, is based on a Hewlett-Packard 9836C that runs under the Basic 3.0 operating system. All programming was in-house and can be divided among three tasks: CAMAC control, data plotting, and data analysis. This diagnostic system was designed to be independent with the exception of master timing. The data recorder's clock and trigger come from the TMX-U master timing system. Two additional requirements are as follows. First, the current shot identification number must be obtained from the TMX-U central diagnostic computer. Second, a means to transfer processed data to the TMX-U central diagnostic computer system must be provided.

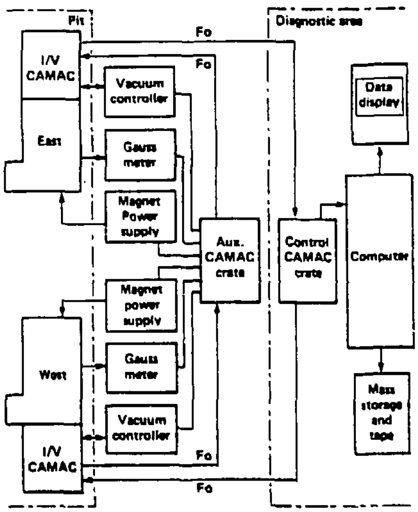

Figure 8. ELIS computer system.

The shot number is obtained by reading the data lines of a dedicated GPIB interface installed in the HP9836C. This interface is connected to a Kinetic Systems 3388 GPIB interface in a separate CAMAC crate having access to the TMX-U diagnostic computer system. GPIB protocol is not used because TMX-U outputs the shot number along with a service request (SRQ) to the interface. The HP9836C then reads the GPIB data lines and issues an interface clear (IFC) command when done. This method is easy to implement, works well, and has little impact on the TMX-U computer system.

To transfer processed data from the HP9863C to the TMX-U diagnostic computer, we currently load the data onto a HP9121 floppy disk and manually transfer this disk to a HP9121 drive connected to the TMX-U computer system. The current, manual data-transfer method will soon be replaced by a shared resource management (SRM) system, which is tied to all computer systems and allows common file access.

The normal sequence of operations for a typical shot is as follows. The TMX-U diagnostic computer loads the shot number into the 3388 GPIB interface at T0-3 minutes. The HP9836C control computer picks up the SRQ from the dedicated GPIB port, then arms all LeCroy 8212A data recorders. It next monitors the data recorder for trigger status. When trigger status is indicated, the LeCroy 8212A data is read out to RAM memory in the HP9836C. There it is formatted and then stored on a local hard disk along with the date, time, and shot number for file identification. An IFC command is issued to the dedicated GPIB to reset the shot number interface. A series of hidden-line data plots is then generated to serve as an overview of TMX-U machine performance. The final step is to analyze the data, generate the resultant plots, and, if required, store the processed data on the HP9121 floppy disk. Then the sequence is repeated for the next shot.

System Specifications

Detector Array
- Detector plate: 128 collector array
- I/V Amplifier: 1 nA to 2 μA, 2 kHz
- Transit record: 2 μA, 100 ms, 128-channel analog to digital converter (ADC) 12 bits

Straight-Through Detector [Refs. 2,3]
- Ion repeller: +9 kV, 1 mA
- Electron repeller: -4 kV, 1 mA
- I/V Amplifier: 10 nA to 20 μA, 2 kHz
- Transit record: 20 μA, 100 ms, 2 kHz, 1-channel ADC 12 bits

Normalization Detector
- Electron repeller: -4 kV, 1 mA
- I/V Amplifier: 10 nA to 20 μA, 2 kHz
- Transit record: 20 μA, 100 ms, 2 kHz, 1-channel ADC

Ion Source
- Anode bias: +10 kV, 10 mA
- Cathode bias: ±5 kV, 10 mA

Einzel Lens
- Element 1: ±2 kV, 1 mA
- Element 2: ±2 kV, 1 mA

Electric Field
- E-field plate: +1 kV, 1 mA
- Voltage monitor: 0 to +1 kV, 2 kHz
- Transit record: 2 V, 100 ms, 2 kHz, 1-channel ADC 12 bits

Results

Figure 9 is an example of the hidden-line data plot for a TMX-U plasma shot on January 11, 1985. The D+ plasma initially forms at about 12-ms shot time and terminates at around 70 ms. Note that the energy spectrum can vary considerable in shape and position on the energy scale during a plasma shot.

Figure 9. Hidden-line data plot for a TMX-U plasma shot.

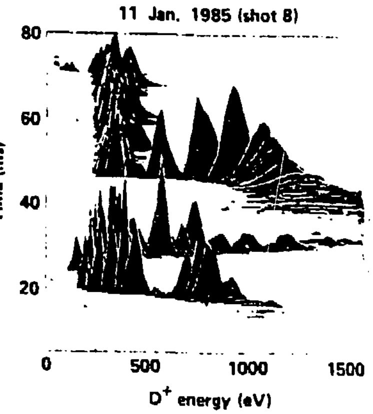

Figure 9. ELIS shot data.

References

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[2] J. H. Foote, G. W. Coutts, L. R. Pedrotti, L. Schlander, and B. E. Wood, Rev. Sci. Instrum., Vol. 56, p. 1117, 1985.

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