AN ENGINEERING TEST STATION FOR TFTR BLANKET MODULE EXPERIMENTS

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Summary

A conceptual design has been carried out for an Engineering Test Station (ETS) which will provide structural support and utilities/instrumentation services for blanket modules positioned adjacent to the vacuum vessel of the TFTR (Tokamak Fusion Test Reactor). The ETS is supported independently from the Test Cell floor. The ETS module support platform is constructed of fiberglass to eliminate electromagnetic interaction with the pulsed tokamak fields. The ETS can hold blanket modules with dimensions up to 78 cm in width, 85 cm in height, and 105 cm in depth, and with a weight up to 4000 kg. Interfaces for all utility and instrumentation requirements are made via a shield plug in the TFTR igloo shielding. The modules are readily installed or removed by means of TFTR remote handling equipment.

Introduction

The Tokamak Fusion Test Reactor[1] (TFTR) now under construction will offer the first opportunity for reactor-prototypic fusion blanket experiments using 14-MeV neutrons. A blanket module test program is currently being formulated for the TFTR, with the first module expected to contain a solid lithium compound for tritium breeding. The unique technical data that can be obtained from TFTR blanket experiments in the early and mid-1980s is discussed elsewhere.[2,3,4] In addition to this engineering data, the blanket module program will provide an opportunity for important fusion technology development. Operational experience would be gained for the first time in the following areas:

- Fabrication of blanket elements for experimental modules. This practical need will serve as a focal point for narrowing down myriad design options for blanket materials and their physical forms.
- Spatial measurements of neutron and gamma-ray flux and spectra throughout a prototypical reactor blanket module, in a reactor-like radiation environment.
- Methods of electromagnetic isolation of blanket modules from the tokamak plasma during discharge start-up and during plasma disruptions.
- Remote handling of blanket modules in a reactor-like environment.

Modular blanket capability for TFTR blankets will be made possible by means of an Engineering Test Station (ETS), which is depicted in Fig. 1. *The basic requirement of the ETS is to provide structural support and interfacing to utilties and instrumentation for blanket modules positioned adjacent to the TFTR vacuum vessel.* This paper describes the conceptual design of the ETS.

The ETS will be located in one of the bays between adjacent TF (toroidal-field) coils, as indicated in Fig. 2. Approximately half of the TFTR bays are potentially eligible to house the ETS, but the number of candidate bays has been arbitrarily restricted to five. The ETS must be capable of remote disassembly and relocation in any one of these five bays.

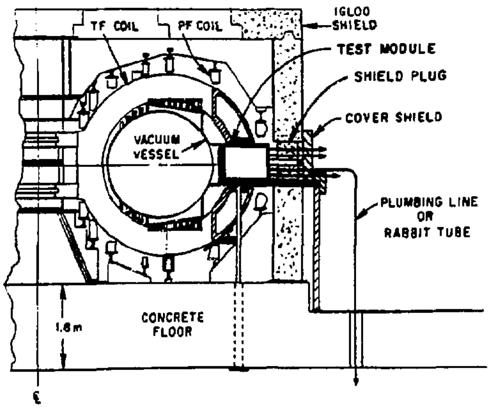


Fig. 1. Elevation view of the ETS. (796340)

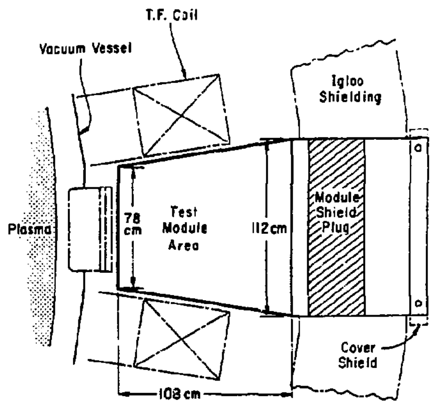


Fig. 2. Plan view showing location of the TFTR Engineering Test Station. (796431)

Functional Requirements of the ETS

Remote Handling

Facilitation of remote handling operations is a key design objective both for the installation and removal of the ETS and for the loading and unloading of blanket modules. The initial conceptual design of the ETS has only one support leg inside the igloo shield (see Fig. 1), and this leg is removable from the basement. All utilities and instrumentation connections to the experimental modules are made outside the igloo wall, where hands-on operations are permitted.

Test Module Size

The maximum dimensions of a test module are 78 cm in width, 85 cm in height, and 105 cm in depth (see Fig. 2). Provision can be made for a module of greater depth. The position of the module is fixed, with the front face located 3 to 5 cm from the vacuum vessel port cover.

Load-Carrying Capacity

- The ETS must be capable of supporting a test module up to 4000 kg in weight, plus a shield plug weighing about 1000 kg.
- The ETS must counteract any torques exerted by a test module experiencing electromagnetic forces due to changing magnetic fields.
- The ETS must retain its integrity during the most severe shaking of the TFTR machine by seismic disturbances or major plasma disruptions.

Anchoring

The ETS must be supported independently. There can be no connections to the TFTR vacuum vessel or TF coils, or to any other TFTR component.

Materials

Only nonmagnetic material can be used in the construction of the ETS and the blanket modules. Where a metal can be used, the prime alloy considered is 304L stainless steel. Electromagnetic forces on the ETS and test modules should be minimized by eliminating large conducting paths. To meet this objective, the conceptual design specifies fiberglass for the module support platform.

Utilities

Access to electricity, water, air, gas, and pneumatic tubes will be made via existing penetrations into the basement outside the igloo shield wall. Interfacing to the module will be made via connectors on the outside of the igloo shield plug (see Fig. 1).

Test Module Interconnections

The test module and igloo shield plug are mounted on the same pallet in order that interconnections for utilities and instrumentation can be made away from the ETS with good alignment assured. A central plug interconnection allows for rapid removal of sample fuel rods from a breeding experiment by pulling a fuel rod cluster attached to this plug through the shield block.[4,5]

Structural Aspects of the ETS

Description of Mechanical Features

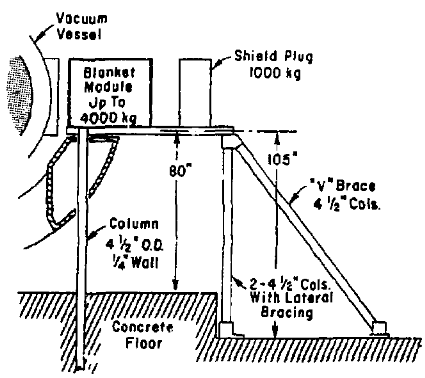
Figure 3 shows the basic structure of the ETS. The ETS platform is supported by 3 steel posts attached to the Test Cell floor. The inboard column utilizes the existing 15-cm hole in the lower shear-compression panel between TF coils.[1] The platform and test module pallet are constructed of fiberglass to eliminate electromagnetic interaction with the pulsed tokamak fields. (Radiation damage to the fiberglass will be negligible for TFTR fluences.) Seismic loads are taken up by diagonal struts attached to the Test Cell floor outboard of the ETS. There is no attachment to any component of the TFTR.

The following are the principal mechanical components of the ETS, all of which must be nonmagnetic:

- Module support platform, including center column attachment and tracks for pallet rollers.
- Central support leg assembly with concrete plug, including a 13-ft.-long column with plug shielding, an upper positioning collar welded to the central column, and a lower support ring for this column. These components are illustrated in Fig. 4.
- Two support columns with diagonal bracing for the outboard end of the module platform.
- Diagonal struts to counteract radial loads (especially for seismic conditions).
- Pallet for the test module, consisting of 304L frame with fiberglass face sheets, rollers, stops, and a fitting for the installation drive mechanism. The pallet interfaces with the blanket module, the shield plug, the support platform, the transporter, and the installation drive mechanism.

Electromagnetic Interactions

An order-of-magnitude estimate was made by Mr. C. Paulson (Ebasco Services, Inc.) of the magnitudes of the electromagnetic interactions between the ETS and the tokamak fields.[3] For this exercise, the ETS platform was assumed to be a plate of 3/8-inch stainless



ETS STRUCTURE ARRANGEMENT

Fig. 3. Model of the ETS used for a simple structural assessment. (796339)

steel attached to two radially directed beams, one on each side of the module area. The test module was taken to be a trapezoidal box with walls consisting of 3/8-inch stainless steel. The calculations considered (1) fields produced at the plasma location due to eddy currents induced in the structure during plasma initiation, and (2) currents produced in the ETS and module structures due to a major plasma disruption.

It was found that during plasma start-up, a current loop in the sides and ends of the test module produces a perturbation field in excess of 10 Gauss at the plasma position. This rather large perturbation can be eliminated by insulating the ends and sides of the blanket module one from another.

During a plasma disruption, eddy currents up to 40 kA can be expected in the steel support platform. These currents reach their maximum values at about 70 μs after initiation of the disruption, and then decay over about 1 ms. The interaction of these eddy currents with the ambient toroidal magnetic field produces forces of up to 200 psia on the steel platform, giving rise to large torques which would have to be taken up by the 3 support columns. Interaction of the eddy currents with the tokamak equi' brium vertical field gives a total impulse force of several thousand lbs directed radially inward toward the machine centerline.

To eliminate the direct electromagnetic interactions with the support platform, the platform must be constructed from a strong nonconducting material such as fiberglass. Alternatively, a stainless steel tubular support structure with electrically insulated joints could probably be used. The present conceptual design specifies fiberglass.

Summary of Response to Loads

Figure 3 shows the structural model used to estimate the response of the ETS to various loads. The following summary is due to Mr. P. Anbro (Grumman Aerospace Corp.). The basic approach was to establish loading conditions, and confirm that load paths are available for all these conditions.

Dead Load. The maximum dead load is 5000 kg, which is carried by the 3 vertical columns. Approximately 80% of this load is carried by the central column (see Fig. 4). The compression stress on the column wall is 2500 psi, which is well below the critical value.

Vit ations. The vibration mode with the lowest fund‑en.al frequency is bending of the support columns in a 'rection tangential to the vacuum vessel. The natural frequency of this mode, with 5000 kg load on the platform, is in the range of 4 to 10 cps.

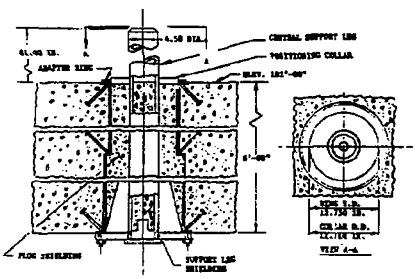


Fig. 4. Central support column of the ETS.

Seismic Loading. The maximum horizontal intensity is estimated to be 0.07 g, producing a frequency of 2 to 7 cps. This value overlaps the natural lateral frequency of the structure, so that there can be a large amplification factor. The maximum lateral acceleration of the test module and shield plug is estimated to be 0.5 g, giving rise to a maximum lateral load imposed on the ETS platform of 2500 kg. The stiffness of the support structure for horizontal loading can easily accommodate 2500 kg.

Electromagnetic Loading. During plasma disruptions, loads can result from eddy currents induced in horizontal conducting loops interacting with the toroidal magnetic field. No eddy currents are induced in the fiberglass platform or pallet. The sides of the test module are assumed to be insulated from each other. Then eddy currents in the top and bottom plates of the module produce moments that tend to rotate the platform about an axis normal to the vacuum vessel. Taking into account the response time of the module and platform (a dynamic response factor of about 0.25), the static load on the platform will be about 175,000 in-lbs. This moment is resisted by lateral bending of the 3 support columns, with a maximum deflection of the platform of several centimeters.

Installation of the ETS

Procedures have been worked out to permit the disassembly of the ETS in one bay and reassembly in another bay,[3] regardless of the degree of activation of the TFTR. As indicated in Fig. 4, each of the candidate bays for the ETS would be prefitted with an adapter ring welded to the existing upper flange of the floor penetration. For installation, the central support column enclosed in case shielding is raised from the basement and secured to the floor liner. Any height variations at the upper end of this column, due to floor variations, can be accommodated by adjusting the outboard legs of the ETS.

The module support platform, with its outer two legs attached, is lifted by the overhead crane hook. The crane operator, with some assistance from a remote manipulator, will move the table through the opening in the igloo wall, and lower the table over the central column. A remote captive bolt through the table into this column completes the table tie-down. Diagonal struts are then attached between the floor-mounted transporter support leg (see below) and both sides of the module platform.

To seal off the opening in the igloo wall, the module transporter is used to install a pallet holding a shield plug (and test module if available). Auxiliary shielding must restore as nearly as possible a complete igloo and substructure shield to minimize neutron streaming through gaps.

The ETS is removed from a TFTR bay by a procedure which is essentially the reverse of the installation procedure described above.

Loading Procedures for a Blanket Test Module

The steps required to install a blanket module are summarized in the following, and illustrated in Figures 5 and 6.

(1) Attach the blanket module and its shield plug to the ETS pallet in a working area away from the TFTR machine. The shield block is held to the pallet by truss angles bolted to the pallet.

(2) Make all connections (rabbit tubes, coolant tubes, electrical, etc.) between the module and shield plug.

(3) Install the loaded pallet on the "transporter."

(4) Set the A-frames of the transporter to predetermined marks to position the crane hook over the center-of-gravity location of the combined transporter, pallet, module, and shield plug.

(5) Erect the outboard transporter support leg in the keyed prelocated hole in the ETS bay area.

(6) Attach the transporter to the overhead crane.

(7) Move the transporter to the ETS bay area, and lower it to position using the tapered guide pins on the transporter to engage the funnel-shaped holes on the ETS platform. The transporter is supported here and on the outboard support leg.

(8) By means of a remote manipulator, rotate the drive screw on the transporter to drive the pallet onto the ETS. Stops at the end of the tracks on the ETS platform determine the final pallet position.

(9) Remove the transporter and the outbord support leg.

(10) Make all service connections to the module at the outboard face of the shield plug. This operation can be hands-on.

(11) Mount an auxiliary cover shield on the ETS to prevent streaming between the shield block mounted on the pallet and the surrounding igloo shielding.

The blanket module is removed from the ETS by following a procedure which is the reverse of the above.

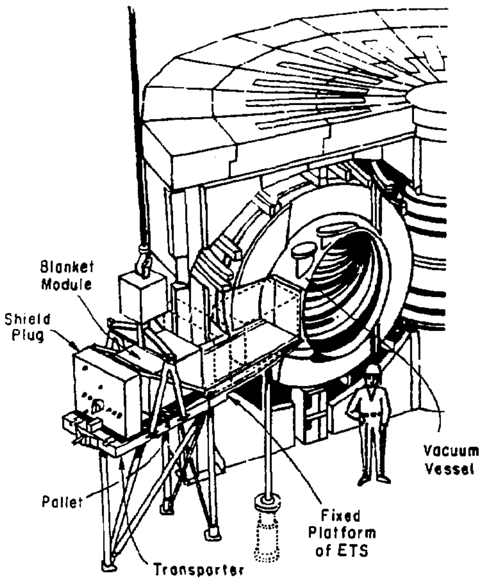


Fig. 5. Loading of a blanket module onto the TFTR Engineering Test Station. (793785)

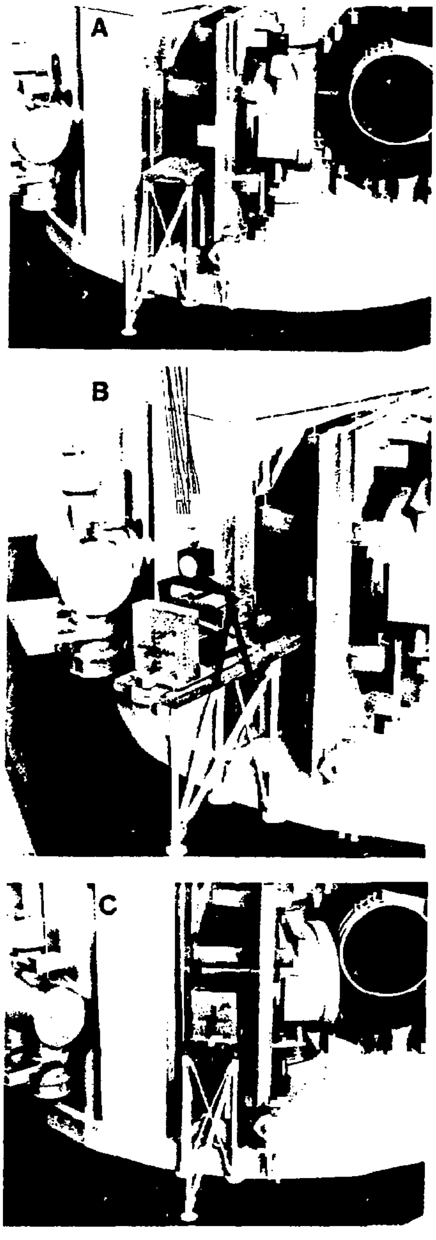


Fig. 6. Scale model of the TFTR and the ETS. (A) Blanket module support platform. (B) Loading of a blanket module. (C) Blanket module in place. (Shielding to be added.) (794595-97)

Design Options

Cantilever Support of the Platform

Conceivably, the entire ETS can be supported by a cantileverd arrangement anchored outside the igloo shield. This system is attractive because elimination of the inboard support column simplifies remote handling. The entire ETS could be carried away to a hot cell if necessary for remote maintenanceor modifications. A potential disadvantage is that a great deal of floor space might be required for the relatively massive cantilever support. This option is currently under investigation.

A proposal to investigate the use of the lintel between the steel columns of the igloo shield for support of the ETS structure appears to be impractical, as the candidate bays for the ETS have only one adjacent igloo support column.

Replacement of Fiberglass

It might be possible to replace the fiberglass platform with a stainless steel girdered structure, with its members electrically insulated from each other.

Installation of Central Support Column

The inboardcolumn, if retained, could be installed through the hole in the upper shear compression panel. The column would then be tapered, so that it catches on the Test Cell floor. A large portion of the load would be carried directly by the floor, rather than supported by the bolts underneath as in the present design.

Module Loading Mechanism

It may be possible to design the transporter and ETS track system so that a blanket module could be installed/removed by a simple push/pull motion with a remote horizontal positioner, rather than with the drive-screw mechanism of the present design.

Location of the Engineering Test Station

The basic requirements in determining a space assignment for the ETS are the following:

- Dedication of the bay to the ETS.
- Closest possible approach to the vacuum vessel.
- No shielding of the blanket module by the "protective plates" internal to the vacuum vessel.
- Clear radial access for the ETS support structure, and for installation and removal of blanket modules.
- Compatibility with space assignments for neutral beams, vacuum pumping stations, and plasma diagnostics.

The first 3 requirements are motivated by the need to use the largest possible blanket module in order to minimize edge effects,[3] and to minimize complications in interpreting neutronics results due to an excessive degradation of the neutron flux spectrum in the field of view of the module front face.

It is expected that a blanket module would be removed no more frequently than once every 3 months, but radial access for sample removal would be required much more frequently.[3,4,5]

Candidate locations for the ETS have been restricted initially to the 5 bays: H, P, L, N, and F. This order is also the desired priority of location, which will depend on the locations and orientations of the neutral-beam injectors.[3]

Acceptance Testing of the ETS

Initial testing of the ETS design concept will be undertaken during 1980 with a full-scale mock-up of the ETS to be installed on the M-3 Mock-Up of the TFTR.[6] This apparatus will be used to investigate problems that may arise in the installation and removal of the ETS, and in the loading and unloading of blanket modules, all by remote techniques.

Generation of deuterium-tritium plasmas in the TFTR is expected to begin in the latter half of 1983. It is advisable to install the ETS in a TFTR bay by early 1982, so that design verification testing could be carried out during hydrogen and deuterium plasma operation in 1982-83. These tests would include continued practice in the remote assembly and disassembly of the ETS, and in the remote loading and unloading of blanket modules, as well as confirmation with a mock-up blanket module that electromagnetic-induced torques can be made sufficiently small to be counteracted by the ETS. Other important investigations at this stage will include testing of the blanket instrumentation under "field conditions," and confirmation of adequate neutron shielding of the ETS.

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