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Engineering Note

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Project: Solenoid Energization, Control, Interlocks & Quench Protection
Doc. No: H981012A

Subject: Initial Solenoid Testing - Notes & Comments

Solenoid Charging Schedule

The following charging schedule was developed by Rich Smith. This schedule will achieve full current in about 15 minutes. If at any time the average coil temperature rises above 5.05 K, then reduce the charge voltage to the previous step. Set the desired current to 4753A. This will result in the power supply providing 4741A to the coil which results in 2.0 Tesla.

At I = 0000 A, set voltage limit to 3.0 V
At I = 0700 A, set voltage limit to 3.5 V
At I = 1100 A, set voltage limit to 4.0 V
At I = 1300 A, set voltage limit to 4.5 V
At I = 1900 A, set voltage limit to 5.0 V
At I = 2300 A, set voltage limit to 5.5 V
At I = 2800 A, set voltage limit to 6.0 V
At I = 3400 A, set voltage limit to 6.5 V
At I = 3900 A, set voltage limit to 7.0 V
At I = 4300 A, set voltage limit to 7.5 V

Central Field Toroid

Both End Field Toroids (EF) were disconnected and the central field (CF) was connected directly to the power supply flags. The CF was operated at 1700A in both polarities through out testing using the Mac based control system. Engineering Note H980811A describes the power connections and H980824A discusses the interlocks, cooling water and safety issues. A safety review of the system was held with Dan Wolff presiding and approval was subsequently granted by the Division Head for operation. The power supply was tested prior to using it to charge the CF toroid and a failed AC balance relay was discovered and replaced. Also, turning the power supply on was found to cause a momentary "glitch" in the control room power such that the controls crate would "latch up" and result in loss of power supply control. A UPS was installed to stabilize the controls crate and no further problems were had. The CF was first turned on for testing at 1030 on 9/24/98. It was turned off for the last time at 1745 on 9/30/98. During CF operation, the 1700A setting produced the following results:

Control System Display of Setting	1699.982 A
Control System Display of Current	1688.792 A
Control System Display of Power Supply Voltage	74.133 V
Calculated DC circuit Power V X I	125.8 kW

The voltage drops across the power supply/CF lead connections were measured to be as follows:

Eastmost connection at the sidewalk	2.4 mV
Eastmost connection at the CF	9.6 mV
Westmost connection at the sidewalk	6.0 mV
Westmost connection at the CF	2.4 mV

Cooldown Resistance Monitoring

Engineering Note H980827A describes the apparatus used to monitor resistance of the solenoid during cooldown. The resistance was monitored both during cooldown and during warmup. The apparatus provided 10A into the solenoid, and the current and voltage were monitored by the control system. The DMACS assignments are as follows:

Signal	DMACS Assignment	Lower & Upper Limit	End Rack Connections
Solenoid Volts	DC_AI40	0.000, 10.000	117,118,119
Solenoid Current	DC_AI39	0.000,101.576[1]	114,115,116
Solenoid Resistance	DC_CA5	= Volts/Current	N/A
Extended Plot of DC_CA5	DC_ET4.G_DATA	N/A	N/A

DC_CA5 and DC_ET4 were for general operator entertainment and are not important. The DMACS Historical Trending software plotted the voltage and current data and created files from it. The resulting data files, in comma deliminated text format may be examined, manipulated and plotted with a spreadsheet program such as Microsoft Excel. The data files are located as follows:

D0-RICKH\\C:\DATA\SOLENOID\DMACS HT Files\Original Data\Resistance During Cooldown.dat
D0-RICKH\\C:\DATA\SOLENOID\DMACS HT Files\Original Data\Resistance During Warmup.dat

The same data files, with non-essential information removed; and converted to Excel 97 format are located as follows:

D0-RICKH\\C:\DATA\SOLENOID\DMACS HT Files\Massaged Data\Resistance During Cooldown.xls
D0-RICKH\\C:\DATA\SOLENOID\DMACS HT Files\Massaged Data\Resistance During Warmup.xls

The strip chart outputs from the apparatus are attached to Engineering Note H980827A and kept in the Engineering Notes file.

Results of Meggering Tests

The solenoid and the central field systems were meggerred per standard procedure (power supply regulator module removed, filter and ground fault detector switches in "megger" position). The results are as follows:

Status	LCW Conductivity	Results	Document
Solenoid System - Warm	1.6 MOhm - cm	1.9 MOhm @ 250V and @ 500V	H980830A
Solenoid System - Cold	9.0 Mohm - cm	2.8 Mohm @ 500V	H980908A
Central Field Toroid System - Normal	9.0 MOhm - cm	10 Kohm @ 250V	H980904B

Dump Resistor and Water Cooled Bus Resistance

The resistance of the water cooled bus and dump resistor looking "backward" from the solenoid connections was measured using the solenoid resistance measuring apparatus described above. The conductivity of the LCW system was not at its final lowest value when the test was done. However the resistance of the water would in the order of Mohms and thus have negligible influence in this test. The measured resistance of the bus and the dump resistor was **48.88 milli-Ohms**. The relevant document is H980901A.

Quench Detector Wiring Problem

Initial tests of the solenoid under power resulted in unexpected voltages on the chimney leads. Further investigation revealed a small wiring error in the protection resistor box located at the north end of the solenoid. This was quickly corrected. Later

[1] 101.576 DMACS upper limit provides for the calibration of the HOLEC current transducer. When the HOLEC reports 0.98448 Volts, DMACs will report 10.000 Amps.

analysis of data from historical trending revealed that the outer and inner coil voltages were opposite polarity from the vapor cooled, transition, and chimney leads. This was due to an error in the schematic of the NIM crate connections in the power supply room. This too was quickly corrected.

Data Logger Results

The solenoid system is designed with a "data logger port" where an AstroDaq-2 8-channel data logger was attached to monitor the solenoid lead voltages during commissioning. The data logger has a 1 Mohm input inpedance on its isolation amplifiers. This impedance was low enough to provide an alternate path for the cable supervisory circuits in the quench detector. This alternate path resulted in a slight offset in the data logger readings of the outer and inner coil voltages. The quench detector bridge circuits were adjusted to minimize the impact of installing and/or removing the data logger from the circuit. In addition, the data logger was not "re-zeroed" before this use and this produced minor offsets in some channels also - particularly in the chimney lead B channel. The data logger was easy to use but much of the data it collected was taken when the quench detector wiring errors were still in place and thus of minimal value. Eventually, good data was acquired of baseline, charging, slowdump and fastdump operation. The raw data from the data logger along with a descriptive readme file is located as follows:

D0-RICKH\\C:\DATA\SOLENOID\Data Logger Files*.*

These files each contain 100 seconds of 1000 Hz data from 8-channels (800,000 data points). They can be viewed, processed, and exported to more manageable form using "AstroView" software which is available as follows:

D0-RICKH\\C:\DOWNLOADS\ASTROMED\ASTROVIEW32\av32v23.exe

Using this software, one can for instance, choose a window around a fast dump trigger, compress the data by 128, making each new point an average of the 128, and export it to MicroSoft Excel format for plotting or further processing. Due to the infinite ways in which this data can be used -- and the enormous size of the files, it will be kept in its raw form and processed as needed.

Initial Solenoid Power Tests

The solenoid energization system was tested in preparation for field mapping. The system was tested beginning 9/10/98 with many charge/dump cycles both forward and reverse, to 500, 1500, 2500, 4000, and 4800 amps. Engineering Note H98090A details some of these charge/discharge cycles. This testing revealed the quench lead miswiring described above which prevented slow dumps from above 4000 Amps due to false chimney lead quench sensing. Once the wiring error was fixed, slow dumps from any current worked fine.

Solenoid Power Component Temperatures

Engineering Note 980914B documents the temperatures reached in the solenoid energy system after about 4 hours of operation. Many of the components operate at too high of a temperature and plans are underway to provide them with cooling. In particular, the solid copper bus bar used in various places in the power supply room reached nearly 72 degrees centigrade even though the designed current density is a conservative $1000A/in^2$. This bus bar was later observed to stabilize after 5 or six hours to 85 degrees. The problem is caused by the fiberglass insulation installed tightly around the bus for safety - to prevent inadvertent contact. The insulation does not allow for convective cooling of the bus. This will be solved most likely by coupling an LCW water line to the bus to remove heat by conduction and make up for the lack of convective cooling. Likewise, the tightly sealed dump switch/reversing switch cabinet does not allow for convective heat loss from the high current components inside. This problem will be solved by providing convective air vents with suitable screens to satisfy safety concerns.

Solenoid PT Lead Resistance

The stainless steel conductors used inside the the solenoid to bring out the potential tap voltages have considerable resistance which caused some confusion during debugging of the quench detector system. These resistances were ultimately measured and documented on Engineering Note H980914A. Once understood, they were easily compensated for by the quench detector balance circuits once the previously mentioned wiring errors were discovered and eliminated.

Solenoid Noise Filter Performance

An HP 3561A Dynamic Signal Analyzer was used to evaluate the solenoid's noise filter performance. A 10X voltage probe was used to measure conducted noise at the input and output of the filter; and a 3.5" diameter, 100 turn sense coil terminated in 10 Ohms was used to sample induced noise in the magnetic field of the solenoid. The sampled values and miscellaneous notes are found on Engineering Note H980930B. The CF toroid field was OFF for all measurements. Note that these samples were not taken within the protocols of any noise measuring standard and are of dubious value for anything other than just relative performance indications. Noise levels are already extremely low due to the operating characteristics of the power supply (low voltage - high efficiency tap). The data indicates that the filter provides at least 30 db insertion loss for common mode frequencies of 720 Hz and higher. Furthermore, the entire system is quiet at high frequencies. Differential mode performance is not readily evaluated with the voltage data. The analyzer front end can not tolerate a differential connection and the individual inputs do not have discernible differences in signal levels to allow a calculated approach. The magnetic field samples described in the next section provide a better indication of the differential performance.

The following table lists the results of the conducted noise test taken with a voltage probe at the input and output of the filter. The listed frequencies were chosen by observation as being the only frequencies showing any activity. The +20 added to each value in the table compensates for the 10X probe. All readings were taken with the solenoid charged to 2 Tesla ie. 4753.5 Amps.

Description	720 Hz	20.25 kHz	36.25 kHz	61.25 kHz	72.5 kHz
Grounded Probe	-100+20=-80dbV	-106+20=-86dbV	-103+20=-83dbV	-106+20=-86dbV	-100+20=-80dbV
-input to gnd	-30+20=-10dbV	-53+20=-33dbV	-56+20=-36dbV	-61+20=-41dbV	-62+20=-42dbV
-output to gnd	-69+20=-49dbV	-87+20=-67dbV	-89+20=-69dbV	-94+20=-74dbV	-95+20=-75dbV
(-) Insertion loss	39 db	34 db	33 db	33 db	33 db
+input to gnd	-30+20=-9.8dbV	-53+20=-33dbV	-57+20=-37dbV	-61+20=-41dbV	-63+20=-43dbV
+output to gnd	-56+20=-36dbV	-88+20=-68dbV	-90+20=-70dbV	-92+20=-72dbV	-93+20=-73dbv
(+) Insertion loss	26.2 db	35 db	33 db	31 db	30 db

The following table lists the results of sampling with the "magnetic field" probe (loop) placed at the outside edge of the solenoid aperature (maximum field) with its axis parallel to the flux. These measurements represent "ripple" in the magnetic field and provide a quality evaluation of the differential mode performance of the filter. No attempt was made to measure "electric field" noise. Electric field noise would result from the common mode noise discussed above. Note that no difference could be seen in the measurements above 7500 Hz with the solenoid on or off. These simple observations tend to indicate that the filter is performing as designed.

Description	360 Hz	720 Hz	1395 Hz	7500 Hz and above
Solenoid OFF	-142 dbV	-144 dbV	-145 dbV	-126 dbV
Solenoid @ 2 Tesla	-110 dbV	-112 dbV	-115 dbV	-126 dbV