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TANDEM MIRROR EXPERIMENT UPGRADE (TMX-U) OVERVIEW-RECENT EVENTS

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Abstract

Since its construction and commissioning was completed in the Winter of 1981, the Tandem Mirror Experiment Upgrade (TMX-U) has been conducting tandem mirror thermal barrier experiments. The work, following the Fall of 1983 when strong plugging with thermal barriers was achieved, [1] has been directed toward controlling radial transport and forming thermal barriers with high density and Beta.

This paper describes the overall engineering component of these efforts. Major changes to the machine have included vacuum improvements, changes to the Electron and Ion Cyclotron Resonance Heating systems (ECRH and ICRH), and the installation of a Plasma Potential Control system (PPC) for radial transport reduction.

TMX-U operates an extensive diagnostics system [2] that acquires data from 21 types of diagnostic instruments with more than 600 channels, in addition to 246 machine parameters. The changes and additions will be presented.

The closing section of this paper will describe the initial study work for a proposed TMX-U octupole configured machine.

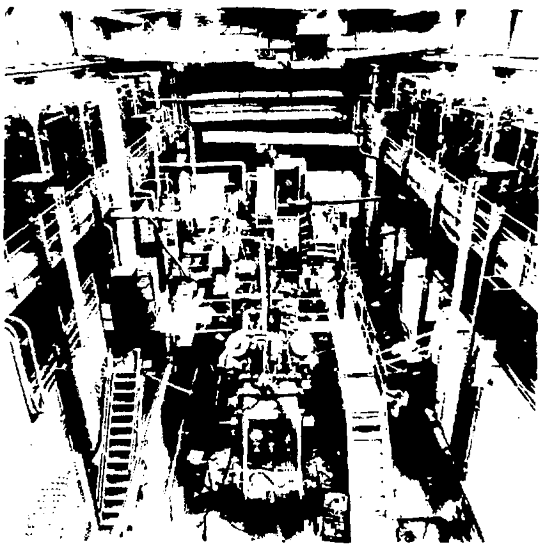

Fig. 1 TMX-U Overview

Introduction

In its basic configuration, the machine shown in Figure 1 is a vacuum vessel 21.3 meters long containing an 8-meter-long central cell, two end cells 3 meters long, and the rectangular-shaped end fan tanks. An internally enclosed magnet set of 24 water-cooled coils, shown in Figure 2, produces a solenoidal magnetic field of 3 kG in the central cell and a minimum-B magnetic well of 5 kG in the end cell. Magnetic mirrors of 20 kG form both ends of each end cell. In the end tanks, the field shape and magnitude has been designed to expand to a 100-Gauss geometry. The vacuum space inside the vessel, as shown in Figure 3, forms three regions radially described as a plasma space at the center extending the length of the vacuum vessel, surrounded by concentric first and second injector regions that are separated by liquid-nitrogen-cooled panels. An extensive gettering system, containing over 1000 Ti-Ta wires, sublimates fresh coats of titanium on every surface before plasma shots, establishing a vessel pressure of 10^{-8} Torr before the shot. Six neutral beam injectors at each

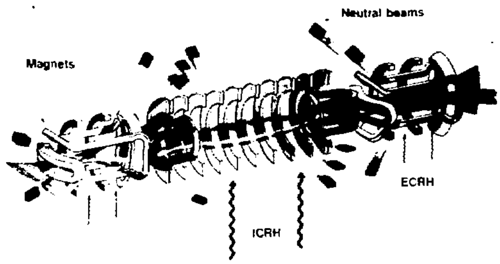

Fig. 2 TMX-U Magnet Set

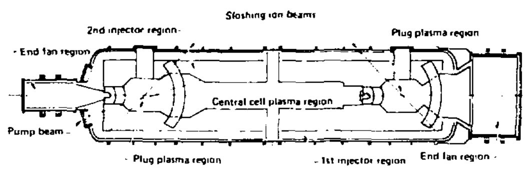

Figure 3 TMX U vacuum regions

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plug produce the sloshing ion plasma geometry, another six injectors are used for barrier pumping, and six in the central cell are used for heating. ICRH systems are used to heat ions in the central cell, and ECRH microwave power is applied for heating electrons in the plugs and for forming target plasmas. Gas fueling is by gas box and individual gas valves in the center cell and plugs. Plasma conditions and characteristics are observed by the 21 different types of diagnostics listed in Table 1. These diagnostics, along with transducers to measure machine parameters (magnets and beam currents and ECRH and ICRH input for example), account for some 900 channels of data that can be read by a diagnostics computer system [2] that collects more than 8 MBytes of data for each shot.

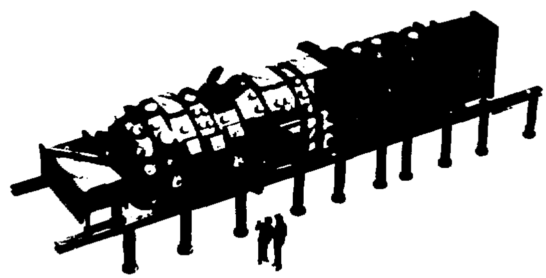

Fig. 4 TMX-U Systems Overview

Diamagnetic loops	Net current collectors
Beam attenuation detector	Fast ion gauges
Secondary emission detector	Thomson scattering
RF probes	Microwave interferometers
X-ray spectrometers	Electron cyclotron emissions
EUV monochromator	Charge exchange analyzer
EUV normal incidence spectrometer	Plasma potential diagnostics
End loss analyzer (ELIS)	Emissive probe
Langmuir probes	High speed framing camera
Faraday cups	

Table 1.

Diagnostic Channels

Following its construction and checkout start in December of 1981 [1], TMX-U has undergone seven experimental physics runs, with the most recent one ending in June of 1985. In the subsequent air cycle, which extended over a period of 4 months, the machine was extensively modified with changes or additions affecting every machine region. The essential elements of this up-to-air cycle consisted of repositioning the sloshing ion neutral beam injectors in the plugs to a 40 degree injection angle to move the sloshing ion turning point to a higher magnetic field, installing new ECRH antennas to provide more uniform heating, and adding 18-GHz microwave heating in the plugs and central cell to heat warm electrons. In the central cell, ICRH antennas on either side of a midplane gas box heat ions symmetrically, and new 2 kV neutral beams will be used to fuel and heat the central cell ions when that system is completed later in the year. Finally, the plasma potential plate systems in the end tanks have been expanded radially to improve particle containment and accountability.

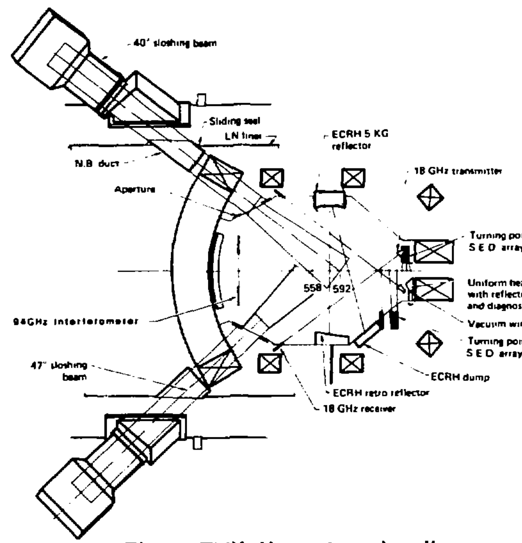

Fig. 5 TMX-U east end cell

<u>Description of Changes</u>

Since experimental measurements and analysis had determined that the sloshing ions were turning inside of the 10-kG point, four of six plug sloshing ion neutral beams shown in Figure 4 have been repositioned to a 40 degree injection angle in order to establish sloshing ion turning nearer the 10-kG ECRH fundamental resonance point. To effect these changes along a line-of-sight, as seen in Figure 5, new tank wall adapters, apertures, and ducting have been installed to maintain gas control. Also, to measure the turning point location, a Turning Point Secondary Emission Detector has been installed adjacent to the east plug outer resonance location, and additional 94-GHz interferometers have been added at both inner and outer 8-kG locations in each plug.

In TMX-U, fundamental mode microwave heating is applied at the inner and outer plug 10-kG resonance points. Additional second harmonic heating is injected at the 5-kG magnetic well. The complete system as modified during the summer air cycle can be seen in Figure 6. Separate 28-GHz gyrotrons power the outer 10-kG locations to 200 kW, and a single tube with splitter has been installed to power the inner 10-kG resonance points. Two additional tubes are used to power the 5-kG locations. The Vlasov reflector antennas, formerly at the 10-kG resonance locations, heated only the central portion of the long elliptical plasma fan, and these have been replaced with new antennas and reflectors designed to provide more uniform heating of the entire fan at 10 kG. These stainless steel antennas have a nominal rectangular cross section and are shaped to fit the plasma shape described as the 25-cm field surface. The radiating surface consists of two parallel rows of slots 0.5 cm wide x 5.2 cm long closely spaced over its length of 1 meter.

An additional 18-GHz heating system has been added in the plugs and central cell. The internal waveguide system pictured in Figure 7 shows transmission horns located in the plug outer 6.4-kG regions, with receiver antennas positioned in opposite locations to measure power. Additional transmitting horn pairs have been located in the transition magnet regions of the central cell. Power to these systems is generated by four 18-GHz klystrons on loan from Oak Ridge National Laboratory. Each klystron system can supply up to 15 kW to its corresponding waveguide. The power components consist of a klystron, magnet, filament, and high-voltage power supplies and the local control panels. Supporting facilities for the entire system provide 665 kW of electrical power and 55 gpm of low conductivity water.

A new ion cyclotron resonant frequency (ICRF) heating arrangement has been installed in the TMX-U central cell to ensure that all cold ions from the gas box will pass at least once through an ICRF resonance. In this arrangement, as shown in Figure 8, a new gas box has been installed near the midplane, and an existing 2 x 170 degree loop antenna has been installed to the west. On the east side, a new dual half-turn antenna has been added. In the new gas box configuration, the surface facing the plasma, corresponding to the 24 cm radius field line, becomes the machine limiting aperture. Gas is supplied by four piezoelectric valves that inject uniformly and directly across the plasma circumference. Gettered stainless steel baffle plates positioned to either side are intended to pump the small fraction of cold gas not interacting with or pumped by the plasma. An existing west gas box located at the 5-kG location has been similarly rebuilt, with its limiter corresponding to the 26-cm field line. Thus, comparisons of fueling efficiencies between the two systems will be possible. Charge-exchange of energetic ions at the gas box is measured by a three channel Secondary Electron Detector, with detectors mounted at 15, 30, and 45 degrees facing the gas box.

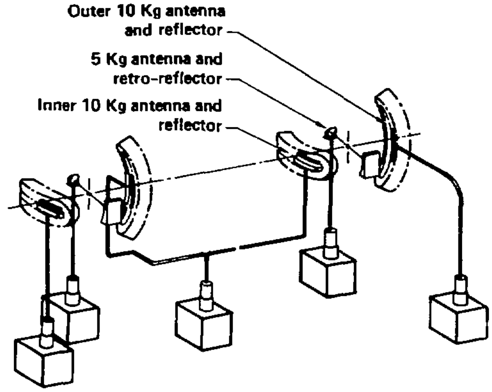

Fig. 6 TMX-U28 GHz ECRH system

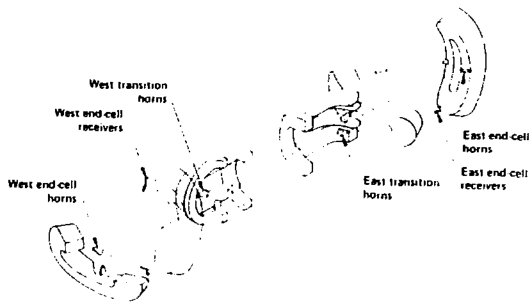

Figure 7. TMX-U 18 GHz heating system

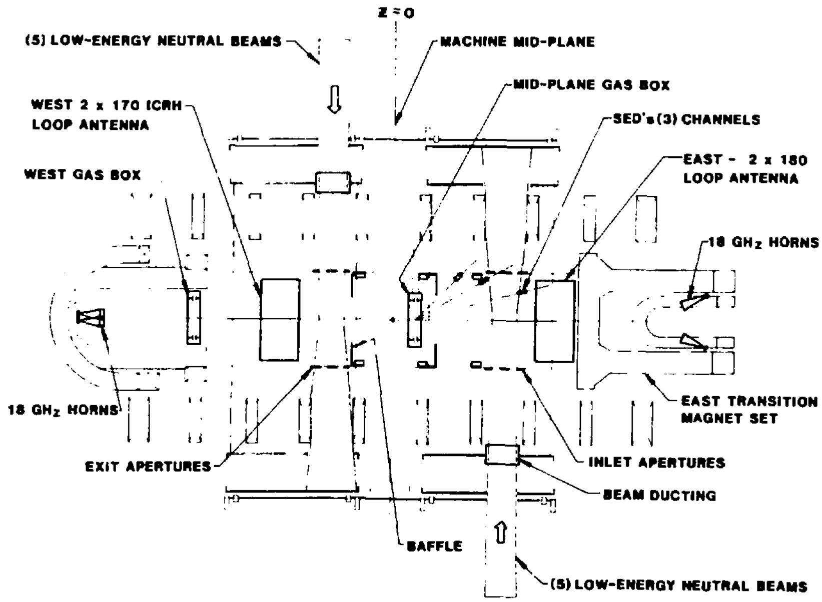

FIGURE 8

TMX-U CENTRAL CELL

Low Energy Neutral Injection (LENI) [3] is a second central cell fueling system being added to TMX-U. Its main advantage will be the forming of beam-fueled, potentially confined, central cell plasmas without the cold ions that are injected by gas box fueling. In this system, ten 2-kV, full-energy-component neutral beams are installed in the central cell. As seen in Figure 9, arrays of five sources each are positioned to either side of the machine. All the internal work consisting of apertures, ducting, alignment, and SED diagnostics have been installed. Six of the ten source modules have been fabricated and are undergoing testing.

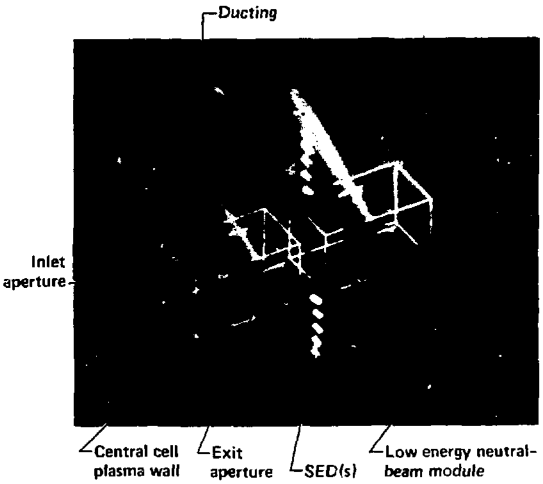

Fig. 9 TMX-U central cell low-energy neutral-beam injection

The PPC system in TMX-U [1] is used to measure end-loss currents and for controlling radial transport by controlling potential gradients across the plate assembly seen in Figure 10.[7] These elliptically shaped plates, located at the end walls, map to circles in the machine central cell. The present system has been expanded from five rings to seven rings and presently incorporates edge field line contours ranging from the 5.2 to the 26-cm field line. These plates are segmented by quadrants to detect azimuthal potential differences. All plates are constructed of 0.32-cm-thick stainless steel, spaced to keep electric fields below 5 kV/cm, and have been designed and constructed to high voltage considerations. A system of 24 Faraday cup detectors are combined with the plates, and mesh-covered openings are positioned to provide viewing for back-mounted diagnostics that include End Loss Ion Spectrometers (ELIS), End Loss Analyzers (ELA), and Bolometer diagnostics. Each plate is electrically isolated from other plates and may be grounded, floated, or biased as required. The system has been tested to stand off 5 kV between plates.

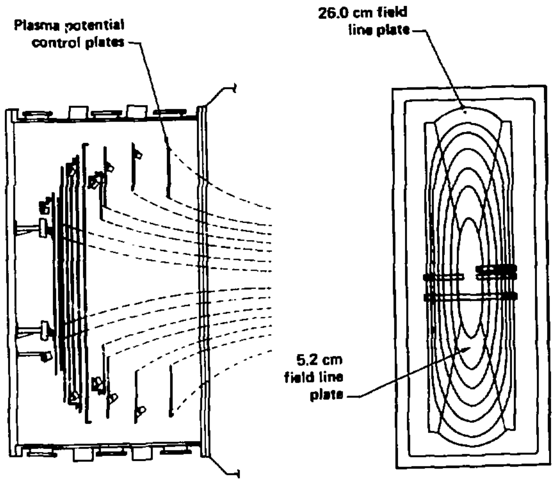

Fig. 10 TMX-U plasma potential control plates

Diagnostic Changes

The TMX-U Diagnostic system, shown in Figure 11, has undergone continuous changes in rearrangement, improvements, and growth since the last reported progress presented in December of 1983. [4] Since that time, three major new diagnostics systems have been added that include an End Loss Ion Spectrometer (ELIS) [5] mounted at the east end fan wall to measure end-plug potential, average central-cell ion energy, and plasma potential in the thermal barrier region. Another system added included five new 94-GHz microwave interferometers which, when combined with one existing 94-GHz interferometer and four existing 140-GHz systems, are used to measure line-averaged densities in all the machine regions. To measure energetic electron x-ray emission, six new x-ray spectrometer systems have been added to the TMX-U end cells and

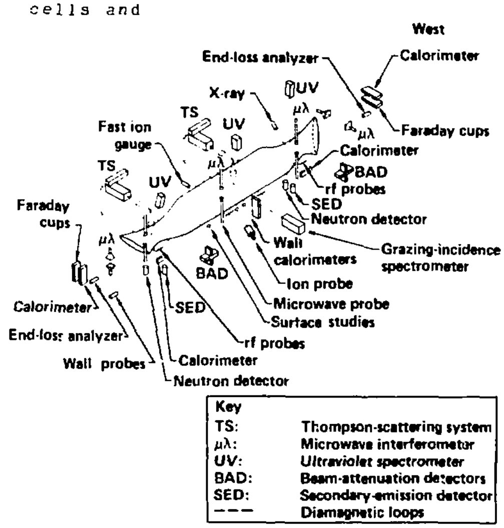

Fig. 11. Diagnostics Instruments For Tandem-Mirror-Confined Fusion Plasmas

west fan tank. [1] Each end cell installation consists of a pair of coaligned but oppositely mounted NaI and HPGe detectors. A single SiLi detector in the east end cell measures first harmonic heating, and a third NaI detector with companion pin hole camera views bremsstrahlung radiation produced by energetic electrons exiting the west end-cell and striking the PPC plates. Above the west end-cell, a second imaging camera system measures the spatial distribution of energetic electrons in its thermal barrier. Finally, internal tank preparations were made during the air cycle to install a time-of-flight analyzer and a second ELIS at the west fan region.

Studies

In a study for improving the end-cell magnetic field geometry, an octupole set design has been investigated as a possible replacement for the existing quadrupole coil set [6]. The component coils of the octupole set consists of a large octupole, two high-field end solenoids, two peripheral solenoids, and a nested transition octupole. The octupole has some basic advantages in that its flux surfaces are more axisymmetric, and since the inner mirror is solenoidal, radial transport is improved [7,8]. The octupole set shown in Figure 12 has a mirror,to-mirror distance of 3 m, with a conductor-bundle cross-section of 10 x 14, 5/8-inch, water cooled copper conductors. When the midplane of this magnet set is positioned in the same axial position as the present quadrupole set, the end-cell vacuum vessel and sloshing neutral beam mounting ports are directly compatable. And since the flux surfaces leaving the end cell are more axisymmetric, the small octupole transition set can be made smaller, permitting nesting within the larger octupole. Further, as seen in Figure 13, the inner mirror also serves as an axisymmetric throttle for a machine central-cell whose circularity has been axially increased by the removal of the quadrupole transition coil sets. The power required for a machine magnet system using the octupole sets as described is 46.5 MW, with 93% of this power required to drive the end-cell octupole sets [3].

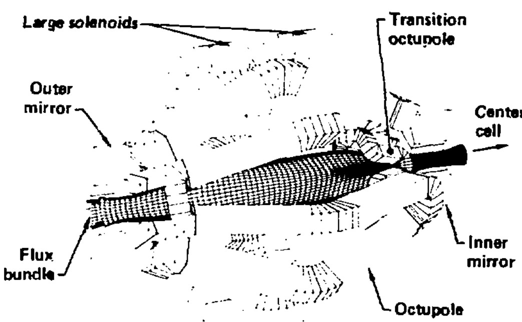

Fig. 12. TMX-U end cell octupole

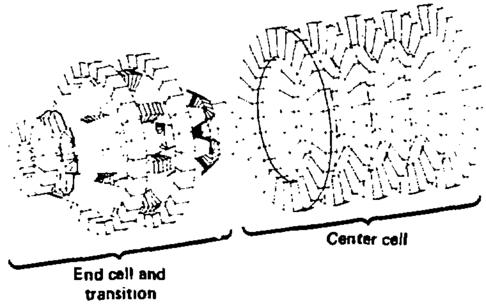

Fig. 13. TMX-U octupole magnet set

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