UCRL--89272

DE84 003742

STATUS OF THE TANDEM MIRROR EXPERIMENT-UPGRADE (TMX-U) DIAGNOSTIC SYSTEM

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This paper was prepared for submittal to
IEEE 10th Symposium on Fusion Engineering,
Philadelphia, PA, December 5-9, 1983.

November 26, 1983

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EXPERIMENT-UPGRADE (TMX-U) DIAGNOSTIC SYSTEM*

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Abstract

This paper presents the current status of the Tandem Mirror Experiment-Upgrade (TMX-U) diagnostics system. For the initial instruments active on TMX-U, the expansions or upgrades that have been implemented are outlined. For the newly added systems, more implementation details are presented.

Introduction

Since completion of the major device-fabrication phase on the Tandem Mirror Experiment-Upgrade (TMX-U), emphasis in diagnostics has shifted from fabrication, installation, and debug to operation and maintenance. Even with the emphasis on operations and maintenance, we have put significant effort into the upgrade and expansion of the total diagnostics system.

The plasma-diagnostic instrumentation systems, installed during the major device fabrication on the TMX-U, consist of 12 plasma-parameter instrumentation systems, a cable system, and a diagnostic timing system. During the two years of machine operations, we made changes and expansions to enhance the performance of the initial instruments. In addition, the number of instruments grew from 12 to 21. The number of diagnostic instruments delivered about doubled; the number of plasma information channels increased moderately from slightly less than 200 to about 250. This moderate increase can be attributed to the increase in instrument complexity that is required to obtain meaningful plasma data. This paper reviews the status of the existing diagnostic systems of TMX-U.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

Diamagnetic Loops

Because of the space limitations in critical regions of the TMX vessel and the desire to install other hardware, the number of diamagnetic loops has been reduced from 14 to 9. In addition, one loop is now used to provide a magnetic field measurement required by the radial plasma potential diagnostic recently commissioned. This loop is no longer available for plasma diamagnetism measurements and leaves only the eight loops shown in Fig. 1 to provide diamagnetic plasma signals.

Even with the use of ripple compensation amplifiers and simple digital-ripple-subtraction algorithms, magnet induced ripple signals limit the system sensitivity. Present noise equivalent signals are on the order of [illegible],000-10,000 A cm. Typical plasma signals have run from 5,000-100,000 A cm. To further improve the system's minimum sensitivty, more complex signal enhancement techniques are being investigated.

Beam Attenuation Detectors

The beam attenuation detector system was one of the first diagnostics to confirm the existence of the initial plasma in the TMX-U. Data from this system are valid for plasma densities above 2 to 3 x 10^{12} atoms per cm^2. Hardware improvements, made prior to and during the major-device fabrication of the upgrade, have yielded a fairly reliable diagnostic system. No major modifications or changes to this hardware have been made since initial installation. Careful design and installation of this hardware has permitted useful data to be extracted from signals exceeding 10 nA. Future mechanical modifications call for a change in the location of four detectors in each array. These modifications will permit the system to provide radial-line density information for plasma diameters approaching 30 cm.

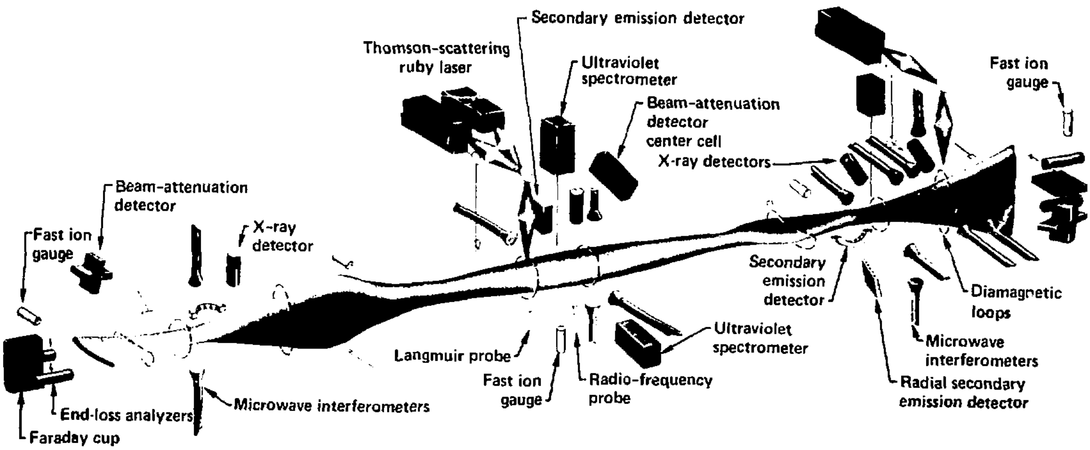

Fig. 1. Diagnostic sensor layout showing existing sensor locations on TMX-U.

Secondary Emission Detectors

Detector additions and deletions have characterized the major modifications made to the TMX system since initial plasma operation. A five detector radial array was fabricated and installed in the summer of 1982. The portable radial array was used to measure the radial extent of the sloshing-ion distribution. The array sensors were made of slightly modified beam-attenuation detectors. The transresistance amplifiers were a copy of units used to process beam-attenuation signals. The utilization of existing hardware designs minimized implementation time and provided a very reliable system. The detector arrays that view each plug have been reduced to nine detectors each.

Radio-Frequency Probes

The original radio-frequency (rf) probe system that was installed on TMX-U has changed very little. As shown in Table 1, the number of probe-tip signals has risen from 21 to 23. The number of data-recording channels has been expanded to 43. Sixteen of these channels are used to record processed microwave-density-fluctuation data that is obtained from the 140 GHz interferometer system. To achieve information on emissions above 10 MHz, a double-tip, high-frequency probe has been installed. Using RG213 cable, probe signals are transported to the 140 GHz microwave racks for processing and recording. To accommodate the study of higher frequency rf emissions, a significant number of fast-data recorders will be added in late 1983 or early 1984.

X-Ray Spectrometers

During the fall of 1981, only the x-ray system on the east plug was activated. Information obtained from this system is used to optimize the design of the remaining systems. Mechanical-shielding designs have been upgraded and hardware modified. These modifications should further reduce the sensitivity of the detector to scattered radiation.

In addition to shielding improvements, each detector collimating assembly has been fitted with a manually retractable calibration source. The iron 55 source provides a quick method of checking the calibration of the system and verifying operational integrity.

The high-speed-spectroscopy amplifier, ADC, and memory were picked with the hope of achieving 300 eV resolution at count rates exceeding 100 kHz. During machine-plasma cycles, the x-ray emissions have been above expectation and contain copious coincident x-ray pulses. The coincident pulses cause an unacceptable decrease in the system-recorded, throughput count rates. To overcome this deficiency, the system is being reconfigured with faster amplifiers and tandem ADC's. To achieve even higher counting rates a 16-channel, high-speed-spectroscopy counting system will be added for each installed detector. Although this system will have low-spectral resolution, the higher counting rates will be useful.

Extreme-Ultra-Violet Monitor System

The extreme-ultra-violet monitor system, used during the early days of TMX-U, consisted of one 0.4-m, normal-incident monochromator capable of monitoring 22 adjacent spatial positions with a time resolved of 125 μs. Support systems were provided to allow this instrument to be loc any one of four machine locations.

Over the past two years of machine operation, two spectrometers have been added to this diagnostic system. A fairly portable normal-incident, 0.4-m, timing-resolving spectrograph capable of measuring emission from 300-2200 A was added shortly after TMX-U plasma operations. In this instrument a 1024-element photodiode array provides over 1000

Table 1. Plasma diagnostic instruments of the TMX-U.

Diagnostics	No. of plasma relevant channels Fall 1981	Fall 1983	Channel additions under development
1. Diamagnetic loops	14	9	
2. Beam-attenuation detector	51	51	
3. Secondary emission detector	21	30	
4. rf probes	21	23	
5. X-ray spectrometers	1	3	
6. EUV monochromator	22	22	
7. EUV-grazing-incidence specrometer	1	1	
8. EUV-normal-incidence spectrometer	0	1	
9. End-loss analyzer	4	4	320
10. Langmuir probes	0	4	
11. Faraday cup	26	26	
12. Net-current collectors	26	38	
13. Fast-ion gauges	3	6	
14. Thomson scattering	2	3	
15. Microwave interferometers	4	5	7
16. Microwave-density fluctuations	0	4	0
17. Bolometers	0	12	8
18. Whistler electron cyclotron emissions	0	1	1
19. Perpendicular electron cyclotron emissions	0	1	0
20. Charge-exchange analyzer	0	1	0
21. Plasma-potential diagnostics	0	1	0

channels of spectroscopically resolved time-dependent data. This hardware is provided by the Johns Hopkins University and is described in detail elsewhere [1].

A third grazing-incident spectrometer has been installed and is operated as a joint effort between E and H Divisions at Lawrence Livermore National Laboratory. This instrument provides time-resolved data for 1024 spectroscopically resolved wavelengths between 20 Å and 2500 Å. This instrument is installed at the TMX-U center cell. The time resolution for both the above instruments is about 4 ms. Further plans for this system include the addition of another normal-incident, time-resolved spectrograph to monitor emissions at the TMX-U center cell. This instrument will be installed permanently at the TMX-U center cell and will have characteristics similar to the Johns Hopkins unit previously installed [1]. Once the installation is complete, the two portable units can be moved without losing center-cell emission data.

End-Loss Analyzers

The only change to the end-loss analyzer hardware installed during the construction of TMX-U has been to increase the maximum voltage capability of the retarding-grid, high-voltage sweep system. This has been achieved by using a high-voltage transformer capacitively coupled to the existing high-voltage power supply. In addition, a 7-kV, dc-bias supply has been connected in series, with the transformer secondary. Using this technique, voltage swings on the retarding grid between 4 to 10 kV can be achieved. This voltage sweep has been satisfactory to investigate the escaping ion energies.

To further investigate the energy spectrum of the end-loss ions, the development of two end-loss ion spectrometers is underway [2]. These two units will incorporate E-parallel to B-magnetic spectrometer modules similar to those developed by Princeton [3]. The major changes in this spectrometer system will be in the signal-detection scheme. In the Livermore units, a dual array of 80 detectors will collect the ion currents and present them to the input of 160 high-gain transresistance amplifiers. Use of the dual array will allow separation of the hydrogen- and deterium-ion species. Signals from the 160 amplifiers will be recorded using transient records. The maximum expected data rate for each channel will be about 5 kHz. The expected energy range for the system is variable. The targeted range should cover 0.5 to 8 keV for deuterium and 1 to 16 keV for hydrogen. In the target range, the energy resolution is expected to be about 200 eV. This diagnostic should be commissioned during the summer of 1984.

Langmuir Probes

Since the initial plasma runs in TMX-U, four Langmuir probes have been added to the diagnostic system as shown in Fig. 1. Probes are located in the east and west plug, east solonoid, and east-fan region. Sweep for each probe tip is supplied using a 100 V, 2 A, bipolar-operational amplifier and triggered function generators. Using the above drivers, probe voltage swings of 170 V peak to peak can be achieved. The probe current and voltage signals are monitored using differential amplifiers and standard transient recorders.

Faraday Cups

The Faraday cup system has not substantially changed since the initial installation on TMX-U. After the cabling was modified to avoid the power-supply noise associated with CAMAC-crate, power-supply emissions, noise levels from the 26 detectors were reduced to less than 50 μV peak to peak. The introduction of 6 plasma-potential control plates at each end of the machine has reduced the sensitivity about a factor of two.

Net-Current Collectors

The original net-current collector system has not changed since the initial installation on TMX-U. However, 12 data-recording channels have been added to monitor the net currents collected by the six plasma-potential control plates located in each end fan of TMX-U. These data recorders will also monitor the potential to which these plates rise when connected to ground through a high impedance.

Fast-Ion Gauges

Initially, three fast-ion gauge channels were installed on TMX-U. Since the initial installation, the number of channels has increased to six. Two of the new units have been added to monitor neutral pressure in the east- and west-plug regions. One of the units (a rover) is set up for use on any of 24-unshielded ion gauges inside the machines. Since the internal gauges are unshielded, this channel can be used only when the magnets are not cycled. For the most part, the hardware has performed rather well. Using the system has provided considerable information on the pressure dynamics in TMX-U during machine cycles.

Thomson Scattering

Two Thomson scattering systems are used to determine the electron temperature and density of the plasma. The original systems provided only a single point measurement in the center cell and east plug. During the design of each system, provisions were made to accommodate the hardware necessary to obtain a second radial or spatial measurement. Since the completion of the initial installation, work has started on obtaining a second radial measurement on the center-cell system.

In addition to installing the hardware necessary for the second radial measurement, considerable effort has been expended to reduce the noise signal levels and install signal amplifiers at the photomultiplier output. The noise reduction was achieved by separating, as much as possible, the signal cables and CAMAC-crate power supplies. As a result, noise levels on the signal lines have been dropped from 4-5 mV to 0.1-0.5 mV (referred to photomultiplier outputs). The effort has improved system-data-error bars and provided reasonable numbers at densities consistent with design expectations.

Microwave Interferometers

The four-channel, 140-GHz interferometer system has provided critical-line density measurements since the early days of machine operation. Because this system is a very important diagnostic, changes have been made to improve the up time of the system. Since klystrons have a limited operational and shelf life, they have been replaced with a solid-state IMPATT oscillator. To further improve the performance of the complex EIO power supply, the internal 300-V, 2-kW, raw-power unit has been replaced with an external supply that has a current-limiting, fold-back circuit. This fold-back circuit dynamically limits the raw power available whenever current surges occur. This allows the EIO supply to recover from load instabilities and momentary shorts without damaging the high-voltage control and conditioning units. Although the modifications have been made at the expense of supply ripple, the improvement in system reliability appears to warrant the change.

To achieve more measurement points along the machine axis, six additional waveguide horns have been added. Four of the horns are available to provide alternate data channels for the 140-GHz system. The remaining two horns will be used to evaluate the solid state 94-GHz interferometer prototype being developed.

The complete 94-GHz system will provide eight additional line-density measurement channels which should be operational by the summer of 1984.

Microwave-Density Fluctuation System

The plasma signals from the microwave interferometer system are each processed to determine the characteristics of high-frequency fluctuations that are indications of instability processes in the plasma. As shown in Fig. 2, the plasma signal is first beat down to baseband by mixing it with the 720-MHz reference signal. A combination of filters and mixers allows a variety of envelope and spectral measurements to be made. Envelope measurements cover bands around 7 MHz and 14 MHz as well as total rf power to below 30 MHz. High-speed transient recorders allow the rf signals to be sampled directly so that several software processing routines can be used (e.g., fast-fourier transforms and cross-correlation techniques). This tells the actual frequency of the instability as well as its propagation direction. Signals above 30 MHz can be monitored on a separate system that selects any 10 MHz band up to 250 MHz and down converts it to baseband where the envelope is monitored and it can be sampled directly by an eight bit 100 MHz transient recorder. The entire system consists of four envelope monitors and two spectral samples for each of four interferometer channels.

Bolometers

To accommodate the requirements for power balance experiments, the installation of a 20-channel bolometer instrumentation system is in progress. To date 12 of the 20 channels have been installed. The total system design is a copy of the hardware developed by J. Schivell et.al. at Princeton [4].

Three bolometers are positioned in each end fan. Physically, these bolometers are as close as possible to the Faraday cups and net-current collectors. Each of these bolometers is covered by a 12% transparent screen to reduce the particle flux. Twelve percent screens also cover the east-plug bolometers, which have a radial view of the plasma at the 5 kG and 20 kG points. No such screens are installed on the west-plug bolometers located at the corresponding 5 kG and outside 10 kG points. Both 10 kG bolometers view the elliptical fan plasma along its semimajor axis.

The bolometers installed have a threshold sensitivity of 0.5 mW and a rise time on the order of 20 ms. Initial runs with bolometers installed have indicated an undesirable sensitivity to ECRH microwave power. To reduce the microwave-sensitive problem,

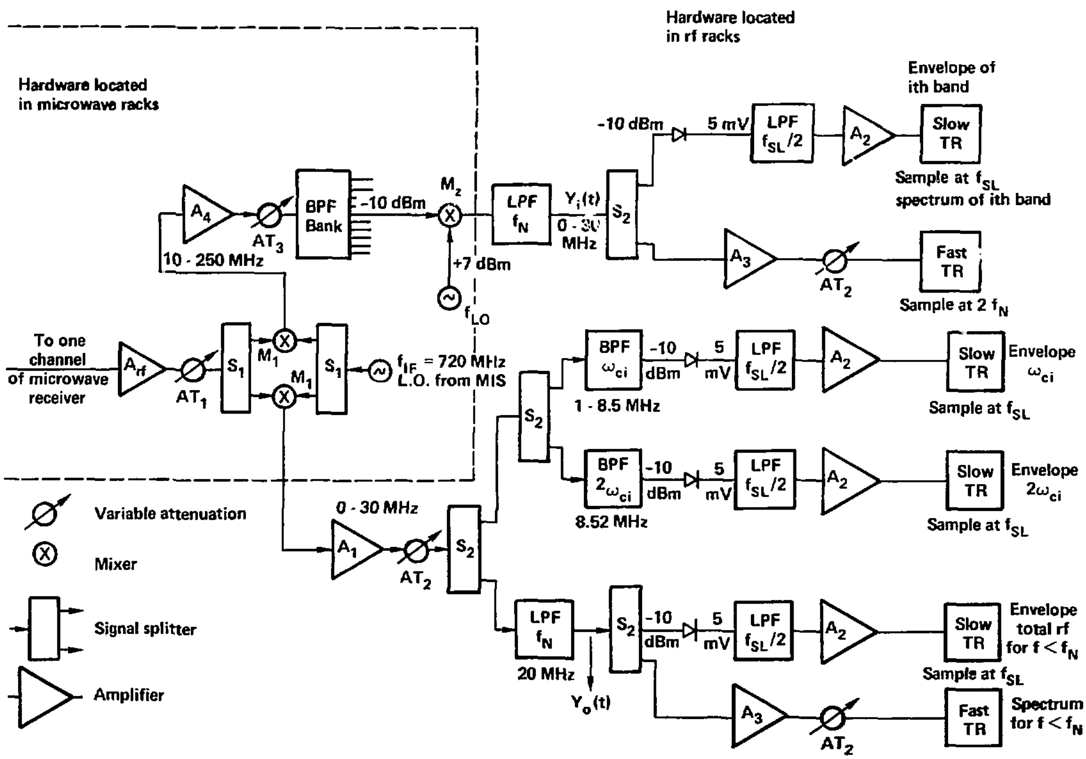

Fig. 2. Signal processing and recording system for one of four microwave-density fluctuations.

cut-off waveguides have been installed on all of the existing sensors. These waveguides are aluminum structures with a 0.4 in. hole bored in the center which slip inside the bolometer housing. With these structures, the existing 4.4 and 8 deg field of views are preserved and an estimated 50 dB of attenuation at 28 GHz is provided.

To accommodate charged particle detection, copper inserts that hold the bolometer input at ground potential are being installed on all end-fan sensors. This insert will prevent charges from building up on the detector surface and repelling subsequent incoming charged particles.

Electron Cyclotron Emission

Evaluation of the electron cyclotron emissions from the east plug are used to measure hot-electron densities. Two types of emission are being examined on TMX-U: Whistler Electron Cyclotron Emission (WECE) and Perpendicular Electron Cyclotron Emission (PECE). The WECE signal originates from the cyclotron motion of the hot electrons and in higher density plasma regions is ducted by the machine B-field toward the fan. As the plasma drops in density, this wave converts to a free-space wave and is picked up by a parabolic reflecting antenna mounted on the end wall of the vessel. This signal is important because its power and frequency depends on the density and temperature of the hot electrons in the thermal barrier region. The emission of this wave in TMX-U is essentially black body; hot-electron temperature could be determined from the signal if a suitable means for calibration on TMX-U were available (e.g., x-ray measurement).

The PECE wave is an X- or O-mode wave and is generated by the higher harmonics of the electron cyclotron emission. These harmonic waves are directed outward perpendicularly to the machine B-field and the antenna is positioned to observe optically thin plasma lines, thus providing good spatial resolution. PECE waves are also dependent on density and temperature of the hot-electron population. Coupled with WECE temperature estimates, the temporal variation in density at a specific location (PECE antenna position) can be determined. The hardware for this system is shown schematically in Fig. 3.

Charge Exchange Analyzer

A charge exchange analyzer has been added to the TMX diagnostic system to provide information on the energy of ions in the east plug. The instrument was designed to view the east-plug midplane at an angle of 45 deg. The field of view is set at about 7-8 mrad. The hardware installed on the east plug is a modification of the single-channel auxiliary analyzer used on 2XIIB [5]. In this diagnostic, charge-exchange neutrals escaping from the plug plasma are ionized in a 28 cm long stripping cell pressurized at

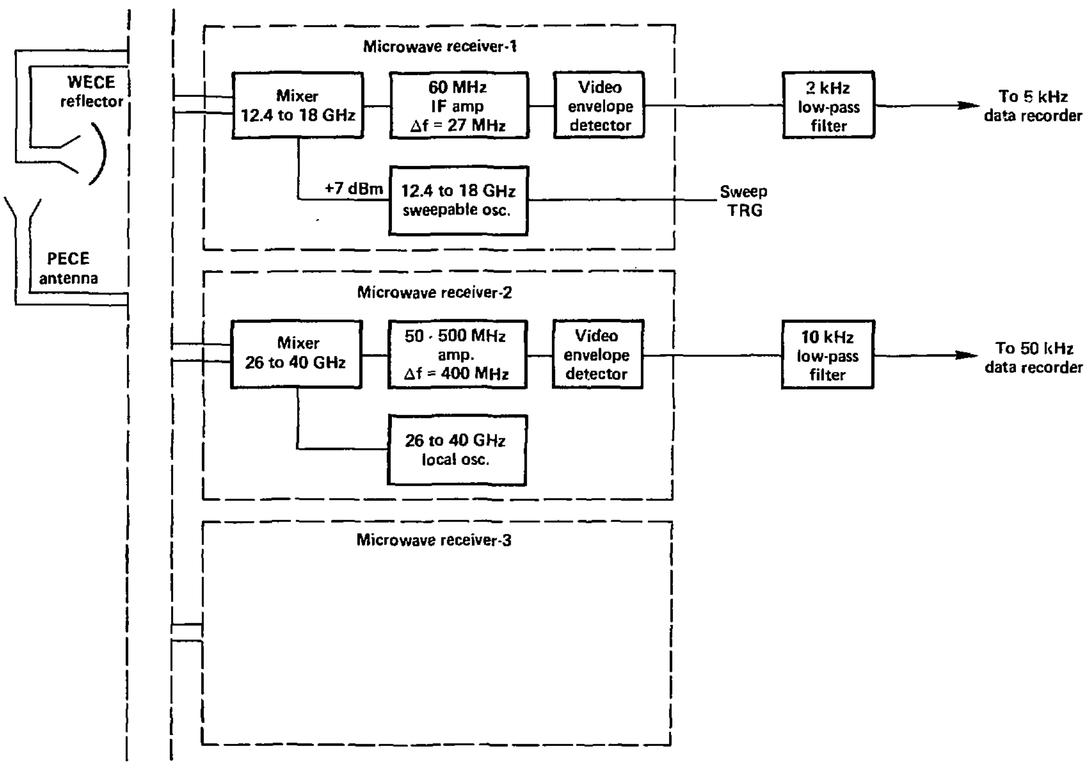

Fig. 3. Electron cyclotron emission monitor hardware.

about 1-0.5 x 10^{-3} Torr with N_2. The energy of the ions exiting the stripping cell are monitored using a magnetic-shielded-parallel-plate electrostatic analyzer. Ion detection is accomplished using secondary electron emission, a plastic scintillator, and a photomultiplier. The energy range for the system was specified at 25 keV with a resolution of about 1000 eV. A full energy scan is completed every 2 ms.

Plasma-Potential Diagnostic

The plasma-potential diagnostic is an instrument used to indirectly measure the plasma potential of the center-cell plasma. The hardware used to achieve initial potential measurements consists of components previously used on TMX by G. Hallock [6]. These components have been installed with the minor modifications necessary to accommodate the TMX-U system geometry.

Since the source design limits the operating voltage to 30-35 kV, plasma potential measurements cannot be made with the TMX-U center cell running at 3 kG. Thus initial measurements will be made with center cell running at 2 kG. To overcome this limitation, arrangements are being made to install a source capable of 125 kV operation. This system is targeted for operation in the summer of 1984.

To prepare for the installation of the above system and avoid growing maintenance problems with an old computer system, the control computer for the system has been upgraded to an HP9836 with a basic operating system. Installation of this system provides more reliable operation and permits much flexibility during systems operation. In addition, the new computer allows the beam deflection system to be easily upgraded using a CAMAC programmable function generator. Use of this function generator provides more accurate control over beam steering and permits rapid, accurate, deflection changes.

Conclusion

The diagnostic instrumentation system on TMX-U is a dynamic growing system. Continued operation of TMX-U will probably result in more additions and changes.

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