Draft

DESIGN DESCRIPTION OF THE LARGE COIL TEST FACILITY PULSE COIL*

R. O. Hussung, C. C. Queen, Jr., K. K. Chipley
Union Carbide Corporation Nuclear Division
Oak Ridge, TN 37830

CONF-811040--45 (Draft)

Summary

The Large Coil Test Facility (LCTF) is being constructed to test up to six large superconducting coils of the configuration needed for tokamak reactors. In order to subject these test coils to conditions which simulate the magnetic environment of an operating tokamak, it is necessary to provide transient vertical fields at the test coil. The LCTF does this by means of a pulse coil set which can be positioned in the bore of each coil. The coils are tested one at a time while the remaining five test coils provide a background toroidal field. Since the pulse coil set is a part of the facility and not considered as a developmental item, it is designed to utilize conventional coil materials and fabrication techniques. The operating environment and magnitude of the induced loads make this coil set somewhat unique. This paper discusses the required operating parameters, the operating environment and loads, as well as the design features of the coils.

Background

In 1978, a study was conducted to evaluate three different design concepts for their ability to simulate the pulse fields present in the TNS tokamak reactor design.[1] From this study emerged the present concept of a pair of vertical axis coils mounted inside the bore of the toroidal test coil.

The coils will be mounted to the top and bottom flanges of a 36-inch tall box beam which is part of the movable pulse coil support system (see Figure 1). This movable support system allows the pulse coil set to be positioned within the bore of any of the six toroidal test coils.[2]

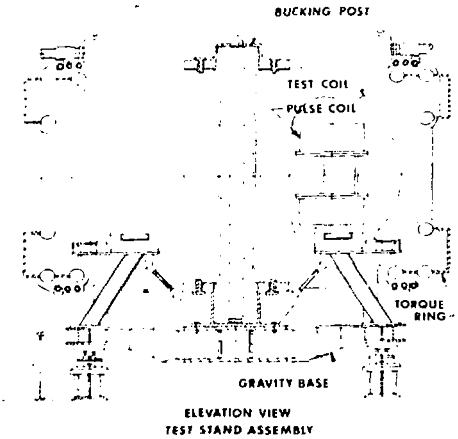

FIGURE 1

Present Pulse Coil Design

The pulse coil set consists of a pair of forced flow liquid nitrogen cooled coils, each having 768 turns wound around a mean diameter of approximately 800 mm. The coils are wound using an extruded copper conductor having a .565-inch square cross section with a .25-inch diameter center cooling hole. The construction consists of winding the conductor two-in-hand into 16 two-layer pancakes. Each pancake has a total of 48 turns in the two layers. The pancakes are stacked and the appropriate electrical jumpers are made to connect all the windings in series electrically, while allowing 32 parallel cooling paths. This conductor assembly is then placed into a structural stainless steel case and the case welded shut. The void between the conductor assembly and case is then filled with an epoxy resin which provides an adequate structure to transfer the winding loads to the structural case. The final assembly, when complete, has a bore of approximately .4-meters, an outer diameter of 1.5-meters, and a vertical thickness of approximately .6-meters. A cross-section as well as a top view of the coil can be seen in Figure 2..

MASTER

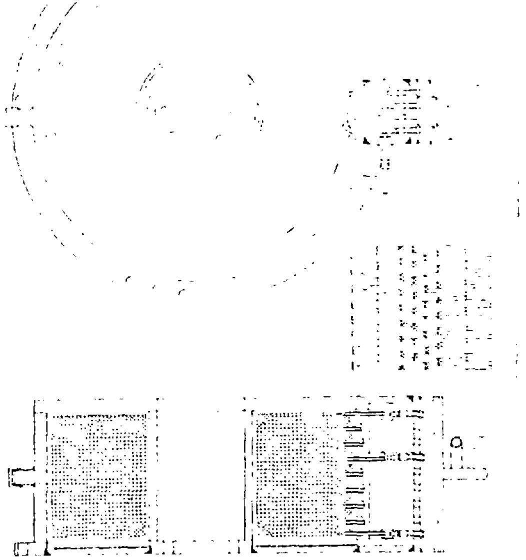

FIGURE 2

The final design parameters for the pulse coil set are shown in Table 1.

Coil Environment

The coils and support system will be installed as part of the LCTF where they will be exposed to a cryogenic temperature of approximately -194° C (77K)

---

*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation

MCW

Pulse Coil Parameters

Number of Turns	*768 (24x32)*
Mean Diameter (mm)	814
Winding Cross-Section (mm)	495x370
Conductor Cross-Section (mm)	14 Sq x 7 mm Hole
Mass of Conductor (kg)	2800
Total Mass (1 Coil) (kg)	5000
Resistance (··)	03
Inductance (H)	27
Maximum Operating Current (A)	*4000*
Maximum Lead Voltage (V)	2500
Stored Energy, Extended Case, $\frac{LI^2}{2}$ (MJ)	22

TABLE 1

and a vacuum environment of 10^{-7} torr. The coils will also be in the presence of a background field generated by the currents in the six toroidal test coils. This background field will vary in magnitude and shape, depending upon the testing condition. There are three different background field conditions which require the presence of a pulsed field:

(1) Normal Test Condition - This condition, as implied by its name, is the most common. The background field present at the pulse coil set is generated by the test coil (the coil in which the pulse coil is positioned) at 100% of its design current, and the other five coils at 80% of their design current.

(2) Alternate D - In this test condition, the test coil is at 110% of its design current, and the other five coils are at 90% of their design current.

(3) Alternate E - This condition has the test coil at 140% of its design current, and the other five coils are at zero current.

The maximum background field present at the pulse coil windings varies in magnitude from 4.1 Tesla for the normal case to 6.3 Tesla for Alternate E. The presence of this background field, combined with the current in the pulse coil windings, generates large forces and moments which will be discussed later.

Pulse Coil Modes of Operation

In addition to the three types of background fields mentioned, the pulse coil set has its own two modes of operation - normal and extended.

Normal pulse coil operation refers to the test condition where both top and bottom pulse coils are pulsed simultaneously to approximately 2000 Amps in one second. The current is supplied by a 600 volt, 4000 Amps supply which will then sustain this current level for 30 seconds before returning to zero current in one second. The magnetic field which results from this condition is shown in Figures 3 and 4.

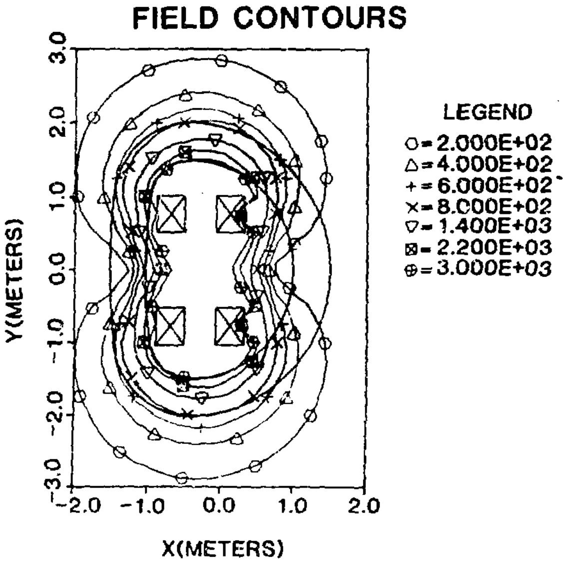

FIGURE 3

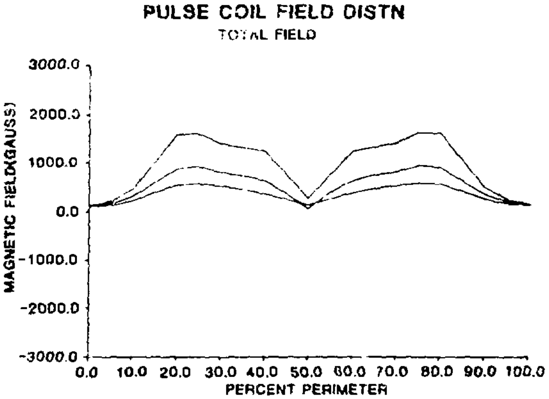

FIGURE 4

Figure 3 is a plot of the absolute field contours in the area of the pulse coil and test coil. Figure 4 shows the magnitude of this pulsed field as a function of perimeter for the inner, middle, and outer windings of the test coil. As can be seen from this figure, part of the inner windings are subjected to a pulsed field of approximately .15-Tesla. Since this field distribution is achieved in one second, this corresponds to a maximum rate-of-change in field of .15-Tesla per second.

The pulse coils and the pulse coil cooling system are designed to be able to repeat this 32 second pulse every 150 seconds for an indefinite length of time not to exceed the design cycle life of 40,000 cycles.

Extended pulse coil operation refers to the test condition where either the top or the bottom pulse coil is pulsed to approximately 4000 Amps in two seconds and the other coil has zero current. The current in the pulsed coil is supplied by the same 600 volt, 4000 Amp supply which again sustains this maximum current for 30 seconds. The coil is then discharged and returns to zero in 2 seconds. The resulting magnetic field distributions for this condition can be seen in Figures 5 and 6. Figure 6 shows a maximum field of .30 Tesla which occurs at part of the inner windings of the test coil. Since this field distribution is achieved in approximately 2 seconds, the corresponding rate-of-change in field is again .15 Tesla per second.

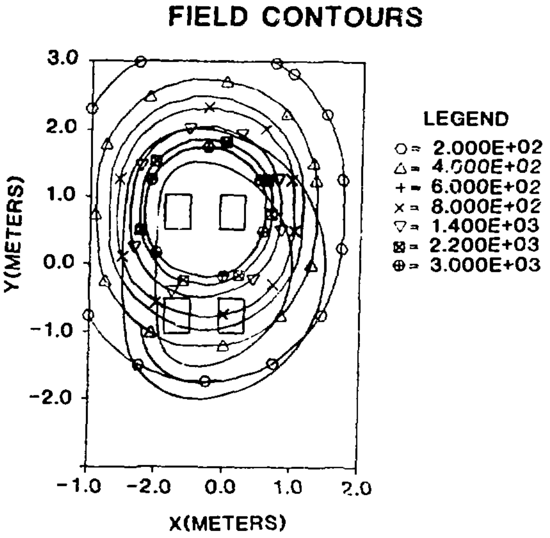

FIGURE 5

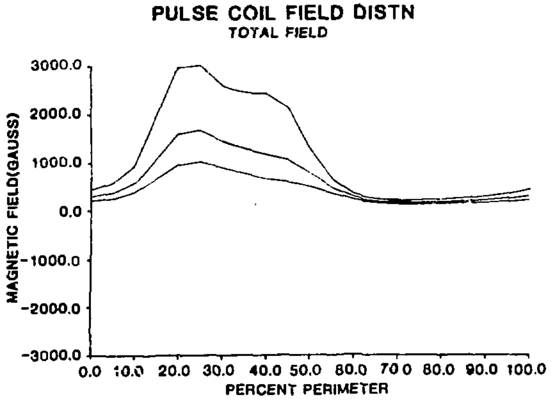

FIGURE 6

Alternate Modes of Operation

Other ways are being considered in which the pulse coil set may be used in the LCTF which will further aid in testing the toroidal test coils. The first way is shorter, more frequent pulses. While the pulse field time profile for the TNS reactor had a 30-second "flat top", there is very little benefit in having this same "flat top" in LCTF. It has, therefore, been suggested that shorter, more frequent pulses be used rather than the one 30-second "flat top This will increase eddy current heating in the test coil while not significantly increasing the applied power to the pulse coil set.

Another way to increase eddy current heating in the test coil is to increase the rate of change in magnetic field at the test coil. While it may not be cost effective to procure a larger power supply to accomplish this during the charging phase of the coil, it is fairly simple to accomplish this increased rate-of-change in field by the installation of a "dump" resistor. This dump resistor will raise the voltage between the coil leads and, therefore, lower the required time to complete the discharge of the pulse coils. While the charging voltage is limited to only 600 volts by the supply, the discharge voltage across the pulse coils can go as high as 2500 volts thus producing a charge in magnetic field at the test coil of approximately .56-Tesla per second (4 times that seen during charging).

A third way of alternate testing is to run the two pulse coils in the cusp or opposing mode. This third option, although slightly reducing the pulsed field in the largest portion of test coil increases the pulsed field in the vertical nose region of the test coil which is where its cryostability is the most critical. This option costs very little as the only requirement would be to be able to reverse the current leads of one coil. The pulse field contours for this condition can be seen in Figure 7 with the corresponding field distribution at the test coil windings shown in Figure 8.

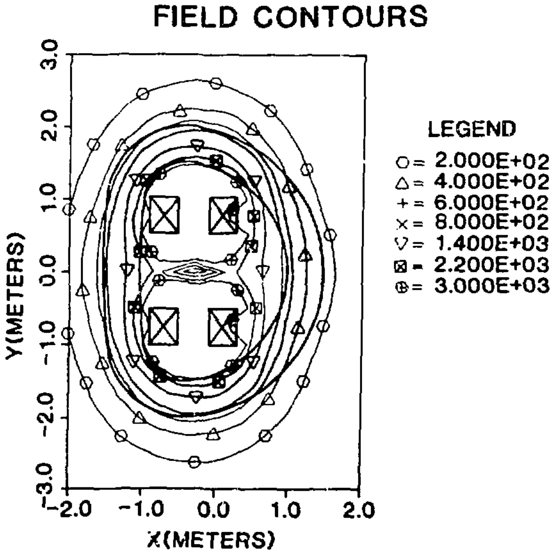

FIGURE 7

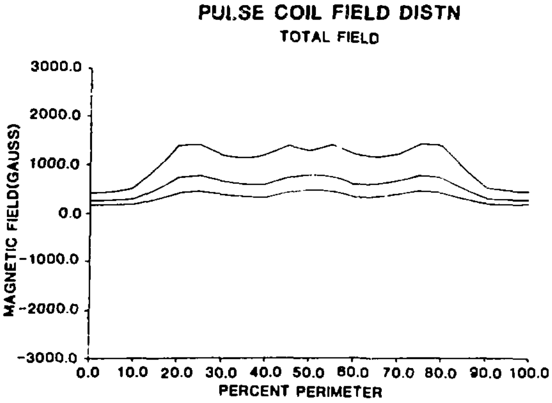

FIGURE 8

Pulse Coil Forces

The three different types of background fields discussed earlier combined with the two different modes of operation for the pulse coil generate a variety of different fields and forces. During normal operation of the pulse coil (2000 Amps in each coil), only the normal background field will be used. For extended pulse coil operation, however, any of the three different background fields may be present. The forces generated on the pulse coils due to this interaction between the background field and the pulse coil currents are very large and unbalanced. The direction and magnitude of these forces and moments on the pulse coil set for the various tests can be seen from Figure 9 and Table 2. These resultant forces are reacted through the pulse coil support system, the gravity base, bucking post, and eventually balanced by the corresponding opposite force imposed on the test coil by the pulsed magnetic field (see Figure 2).

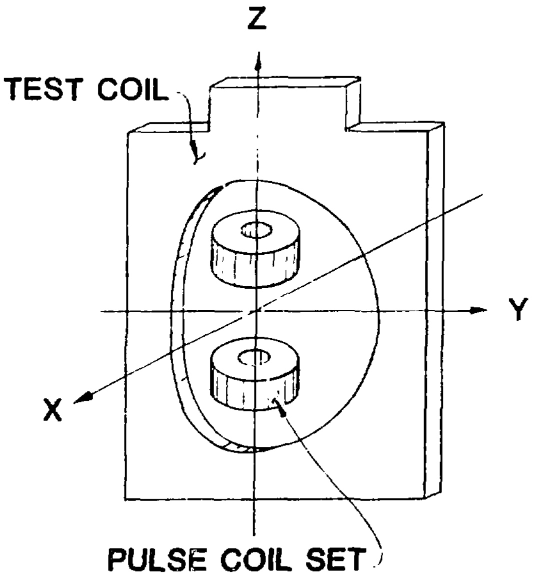

FIGURE 9

PULSE COIL MODE	NORMAL		EXTENDED		
BACKGROUND FIELD	NORMAL		NORMAL	ALT. D	ALT. E
PULSE COIL	UPPER	LOWER	UPPER	UPPER	UPPER
Fx (lb)	1.53×10^5	-1.53×10^5	3.06×10^5	3.39×10^5	4.32×10^5
Fy (lb)	0	0	0	0	0
Fz (lb)	-1.19×10^4	1.19×10^4	0	0	0
Mx (ft-lb)	0	0	0	0	0
My (ft-lb)	1.77×10^6	1.77×10^6	3.54×10^6	3.87×10^6	4.93×10^6
Mz (ft-lb)	0	0	0	0	0

TABLE 2

References

1. B. E. Nelson, P. B. Burn, "Pulse Coil Concepts for the LCP Facility", Procedures of the 7th Symposium on Engineering Problems of Fusion Research, 1977.
2. C. C. Queen, "Design Description of the Large Coil Test Facility Pulse Coil Support and Transport System", Procedures of the 9th Symposium on Engineering Problems of Fusion Research, 1981.