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AN OCTUPOLE COIL CONFIGURATION FOR THE TANDEM MIRROR EXPERIMENT UPGRADE*

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Abstract

The octupole plug concept offers the attractive possibility of reducing the length of the plug and transition sections in tandem mirror reactors. In the Tandem Mirror Experiment Upgrade (TMX-U), we are designing an octupole plug-transition that will replace our current quadrupole plug-transition. The reduction in length is made possible by the more nearly circular plasma cross section throughout the plug and transition sections.

The principal physics of the design is the magnetohydrodynamic (MHD) stabilization of the core plasma in the plug by a hot electron ring in the mantle region surrounding the core. This hot electron mantle is MHD stable because of the good curvature field lines provided by the octupole. The positive radial pressure gradient in the hot electron mantle in turn stabilizes the core's plasma.

Each octupole set consists of six coils replacing the transition and plug sets in the existing TMX-U experiment. The central cell coils will remain unchanged. Five of the coils for each of the new sets will be fabricated, while one, the 6-T mirror coil, will be reused from TMX-U. This paper will elaborate on the design configuration of the magnets. In particular, the configuration provides for adequate neutral beam lines-of-sight, and access for 0.615 MW of electron-cyclotron resonant heating (ECRH) on each end.

Introduction

Studies are being made into new end-ce configurations for the TMX-U experiment. In one of these studies, the current quadrupole end-cell and transition coil set (Fig. 1) is replaced by an octupole end-cell and transition set (Fig. 2).

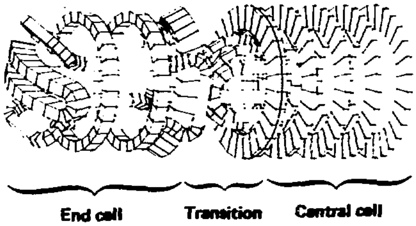

Figure 1. TMX-Upgrade Magnet Set

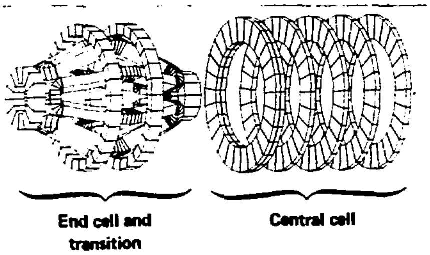

Figure 2. TMX-Octupole Magnet Set

Magnet Design

The octupole geometry allows the use of the existing quadrupole end-cell vacuum tanks and neutral beam access ports. To take advantage of this, the new octupole end cell is centered at the same axial location as is the current quadrupole end cell. All of the existing large circular coils in the central cell and transition regions remain in place. The inner octupole mirror coil is an existing axisymmetric throttle coil.

Note that the octupole coil set is somewhat shorter and more compact than the quadrupole set. The end-cell mirror-to-mirror length [illegible] 3 m in both coils sets. However, the octupole geometry allows the transition set to be much smaller and nested inside of the end-cell set (Fig. 3). The smaller octupole transition is possible because the end-cell magnetic flux surfaces are more axisymmetric and are distorted less from their central cell circular shape (Fig. 3). This more axisymmetric flux surface shape also has definite physics advantages in MHD stability and in radial transport considerations. [1,2]

The octupole coil set was designed using the EFFI magnetic field code. [3] Figures 4-8 are EFFI output. Figure 4 shows the on-axis B field. The mirror-to-mirror central cell length is 8 m. The end-cell mirror-to-mirror length is 3 m. The inner mirror also serves as an axisymmetric throttle.

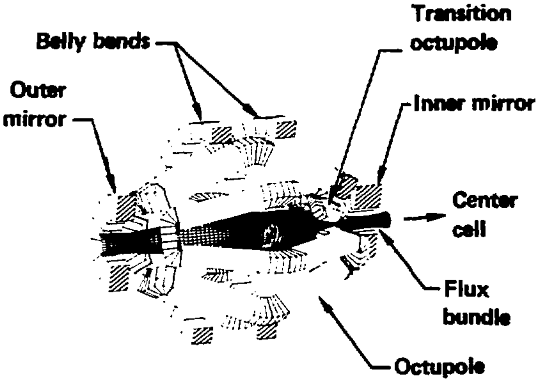

Figure 3. TMX-Octupole End Cell Detail

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Figures 5-7 show typical cutting planes through the end-cell at 45, 22.5, and 0 degrees respectively. The magnet cross-sections intersected by the cutting planes are shown. The sloshing neutral beam paths are shown to indicate the beam access. The figures also show the field strength B contours and the projections of the field line trajectories. The field lines are started in the cutting plane either at the center cell or at the inner mirror. Note that the 45 degree and the 0 degree planes are symmetry planes so that the field line trajectories shown are true. The 22.5 degree plane is not a symmetry plane, and so the field lines do not lie in the cutting plane.

Figure 8 shows a cross-section cut through the end-cell midplane. Cuts through the main octupole are shown as rectangles in the circular array toward the outside. The rectangles at the center are the neutral beam footprints for two typical beams.

The field lines divide the end-cell into three regions. The region inside of the nominal 0.15-m plug radius field line represents the core plasma. The region between the nominal 0.15-m and 0.225-m field lines represents the plasma halo region. The halo region must clear the magnet set while mapping through the machine. The region between the 0.225-m and 0.375-m field lines represents the hot electron mantle.

This hot electron mantle stabilizes the core plasma. The mantle contains a minimum B ring (Figures 5-8) that traps hot electrons. The field lines through this mantle must have a 2:1 mirror ratio to trap these electrons. Also, these field lines must have sufficient good curvature (concave radially outward) to be MHD stable. The positive radial pressure gradient through the mantle region in turn stabilizes the core plasma. For more physics details, se Reference 1-2.

Table 1 lists the electrical characteristics of the magnet set, including the required currents and the power. The total power required by the magnet set is 46.5 MW. Forty-seven percent (47%) of this power is in the end cell octupole.

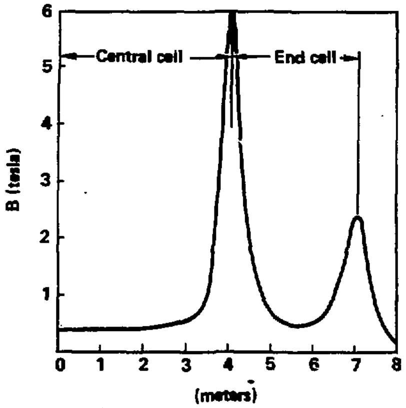

Figure 4. On-Axis Field

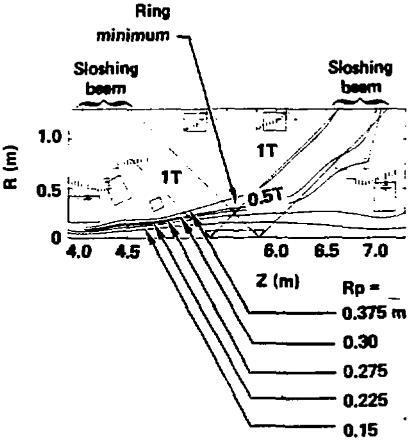

Figure 5. End Cell Field Line Trajectories and Field Strength Contours. θ = 45°

Table 1. TMX Octupole Magnet Configuration

EFFI ID	Cen Cell kG	In Mir kG	Min kG	Out Mir kG	Date
opea81	4.00	60.0	5.00	24.0	10/22/84

Coil	Turns	X-Sec (cm)	X-Sec (cm)	R (ohms)	I-Turn (amp-turn)	I-Turn/A (a-t/cm²)	I (amp)	V (volt)	Power (MW)
Plug Out Mir	192	21.79	29.06	0.0517	1294000	2043.53	6739.58	348.44	2.3483
Plug Out Sol	80	22.75	17.92	0.0374	385000	944.37	4812.50	179.99	0.8662
Plug Octupole	140	18.16	25.42	0.3373	800000	1733.00	5714.29	1927.43	11.0139
Plug In Sol	80	22.75	17.92	0.0374	345400	847.23	4317.50	161.47	0.6972
Tran Octupole	64	11.01	11.01	0.0532	163500	1348.79	2554.69	135.91	0.3472
Plug In Mir	480	31.07	26.34	0.1909	2768000	3382.28	5766.67	1100.67	6.3483
Tran Dbl Sol	152	17.82	41.79	0.0640	540000	725.13	3552.53	227.37	0.8078
Tran Sgl Sol	76	8.91	41.79	0.0320	83600	224.52	1100.00	35.20	0.0387
CC Out Sol	76	8.91	41.79	0.0320	243100	652.88	3198.68	102.36	0.3274
CC Mid Sol	76	8.91	41.79	0.0320	212800	571.51	2800.00	89.60	0.2509
CC In Sol	76	8.91	41.79	0.0320	195200	524.24	2568.42	82.19	0.2111
Total, 1/2 Mach									23.2569
Total									46.5138

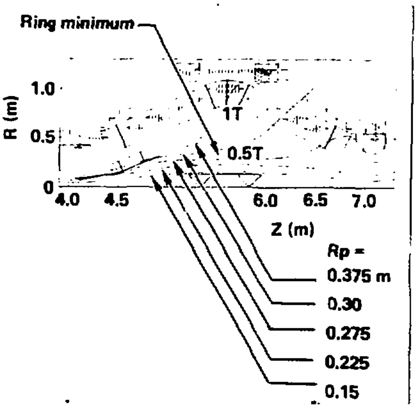

Figure 6. End Cell Field Line Trajectories and Field Strength Contours. 0 = 22.5°

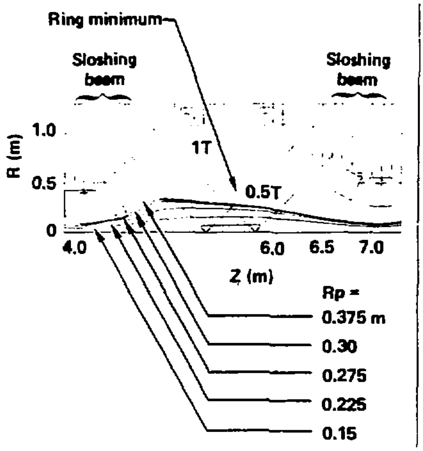

Figure 7. End Cell Field Line Trajectories and Field Strength Contours, 0 = 0°

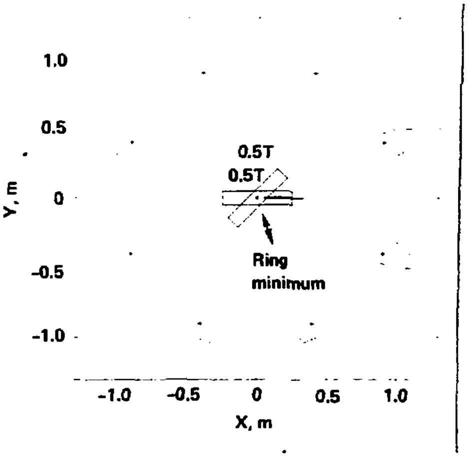

Figure 8. End Cell Midplane Cross-Section Field Strength Contours

References

[1] D. E. Baldwin, "Advantages of Higher-Order Multiple Tandem Mirror Plugs", MFE/TC/78-168, April 27, 1978, Lawrence Livermore National Laboratory, Livermore CA, Memo.

[2] E. B. Hooper, Jr., Octupole Anchor for Tandem Mirrors, UCID-20050, March 21, 1984, Lawrence Livermore National Laboratory, Livermore, CA.

[3] S. J. Sackett, EFFI - A Code for Calculating the Electromagnetic Field, Force, and Inductance in Coil Systems of Arbitrary Geometry, UCRL-524402, March 29, 1978, Lawrence Livermore National Laboratory, Livermore, CA.