TOKAMAK PHYSICS EXPERIMENT (TPX)

TOROIDAL FIELD MAGNET DESIGN, DEVELOPMENT
AND MANUFACTURE

Contract B235308

SDRL 31

Magnet Sensors

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Engineering drawings for this project
are identified as CAPE- 3106.
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TF Magnet Sensors

The requirements for magnet sensors to verify the TF magnet system operation and aid in diagnostic assessment are defined. However, generally one does not specify such a system in the absence of a definition of the Local I&C system. Also, one would expect that there would be great benefit (economy, redundancy, compatibility, etc.) in specifying common components for all of the magnet system. Thus, specifying the sensors requirement we have tried to be flexible to accommodate future adjustments to these systems.

See also reference documents: SDRL 33- Coil Verification Test Plan, SDRL 34- Material & Component Test Plan, and SDRL 45- Acceptance Test Plans

1. Conditions affecting the selection of TF Magnet System Instrumentation

1.1 Thermal Extremes

The TF magnet system must operate from room temperature down to LHe temperatures. At the same time it should be protected from thermal extremes, such as:

- TF temperature differentials during cooldown
- TF/PF temperature differentials during cooldown
- Pulse operating loads
- Heat loads from disruptions or a quench
- Intercoil structure-coil case temperature differential during operation
- the vacuum vessel radiant heat load during operation- including the vacuum vessel feedthroughs including the diverter water headers.
- The bakeout of the vacuum vessel and other components.

Figure 1 shows the temperature differential across the outboard intercoil structure during normal operation in the absence of case cooling. With the case at about 6.8K, the maximum temperature of the intercoil structure would be in excess of 100K! Such a condition is possible if the case cooling were inadvertently interrupted or reduced without being detected, or if the structure cooldown rate is set too high.. Large stresses ($> 1\text{Gpa}$) would appear at the ICS/case wall, and significant distortion of the ICS would occur from this kind of fault, as Figure 2 shows. Hence accurate temperature sensors on the TF structure are essential to the correct functioning of the TF magnet system.

1.2 Structural Extremes

The TF structure must operate from the condition of a large toriodal preload in the warm state, to cyclic operation and disruptions at LHe temperatures. Figure 3 shows that the highest stress in the TF structure occurs outboard at the corners of the large equatorial ports. The origin of this loads is the TF overturning moment being reacted against the ICS in the corner of the port opening. We would expect to monitor this condition for both normal and disruption loads to verify the analysis that support the TF system design. On the inboard leg the stresses are lower than this, and generally are the highest near the intersection of the wedging faces and the nose face. There would have to be strain measurements there to verify that there is no significant load imbalance, and that the noses stay wedged under normal and fault conditions. Also, as we indicated above, an incorrect cooling rate to various parts of the structure could result in very large stress, and we would want some redundancy to detect that either thermally or structurally.

1.3 Other Requirements

We need:

- Better definition of the Local I&C system to better select instrumentation components, including allowed signal types and levels, available DA and AD channels, bit resolution and acquisition rate
- Better definition of the ground fault detection system, particularly 'lifting ground to verify electrical isolation of components operation'. That is, is a electromechanical switch assumed, or is a resistive connection between a system and ground sufficient?
- Develop cold testing to verify the mounting, as well as the temperature and field compensation of the chosen strain gages systems.

2. Coil Instrumentation

2.1 Quench Detection System

A specification of quench detection within an adequate time to insure a coil dump and avoid exceeding a maximum hot spot temperature of 150K has been adopted. A small initial quench zone is more difficult to detect than a large initial quench zone. To not exceed a maximum temperature of 150K during a small disturbance quench, the detection system should be capable of detecting a voltage of 0.81V after a time of 1.23 s [13-950808-BW-YLvovsky-01].

The quench detection system will include three independent systems to provide fast and accurate quench detection: 6 internal co-wound voltage taps (with a 10:1 signal-to-noise ratio as a goal), 2 internal fiber optic temperature sensors, and external flow meters on all coil helium flow return circuits [1314-950628-MIT-SSmith-01]. These systems will be provided by the project for installation during TF magnet assembly. It is our task to incorporate those systems into the TF preliminary design, and we have done that.

2.2 Other Electrical, Thermal or Structural

One can add strain gauges and additional temperature sensors to monitor the coil, however doing so can (and often does) add electrical fault modes or introduce stray voltage levels and noise that interfere with the normal operation of the quench detection system. The quench detection system fiber optic sensors would be available for routine or diagnostic temperature measurements, in any case, and there will be temperature sensors on the coil case surrounding the coils from which the winding pack temperature could be inferred. Generally the coil will be somewhat cooler than the case structure given that it has more cooling, but the use of the fiber optical sensors should be sufficient to monitor that. For these reasons we do not foresee adding any additional instrumentation to the coils themselves.

3. Structure Instrumentation

3.1 Thermal

Temperature sensors are needed on the structure in the nose region, mid-ICS, case walls near the ICS and in the vicinity of the additional mounting structures for the support structure, CS, PF and FECC systems. We favor the use of 'Cernox' thin film resistors glued into mounting blocks that are a part of, or are hard soldered directly to the TF structure, and placed under any surface taping or MLI. They are simple, robust, radiation resistant and sufficiently accurate for this application. They also have a very low magnetoresistance and a high sensitivity over a wide dynamic range. However such instrumentation should be compatible with other cold temperature sensors used on TPX, for obvious reasons, and we are happy to use another technique more favored, provided that it meets the same criteria for simplicity, ease of mounting, and robustness.

3.4 Pressure

The TF magnet system and the TF lead box share a common vacuum with the cryostat. It is assumed that there will be sufficient pressure transducers installed around the cryostat to determine accurately the vacuum level in the vicinity of the TF lead-box for monitoring and protection. The TF lead box will include sufficient openings such that there will not be a significant pressure differential between the cryostat and the lead box interior.

4. Ground Fault Protection

4.1 Coil Ground Faults

There is a requirement that it be possible to 'lift' the coil groundwrap ground in order to verify the integrity of the groundwrap isolation from other systems. In our design, each coil groundwrap is separated into two pieces, with a break in the middle of the coil and another in the lead area. We will provide single point grounding cables for each half, originating in the lead area. The actual location for the ground termination of these cables has not been specified by the project, but one notes that it requires a cold (4K) ground, otherwise the grounding cables, of high conductivity material, would also conduct significant heat levels into the magnet system. We will also provide a signal cable for injection of an ac voltage to verify ground isolation.

4.2 Octant Ground Faults

We will provide a high electrical conductivity path from each octant to the cold ground, as well as an instrument cable for ac injection to verify the isolation each octant. The method of breaking the ground to verify isolation will be developed in final design.

5. Summary- TF Magnet System Requirements

In addition, thermocouples should be placed near the vacuum vessel throughports in each octant as well as near the inboard leg and outboard leg inside diameters, to measure the temperature of the TF magnet system during vacuum vessel bakeout. Standard commercially available sensors are sufficient for this purpose.

3.2 Structural

Strain gauges can be useful for magnet operation verification (and diagnosis), provided that they can be temperature and magnetic field compensated, as well as mounted such that the mounting interface does not obscure the strain to be measured (see also SDRL 34). We favor strain gauge arrays. The minimum number of gauges in an array should be 2, but as many as 6 have been employed in superconducting magnets. There are a variety of off-the-shelf strain gauges, including multiple gauge arrays, that can be used in this way, and the decision on which to adopt should again be based on defining a common system for use in all TPX areas. All strain gauges will be mounted on the exposed surfaces of TF coil cases and intercoil structure, using compatible adhesives. Each of the 8 octants will use six strain gauge sets, three located on the inboard leg nose, at the top center and bottom in such a way that they do not interfere with the EC breaks, and three mounted on the outboard legs next to the full equatorial port. Of the outboard sets, two will be placed near opposite corners of the port and used to sense the coil case overturning stresses (the highest in the TF system), and the other will be located on the upper bolted joint flange to assess the global toroidal load.

3.3 Magnetic

One can add a Hall probe to each octant to verify the magnetic field, and aid in detecting quenches, however the value of such a system is marginal relative the added heat load of installing them, hence we do not recommend doing so.

SYSTEM	PURPOSE	PER COIL	PER OCTANT
Co-Wound Voltage Taps	Quench	6	
Fiber Optic Temp. Sensors	Quench	2	
Flow Meters	Quench	4	
Coil Ground Sensor	Ground Fault	2	
Octant Ground Sensor	Ground Fault		1
Carbon Resistors	Structure Low Temperature		24
Thermocouples	Structure High Temperature		5
Strain Gauge Arrays	Structure Strain		6

ANSYS 5.0 A
FEB 27 1995
08:47:06
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
TEMP
SMN =6.808
SMX =108.939
6.808
15.318
23.829
32.34
40.851
49.362
57.873
66.384
74.895
83.406
91.917
100.428
108.939

Temperature (k)

Figure 1
Coil Case & ICS Temperatures - No Cooling

ANSYS 5.0 A
FEB 11 1995
08:55:41
PLOT NO. 7
DISPLACEMENT
STEP=2
SUB =1
TIME=2
RSYS=0
DMX =.005915

DSCA=6.176
ZV =1
DIST=.365316
XF =1.636
YF =-.332105
VUP =X
CENTROID HIDDEN

Figure 2

ICS Deformations due to Steady State Heat Loads

ANSYS 5.1 24
 AUG 13 1995
 16:43:17
 PLOT NO. 2
 NODAL SOLUTION
 STEP=1
 SUB =1
 TIME=3
 SINT (AVG)
 TOP
 DMX =0.01758
 SMN =0.242E+07
 SMX =0.502E+09
 0.242E+07
 0.579E+08
 0.113E+09
 0.169E+09
 0.224E+09
 0.280E+09
 0.336E+09
 0.391E+09
 0.447E+09
 0.502E+09

(MPa)

Figure 3
 OUTBOARD LEG STRESS INT., MPa (EXTERNAL VIEW) (@4k-case13)

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