TMX MAGNETS: MECHANICAL DESIGN*

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Summary

The Tandem Mirror Experiment (TMX) system, part of the Lawrence Livermore Laboratory magnetic mirror program incorporates in its design various types of coils or magnets. This paper describes the physical construction of each coil within the system as well as the structural design required for their support and installation.

Introduction

The Tandem Mirror Experiment (TMX) magnet system, (Fig. 1), consists of two baseball-type coils, four "C" coils, two 86-deg transition coils, two 210-deg transition coils, two octupole coils, and six solenoid coils. The baseball coils enclose the "C" coils, and together they form a set called the plug coils. The 210-deg transition coil is nested within the 86-deg transition coil, forming the transition coil set. The solenoid coils are mounted separately around the exterior of the central cell of the machine.

Each coil will be water-cooled, vacuum impregnated and constructed of hollow-core copper conductors. The plug coil, transition coil set, and octupole coils will be installed inside the vacuum chamber of the TMX machine (Fig. 2) and designed to sublimate titanium onto their surfaces.

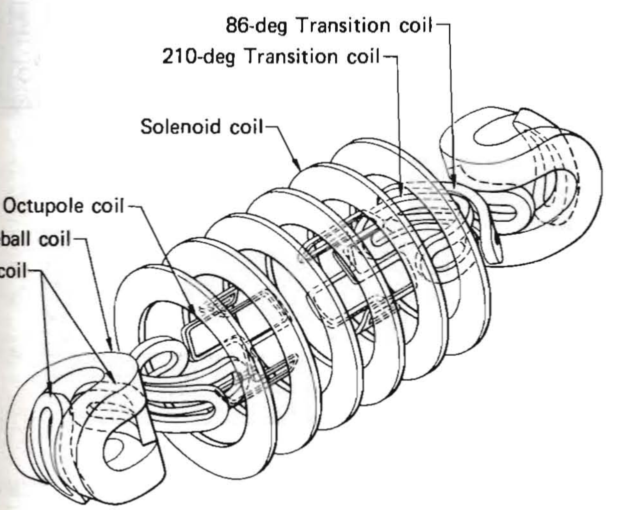

Fig. 1. TMX magnet system.

General Construction Features

The baseball, "C" and transition coils are bifilar-wound for the possible use of LN as a coolant in the future. This construction provides a counterflow of LN and N_2 gas within adjacent conductors. The method was used in the Alice quadrupole[1] and Baseball I magnets with great success. No visible resin cracking as a result of thermal gradients was observed.

Dacron sleeving for the conductor insulation was selected because of its high abrasion resistance during winding, and its excellent properties at cryogenic temperatures.

The void regions in terminal and transition areas are filled with epoxy fiberglass blocks to prevent conductor shorts, and to reduce large areas of unreinforced epoxy after impregnation. Other void areas are filled with fiberglass mat for the same purpose.

The polyester dacron-mylar-dacron (DMD) between layers is saturated with epoxy on the mat surfaces to provide abrasion and voltage breakdown resistance in the film. A partially wound "C" coil is shown in Fig. 3.

Construction

Baseball Coil

The baseball coil (Fig. 4a) is bifilar-wound in horizontal pancakes using a 1.63 cm square, hollow copper conductor. The conductor has two 0.05-cm-thick walls of dacron sleevings installed prior to winding.

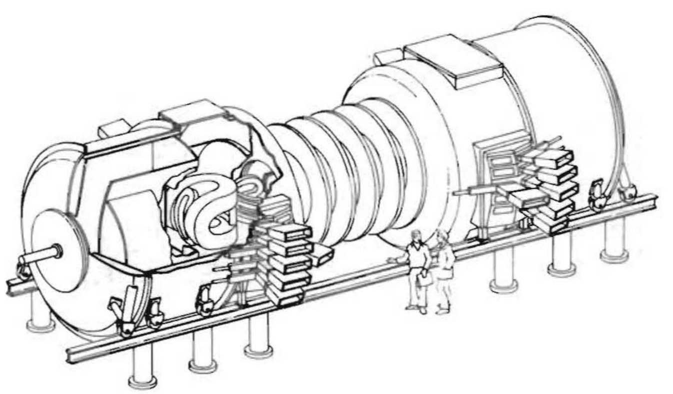

Fig. 2. TMX machine assembly.

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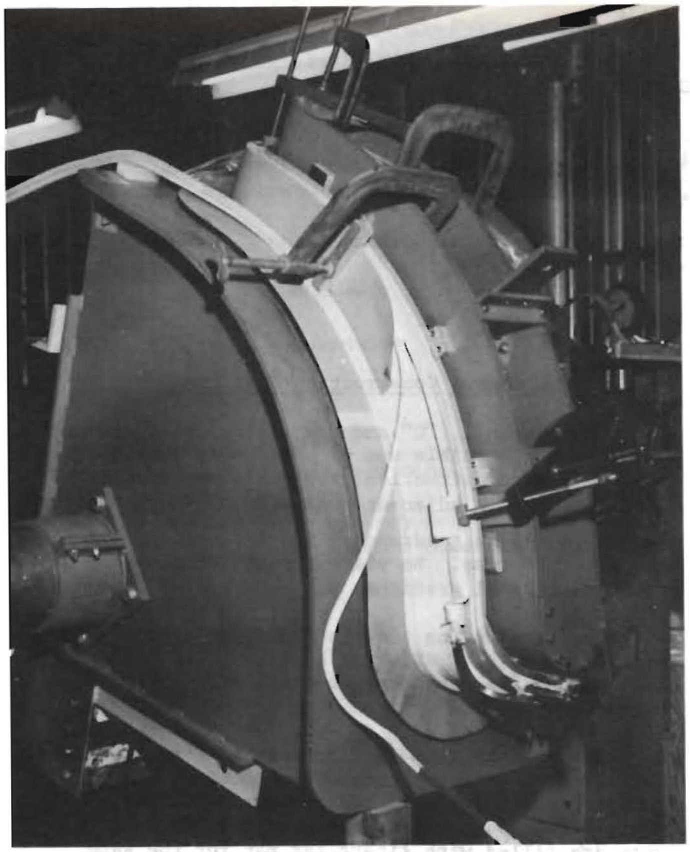

Fig. 3. Partially wound "C" coil.

The conductor is wound onto a 0.05-cm-thick stainless steel (316 SS) inner potting case that has been mounted to a special coil winding form. Each layer of the conductor is separated by a layer of DMD 0.04 cm thick to protect it from winding abrasions. Every other layer is hydraulically coupled to form parallel cooling paths and to maintain a series of electrical connections between pancakes. The coil is vacuum-impregnated and enclosed by a guard vacuum case. The thickness of the guard vacuum case was established, by using mathematical models to resist the opening forces caused by the magnetic fields. The radius of the coil at the centerline is 46 cm in both curves with a 16-cm-straight section along one axis.

"C" Coil

The "C" coil (Fig. 4b) is bifilar-wound in vertical pancakes using a 1.19 cm square, hollow, copper conductor with one dacron sleeve 0.05 cm thick. The construction techniques are similar to those for the baseball coils as shown in Fig. 4(b). The major radius at the centerline of the coil is 82.85 cm and the minor radius is 17.75 cm.

Transition Coils

Both transition coils are wound using a 1.63 cm square, hollow conductor, bifilar-wound in vertical pancakes. The construction techniques are identical to baseball and "C" coils. The cross-sections are shown in Figs. 4(c) and 4(d). The major radius at the centerline of the 86-deg transition coil is 120 cm and the 210-deg transition coil is 61 cm. The minor radius at the center is 19 cm for both coils.

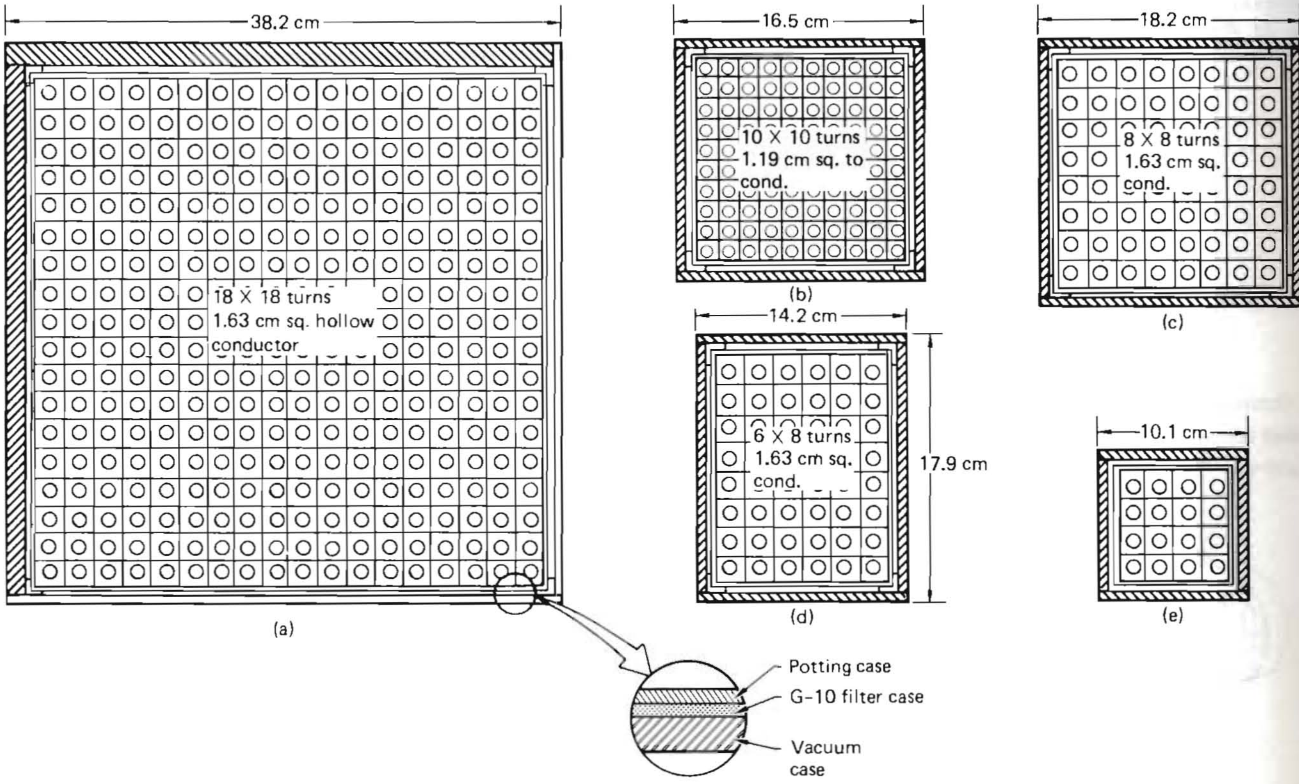

Fig. 4. TMX transition coils: (a) Baseball coil (b) "C" coil (c) 210-deg transition coil (d) 86-deg transition coil (e) Octupole coil. Enlarged section of (a) is similar for all coils.

Octupole Coils

The octupole coils (Fig. 4e) are singularly wound in horizontal pancakes using a 1.63 cm square, hollow conductor. The basic construction is similar to all of the above coils. The major radius is 56 cm at the centerline.

Solenoid Coils

The solenoid coils were wound in 1962 for the 2X experiment. They consist of 76 turns of a 2.07 cm square, hollow conductor and are 182.88 cm I.D. × 318.77 cm O.D. × 8.89 cm thick. Both the faces and the bores of each solenoid coil are metal clad and are provided with sleeves for tie rod spacers.

Structural Design

The structural design of the individual coils, as well as their subassemblies is based on resisting the forces and stresses that have been computed using the Lawrence Livermore Laboratory (LLL) computer codes, EFFI and SAPIV. At the time of this writing, the major mathematical modeling on the plug coil set had been completed. Work is currently in progress to model and analyze the transitions and octupole coils.

Plug Coils

The plug coil (Fig. 5), consisting of two "C" coils enclosed by a baseball coil, will be installed in the end vacuum tanks, as previously shown in Fig. 2. The "C" coils are held in position by retainer brackets. Tie bars are installed and sized to carry the entire opening force of the assembly which is approximately a force of 672 kN. The guard vacuum case of both coils has been sized to safely resist the opening forces with a maximum deflection of 0.08 cm at the tip of the baseball coil.

The assembly is suspended by four hangers attached to special attachment points in the vacuum chamber and to the attachment points indicated in Fig. 5. After installation and alignment, the coil will be secured by tie bars and turnbuckles to the tank bottom for earthquake stability. The system will be sized to withstand a minimum 0.5-G earthquake load.

Transition Coils

The transition coil set consists of 86- and 210-deg coils assembled together with structural supports (Fig. 6).

The external cases of each magnet shall be reinforced to stiffen the coils against deflections greater than 0.08 cm.

The set will be supported from the flange area of the end tank at the central tank connection providing an 0.5-G earthquake support with ties.

Octupole Coil

The octupole coil will be radially suspended from the walls of the central cell vacuum tank and confined by two rings (Fig. 7).

Solenoid Coils

The six solenoids are to be installed around the exterior of the central cell as shown in Fig. 2. They will be mounted with supports directly to the TMX machine structure.

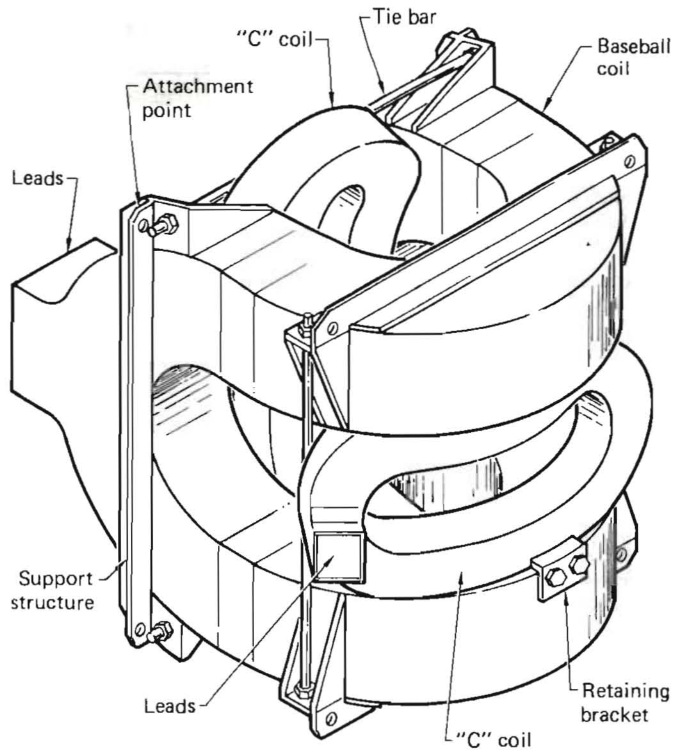

Fig. 5. TMX plug coil.

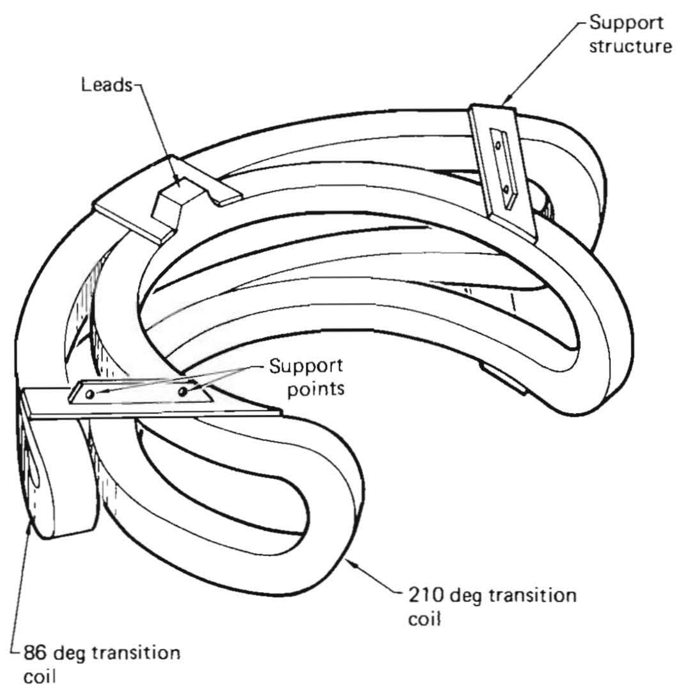

Fig. 6. TMX transition coil.

Magnet Geometry and Power Requirements

Tables 1 and 2 describe the magnet geometry and power requirements for each of the above coils.[2]

Table 1. TMX Coil Geometry.

Coil type	Quantity	Z-location (cm)	Mean major radius (cm)	Mean minor radius (cm)	Half elongation (cm)	Half lobe sweep angle	Estimated total cross-section (cm^2)
Baseball plug	2	±320.	46.0	46.0	8.0	NA	38.19 × 38.19
Outside plug C-coil	2	±295.	82.85	17.75	NA	33°	16.50 × 16.50
Inside plug C-coil	2	±345.	82.85	17.75	NA	33°	16.50 × 16.50
Outside transition C-coil	2	±124.	120.0	19.0	NA	43°	14.05 × 18.14
Inside transition C-coil	2	±165.	61.0	19.0	NA	105°	18.14 × 18.14
Transition octupole	2	±79.	56.0	NA	35.0	NA	10.00 × 10.00
Solenoid coil	6	±160,±96,±32	113.0	NA	NA	NA	9.00 × 42.00

Table 2. Power and Conductor Requirements for TMX Coils.

Coil type	Amp. turns per coil	Turns per coil	Conductor size (cm)	Total length (m)	Current (amp)	Total voltage drop (V)	Total power (MW)	Power supply
Baseball (2)	1,500,000	18 × 18	1.63	4,160	4,568	1,992	9.1	14
Outside plug "C" coil (2)	450,000	10 × 10	1.19	604	4,400	498	2.2	4
Inside plug "C" coil (2)	400,000	10 × 10	1.19	604	4,000	452	1.8	3
Outside transition "C" coil (2)	130,000 (222,000)	6 × 8	1.63	458	2,708 (4,625)	130 (222)	0.35 (1.03)	1 (2)
Inside transition "C" coil (2)	210,000 (222,000)	8 × 8	1.63	718	3,281 (3,469)	247 (261)	0.81 (0.91)	2
Transition octupole (2)	56,000 (62,000)	4 × 4	1.63	292	3,500 (3,875)	107 (118)	0.38 (0.46)	1
TOTALS	NA	NA	1.63 1.19	5,628 1,209	NA	3,426 (3,543)	14.64 (15.5)	25 (26)

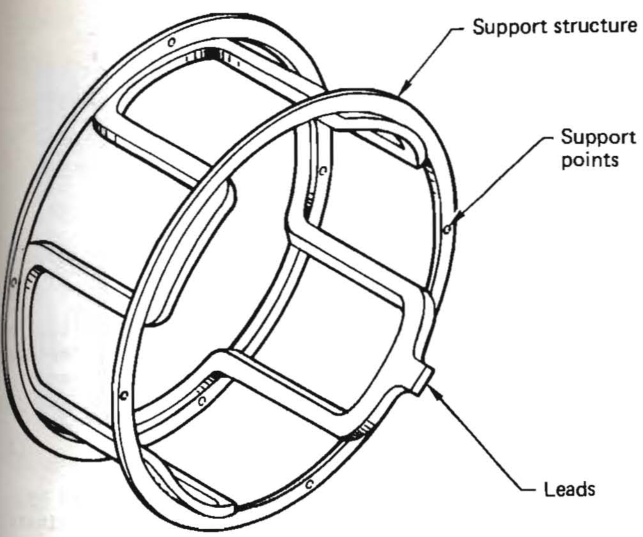

Fig. 7. TMX octupole coil.

Acknowledgments

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References

1. Arthur R. Harvey, "Mechanical Design and Construction of the Alice Mirror and Quadrupole Magnets," in Proc. 1965 Symp. on Engineering Problems of Controlled Thermonuclear Reactors, Conf. No. 650512, 1965.

2. F. K. Chen, A. K. Chargin, B. S. Denhoy, and A. F. Waugh, "Designing for the Magnetic Field Requirements of the Tandem Mirror Experiment," in Proc. 7th Symp. on Engineering Problems of Fusion Research, Knoxville, Tenn., 1977.