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M. C. Calderon, F. F. K. Chen, and B. S. Denhoy
Lawrence Livermore Laboratory, University of California
Livermore, California 94550

Summary

The injector system for the Tandem Mirror Experiment (TMX) contains the components required to create and maintain a high-temperature, high-density plasma. These components include a streaming-plasma gun in each of the plug tanks to form the target-plasma, 24 neutral-beam source modules for injecting neutral deuterium atoms to heat and replace losses from the plasma, and a gas box system that applies a streaming cold gas to the plasma to stabilize it. This paper discusses the mechanical design problems and solutions for this injector system.

General Description

The arrangement and location of the basic injector system components for each TMX plug tank can be seen in Fig. 1. The plugs are identical and are arranged as mirror images. A base-case arrangement of neutral-beam sources will contain sixteen 20-keV and eight 40-keV injectors, which deliver to the target plasma 800 A and 320 A of neutrals, respectively. These are the total rated currents and include the half- and third-energy components as well as the full-energy ions.

At each plug tank, the streaming-plasma generator is located radially to the machine axis and is designed to position the gas discharge nozzle parallel to the local field lines that exit the plug magnets at a 2-kG field location. The nozzles also traverse the radial distance between the 7-cm, 500-G and the 15-cm, 2000-G central field magnetic flux line, as shown in Fig. 2. These plasma guns, which are of the loaded titanium-washer type, can provide a 3-ms discharge pulse and are provided with mounting hardware suited for TMX application. Each gun is required to operate independently and has its own timing and triggering controls.

The mounting system for the neutral-beam injector modules permits several configurations. For the base case, Fig. 1 shows two injector groups of six sources at each plug tank positioned about the horizontal plane and facing each other. This pattern of a single unit with an array of five modules in a vertical column can be extended to include a total of 10 sources per mounting location for a total of 20 per plug tank. Figure 3 shows arrangement for the basic case and the large-diameter plasma experiments. In both conditions, the 40-keV sources occupy the outer positions with the 20-keV modules in between. All the beams are located at a radial distance of 3.2 m from the machine centerline and aim at the machine centerline. Centerline and off-axis aiming locations governed by the type of experiment. Figure 1 also indicates positions in the central cell where modules can be mounted and used for injection into the central-cell plasma for additional ion heating.

Twelve of the sixteen 20-keV sources required for TMX will be transferred from the 2XIIB machine. The eight 40-keV injectors needed will be of a new design and construction, and the arc chambers are presently under fabrication. Specifications for these sources are listed in Table 1, and a source schematic is shown in Fig. 4.

Aperture plates for the source beams will attach to structure windows in the liquid nitrogen (LN) liners and can be removed for modifications or replacement. The beam profiles will vary with the different configurations, but a double vertical array of five sources produces a shape as shown in Fig. 5. The inner and outer aperture plates are located at 1.38 and 1.96 m respectively from the center line of the machine. These are water-cooled aperture plates and are shaped and positioned to preclude the plasma from shining on any LN surface that would produce reflux of gas to the plasma. The apertures accommodate source beam diver-

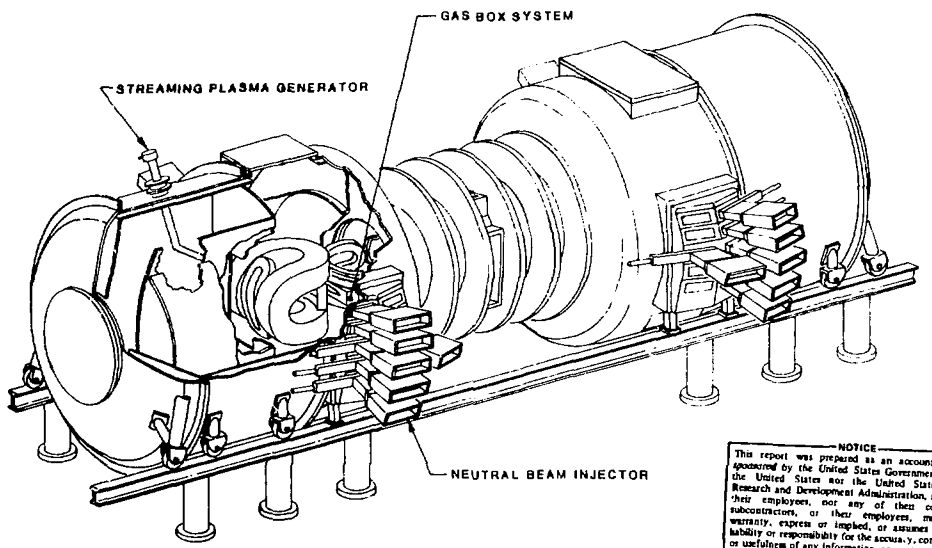

Figure 1. TMX Injector System.

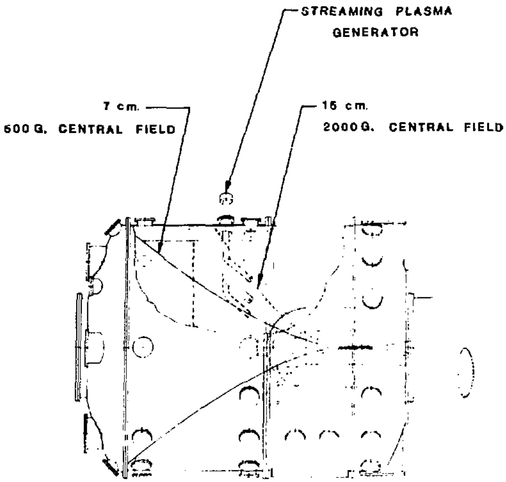

Figure 2. Streaming Plasma Generator System.

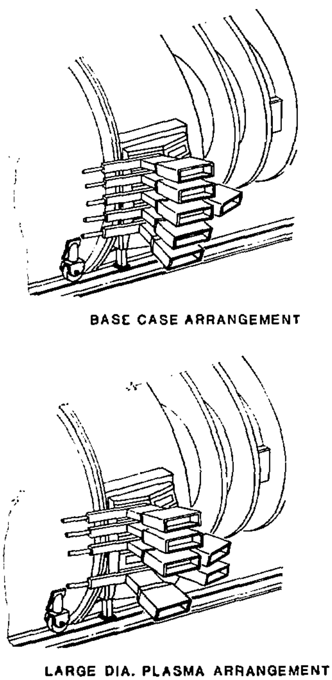

Figure 3. Neutral Beam Module Arrangements.

Table 1. Neutral Injector Module Specifications.

Parameter	20-keV Module	40-keV Module
Max. neutral beam energy	20 keV	40 keV
Avg. neutral beam energy	~15 keV	~29 keV
Power supply drain	80 A	65 A
Extractor current density	0.5 A/cm^2	0.4 A/cm^2
Extractor dimensions	7 cm × 35 cm	7 cm × 35 cm
Overall dimensions	29 cm × 58 cm	20 cm × 58 cm
Pulse length	25 ms	25 ms
D_2 gas inlet	30 Torr·ℓ/s	30 Torr·ℓ/s
Beam divergence	±2° W × ±0.5° H	±2° W × ±0.5° H
Beam at plasma (rated value)	50-A neutrals in 10 cm high × 33 cm wide.	40-A neutrals in 10 cm high × 33 cm wide.

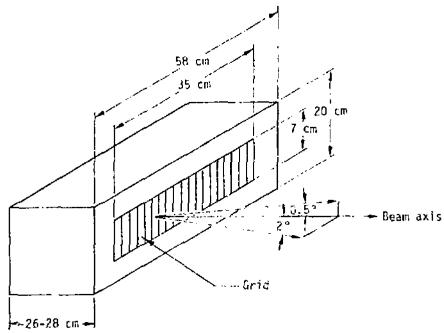

Figure 4. Simplified Diagram of a Neutral-beam Injector Module.

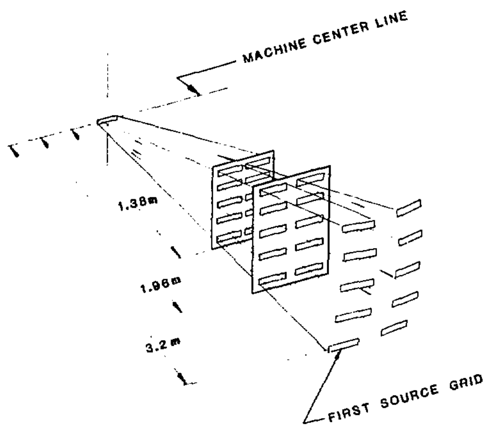

Figure 5. Simplified Beam Apertures and Locations.

gences of ±0.5° in the direction of the source grid wires and ±2° transverse to the source grid wires.

Figure 6 shows a typical arrangement of source, bellows mounting, spool support, shielding, and isolation valve. In this arrangement, the magnetic shield is fixed and the source moves with two rotational degrees of freedom provided by an adjustable plate platform that incorporates a rectangular metal bellows. With this provision, a laser is mounted on the source and the source is visually aligned to a reference location. The final fine adjustment is made using a segmented calorimeter.

Magnetic Shielding

The magnetic shielding shown in Fig. 6 has been designed to accommodate both the 20- and 40-keV sources. Spacing of the modules in the vertical direction has provided adequate clearance within the magnetic shields to prevent electric breakdown from the 40-kV extraction structure at maximum offset. The use of a corona shield will provide further assurance against voltage arcing. These magnetic shields are also compatible with the use of a gas dielectric (SF_6). The outer shell is ASTM A-36 steel with 0.17% carbon, 0.95-cm thick inside of which two high-permeability shells 0.13-cm thick are inserted to maintain the magnetic field intensity perpendicular to the centerline of the neutralizer at a level of 0.5 mT. Ions passing beyond the shielded space will therefore experience a displacement no greater than 2 cm at the plasma. This shielding isolates a space beginning approximately 0.4 m radially beyond the first source grid and extends towards the machine for a length of about 0.63 m from this same grid. The material combinations and thicknesses needed to reduce the magnetic field intensity were computed using the LLL JASON[1] computer code, which was developed to solve complex electrostatic problems using finite element methods.

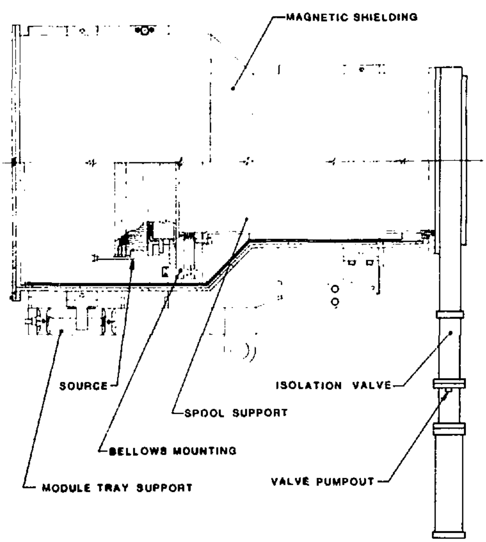

Figure 6. Typical Arrangement of Source, Bellow Mounting, Spool Support, Magnetic Shielding and Isolation Valve.

Close-packing of the source modules in both the vertical and horizontal directions coupled with their proximity to the facility neutron shielding walls required that handling for installation and maintenance be performed from the sides. A swing-out system shown in Fig. 7 permits a vertical lift of any source without interference to the other mounted sources. Because each module approaches 1000 pounds, methods of mechanical advantage for handling are required, and an emphasis has been placed on safe handling practices. The modules are landed on tray supports that pivot on the outer columns. Once the the modules have been swung into alignment postion, the tray is locked to the center column and a screw arrangement moves the modules forward to the isolation valve over captive rollers in the tray. The vacuum tie can now be made, and the unit is secure.

Isolation Valve

The isolation valve is attached to the source mount housing and is removed only for maintenance or repair. Individual source modules can therefore be removed for maintenance while machine vacuum conditions are maintained. Thus, the LN liners can be kept cold during these operations. These valves, as shown in Fig. 6, have a clear opening of 0.13 m × 0.38 m wide and are designed to provide an O-ring seal against a 1-atm pressure loading and to be leak tight to 10^{-8} std. atm. cm^3/s. The body can resist a moment normal to the faces of 28,000 in-lbs with no degradation of performance. A pumpout in the valve body permits evacuation of the source volume before the valve is opened to vessel vacuum. Inadvertent operation is prevented by interlocking. Twenty-four of these valves are mounted on the machine, and an additional unit has been purchased for testing and to serve as a spare.

Gas Stabilization System

The plug tank gas boxes are located in the transition area between the inside plug C-coil and the outside transition C-coil. As shown in Fig. 8, the gas box extends part way into the transition coil; its thickness has therefore been determined by the inner dimensions of the coil, and the length must include the 15-cm fieldline at this location. The gas box is supported at its edges by an angle frame welded to the inside surface of the transition C-coil and is removable. Four fast-pulse valves provide about 150 A of deuterium gas into the box; approximately half is ionized in the plug plasma and the remainder leaks past the face plates of the box. Each box face normal to the machine axis is an assembly of two overlapping plates in which an elliptical-shaped cutout has been machined to match the contour of the plasma fan. These contoured plates are remotely controlled and form an iris that provides a variable cross section for different plasma conditions.

The pulsed gas guns shown in Fig. 8 are of the 2XIIB type. Because the long valve rod is solenoid-actuated from the back of the unit, the gas guns require straight-line mounting from the tank wall to the gas box. A study is underway to determine the possibility of using piezoelectric-actuated valves whose mounting becomes independent of orientation and that would permit faster actuation times. Also, the valves could easily remain open beyond 25 ms.

Conclusion

With most of the injector components either designed or being fabricated, a period of testing and assembly will precede the mounting of the first neutral beam sources in May 1978, which in turn will be followed by the mounting of the gas box and the streaming-plasma generator systems.

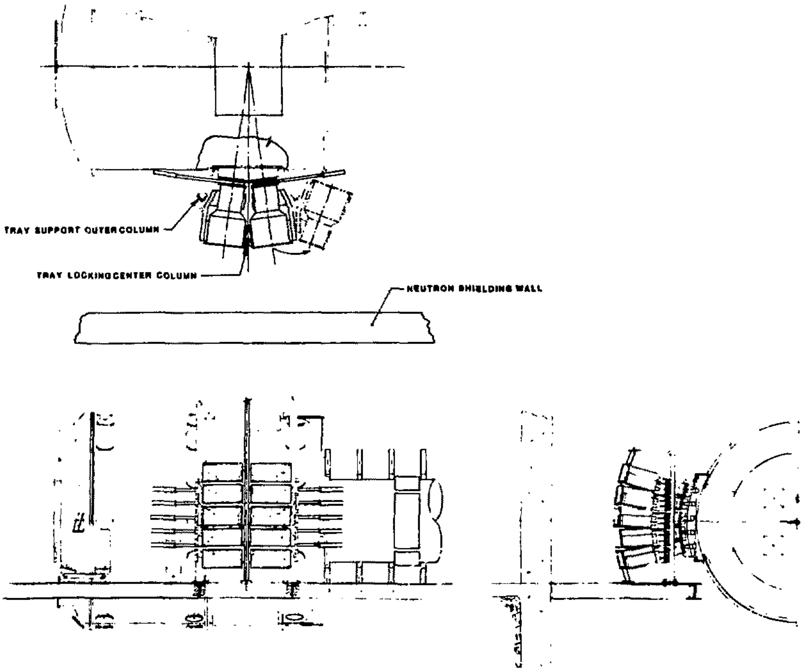

Figure 7. Source Module Handling System.

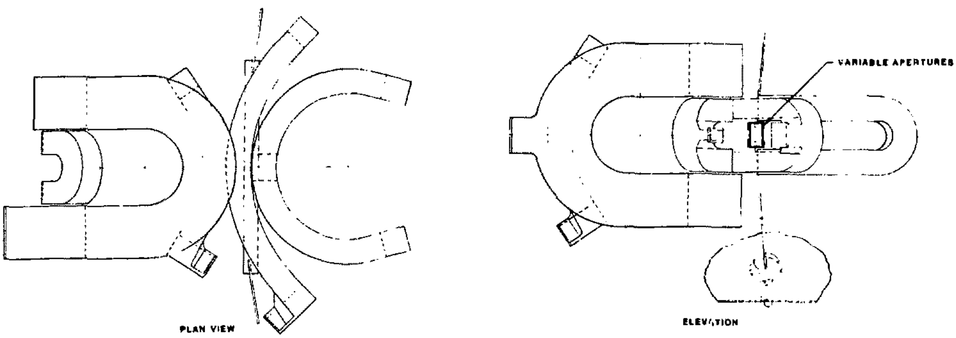

Figure 8. Gas-stabilization System.

Acknowledgments

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