INTERFACE CONTROL DOCUMENT TITLE AND APPROVAL PAGE

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ICD Number:NCSX-ICD-310-840-0001	**Primary Author: Ed Lazarus (WBS 84)**
Impacted WBS Elements: WBS 84 to WBS 3	**Type of Interface: Mechanical/Envelope**

Description of Interface:

Equilibrium Magnetic Sensors for NCSX. Defines magnetic diagnostics physics requirements to WBS 3.

Record of Revisions

Revision Number	Description	Date
0	Initial Issue	April 14, 2003

Approvals

WBS Manager: Signature Not Verified David Johnson Digitally signed by David Johnson DN: cn=David Johnson, c=US Date: 2003.04.15 09:29:59 -04'00'	**WBS Manager:** Signature Not Verified Michael Zarnstorff Digitally signed by Michael Zarnstorff DN: cn=Michael Zarnstorff, o=PPPL, c=US Date: 2003.06.06 17:23:50 -05'00'
Project Engineer: Signature Not Verified Larry Dudek Digitally signed by Larry Dudek DN: cn=Larry Dudek, c=US Date: 2003.04.16 08:23:57 -04'00'	**Project Engineer:**
Systems Engineering Support Manager:	

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(Use Continuation Sheets as Necessary to Include the Following Applicable Information)

Scope of Interface:

This ICD provides a preliminary estimate of magnetics requirements, which interface to the vacuum vessel, all magnets, and the structural shell. (See attached document). The sensors are in 5 categories:

1) Attached to the outer surface of the vessel.
2) Part of the construction of magnets
3) Attached to the structural shell
4) Mounted to the inner vessel wall
5) Connected to buss work

Equipment and Responsibility List:

1) Physics consequences of revisions - Ed Lazarus (WBS 84)
2) Hardware realization – Brent Stratton (WBS 3) to various other hardware-related WBS Managers (e.g., WBS 11, WBS 12, WBS 13, WBS 14)

Related ICDs:

Notes and Abbreviations:

Interface Block Diagrams:

Installation Information:

Some items will be part of primary assembly (vessel sectors and modular coils)

Other Pertinent Information:

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Estimate of Equilibrium Magnetic Sensor Requirements for NCSX

Ed Lazarus

March 20, 2003

This is a first cut at the requirements for equilibrium magnetic sensors (hence forth simply 'sensors") for NCSX. Note the restriction equilibrium, there is a requirement for stability magnetic sensors that is not part of this task. I will first explain the rational for this estimate, then a "base set" that assumes stellarator symmetry. Next is some discussion of requirements to verify stellarator symmetry and finally, the topic of redundancy is addressed. The reader should be aware that this type of work has not previously been needed in stellarators and these initial estimates are highly uncertain. Also no consideration is yet given to measurement error.
It is expected that the nominal accuracy of integrated measurement will be 1%, which has implications for the integrity of the sensor position.

There are some items that can easily be specified simply on the basis that we are building a current carrying, finite beta toroidal device.

1. Each magnet that could be independently powered should have a Rogowski coil or shunt to measure its current and a co-wound sensor to detect the flux through it. This sensor should be on the plasma-facing side of the magnet wherever possible and redundancy is required. The design should be at a level where failure of the sensor is no more likely than failure of the magnet. We expect the control signal to the coil to be the error in this flux measurement.
2. A Rogowski coil to measure the plasma current. If the toroidal current in the vessel can be significant relative to the plasma current, there should be one inside and one outside the vessel. There should be two active sets.
3. Diamagnetic flux loop to measure beta. There should be 2 active measurements

The basis for shape control measurements is the fact that the equilibria are described by toroidal mode number about 5 (=> 2*5+1 modes) and poloidal mode number and poloidal mode number ≤ 12. Half field periods are repetitive, so we might expect 132 measurements per half field period. Now I will consider a mix of saddle coils on the outside and magnetic probes on the inside of the vessel. On the assumption that the probes will be of uniform style and mounting, I will restrict the orientations as follows. The first direction is the local normal to the vessel, the second is horizontal in the plane parallel to the local vessel surface (as seen with a carpenters level) and the third will be the cross product of these. Thus a resolution of B_R and B_ϕ would require all three measurements. The "theta" angle has no real meaning outside the plasma. I will refer to these measurements as n(ormal), h(orizontal) and c(ross product of the two).

1. <u>Saddle coils on the outside of the vessel.</u> Conceptually we want to cover a half period of the vessel surface in rectangles of 6° in toroidal angle and 30° in poloidal angle. It seems to me that it would be easier to place every other saddle coil at its reflection point in the other half period, to avoid overlap and allow room for leads. I think these can be < 1.5 mm diameter MgO insulated coax with a stainless steel outer conductor (electrostatic shield). We should consider twisting the leads of the MI coax to prevent stray pickup, although this may mean we need to use smaller cable for a fixed build. (The RFX group uses MI coax as small as 0,25 mm dia.) It is highly desirable that any construction with MI coax continues the unbroken coax to a stable, accessible access point, so the most likely failure point is readily reparable.
2. <u>Probes on the inside of the vessel.</u> An array of probes that measure B_C on the inside of the vessel that covers a half period and has a similar location criterion, spaced at 6° toroidal and 30° poloidal intervals. I suspect these would be segmented Rogowskis with cross sections of a few cm^2 and several tens of turns. These might also be 0.75 mm dia. MgO coax with the lead connections made outside the primary vacuum as is done on DIII-D. These summed together might serve as an inside Rogowski measurement of plasma current.

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3. Toroidal flux measurement. Because the vessel is not approximately conformal to the plasma, I suspect there will be a gradient in toroidal flux at the vessel. Anticipate toroidal flux loops at the symmetry planes (2 sensors) conformal to the wall. I don't see a measurement preference for inside or outside at this time, thus outside is a better choice from the viewpoint of protection and stability.
4. Structural shell measurements. The shell has 18 toroidal breaks and one poloidal break. Plan for two saddle coils of approximately half the full size of each electrical segment.

We will need experimental verification of stellarator symmetry and redundancy. My attitude is that the outside of the vessel is the best attachment for magnetic diagnostics. After device assembly they will be highly protected and should be perfectly immobile. Also they will be inaccessible unless the machine is disassembled. I would replicate the saddle coils in a second field period. It will be important that the detours around ports be identical. I envision these to be directly on the vessel, under the cooling tubes with welded straps fixing there position, as is done on DIII-D. Since this is now done in two periods, and redundancy implies only the loops, with no attached measurement capability, I might consider doing all 3field periods. Note that if all field periods have identical construction, the distinction between redundancy and testing stellarator symmetry is only in the instrumentation. This may be cost effective.

If I distinguish measurement from redundancy, that is an integrator/digitizer exists or not, the set of equilibrium measurements described here is about 400, enumerated in the table below.

Type	# Instrumented	# Spare	Purpose
Coil flux	50	50 -- 150	Discharge programming
Coil current	50	0	External field
Saddle	132	132-264	Equilibrium
B_C	132	132	Equilibrium
Shell saddle	36	0	Error field
Rogowski coil	2	2	Equilibrium
Diamagnetic loop	2	2	Equilibrium
Total	404	> 318	