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Data Acquisition and Protection for New DIII–D In-Vessel Coils

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Abstract. The installation of new internal magnetic coils (I-Coils) in the DIII–D tokamak at General Atomics required extensive additions to the experiment data acquisition and protection capabilities. This set of 12 coils (up to7 kA each) is designed to allow improved feedback stabilization of resistive wall modes which limit the plasma performance. The acquisition and signal conditioning needs of the I-Coil power system presented an opportunity to try a new data acquisition approach which increased both the sampling rate and sample size per channel compared to the standard DIII–D CAMAC acquisition equipment. A 96 channel Compact-PCI (cPCI) digitizer system was purchased for the I-Coil project to acquire up to approximately 380 MB of power supply and coil current data per plasma discharge. Additional instrumentation and control was provided to protect personnel, the new coils, the tokamak, the facility and improve machine availability. This paper will present discussions of technical and programmatic requirements, bases for requirements, the design selection outcome, installation experience, integration issues, commissioning experience, and lessons learned. The data acquisition system is described in detail including a conservative signal isolation scheme, signal grounding standards, anti-aliasing filters, and synchronization of acquisition. Protection interlocks are described, including high voltage isolation, water flow measurement, and the coil grounding-shorting switches.

I. INTRODUCTION

The DIII–D project has installed twelve new internal coils (I-Coils) inside of the tokamak vacuum vessel. These coils permit flexible error field compensation and resistive wall mode (RWM) feedback stabilization [1]. The coils are designed to operate at up to 7 KA and are water-cooled. Five DC supplies and four switching power amplifiers (SPAs) supply coil current via a patch panel. Commands from the DIII–D plasma control computer system set coil currents in real time to achieve the desired plasma response.

Data acquisition, control and protection requirements were established to accommodate experimental needs and assure investment protection.

II. FUNCTIONS AND REQUIREMENTS

A. *I-Coil data acquisition functions are:*

- Acquire I-Coil power supply data (current, voltage and commands for 5 DC supplies and 4 SPAs)
- Acquire 12 I-Coil currents
- Acquire power supply and SPA commands from the plasma control system
- Interface to DIII–D data acquisition system
- Make data available to shot-data archive

B. *Acquisition performance requirements include:*

- Measure coil currents to 10 A accuracy
- Measure power supply and SPA currents and voltages with accuracy sufficient to assess power supply performance
- Acquired data shall be available for display immediately after the shot in the same manner as all other DIII–D data
- Data shall be sampled at 20 Hz to 100 KHz. Note: In order to achieve the temporal resolution for SPA performance analysis, voltages from those supplies needed to be acquired at with 50 KHz bandwidth. This is the highest bandwidth required for the I-Coil systems.
- Data shall be acquired at maximum sample rate for at least 10 s.
- Data sample clock shall be synchronized to all other DIII–D acquisition clocks

C. *Equipment protection functions are:*

- Protect I-Coils from over-temperature damage
- Prevent steam generation
- Protect interfacing systems
- Interface to operator

D. *Protection system performance requirements are:*

- Water flow must be adequate to each coil for shot setup to be allowed to proceed.
- Water temperature at outlet must be acceptably low for each coil for shot setup to be allowed to proceed.
- Coil temperature must be acceptably low for each coil or the shot shall be aborted.
- 5000 V of isolation shall be provided between the coils and power cables and instrumentation systems.

III. DATA ACQUISITION DESIGN SOLUTION

Most of the data acquisition on the DIII–D experiment is implemented with computer automated measurement and control (CAMAC) hardware. This infrastructure has existed since the beginning of this project in 1978. For the most part, these systems meet performance requirements. They could have been used for the I-Coil data acquisition. However, many of our CAMAC components are becoming obsolete and unserviceable. VME and PCI systems have already been used at DIII–D for newer acquisition systems [2]. PCI is successfully deployed for the plasma control system. Plasma control is in a relatively benign environment near the control room. The best place to locate the I-Coil acquisition system is out in the power supply area, which is not environmentally controlled. For this reason we thought it best to consider CAMAC or compact PCI (cPCI). A rough cost comparison between an all-new CAMAC installation and a cPCI installation was done which showed cPCI as the less expensive of the two solutions by about 20%. Even though cPCI was considered to present more schedule risk, we decided to adopt that solution. Also, it is considered important for the project to migrate away from CAMAC to more serviceable acquisition and control platforms. This single deployment of a cPCI acquisition system does not set a precedent for future systems on DIII–D, but has given us more experience with what alternatives there are. Future design solutions for acquisition and control on this project will be driven by performance requirements, as this one was. PCI and cPCI are attractive now due to their market predominance. Indeed, some PCI components are now just commodities, a status never realized by VME or CAMAC.

The I-Coil data acquisition system is shown in Fig. 1. Assembly details of the acquisition computer are in Fig. 2. The computer supports three 32-channel digitizer cards with a 1 GHz Pentium CPU running LINUX. Data is transferred after a shot via an Ethernet TCP/IP connection to be included in all other DIII–D shot data [3]. The digitizers support up to 250 Ksample/s operation and each has 128 MB memory on the digitizer card. The vendor, DTAQ Solutions Ltd., supplied an additional board for each 32-channel digitizer that provides an anti-aliasing filter for 50 KHz, and input protection up to 100 V channel to channel or channel to ground. Outboard of the acquisition computer we installed isolation amps on some channels to eliminate ground loops.

We had very good success with the commissioning of this system. Since it was delivered already configured by the vendor, we essentially had only to connect our signals and get the data out. The sole significant challenge was a stop trigger problem resulting in apparent channel swapping of the data. We understood that the stop trigger was latched and asserted on the next clock transition. This is not the case; the stop trigger must span the duration of one sampling clock period to assure it is there when the appropriate clock edge arrives. A pulse stretcher after our standard timing receiver filled this requirement and eliminated the observed abnormalities in the data (Fig. 3).

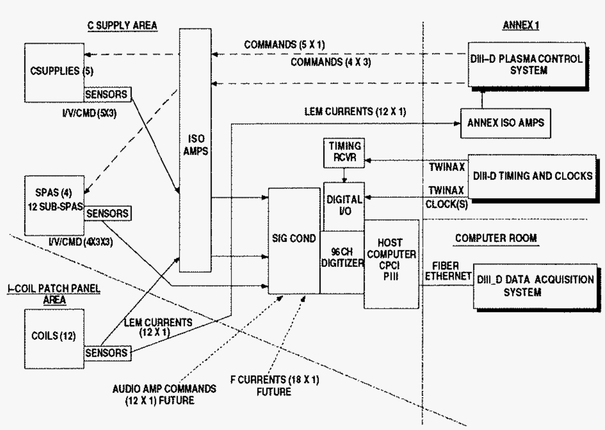

Fig. 1. Context diagram of I-Coil data acquisition system.

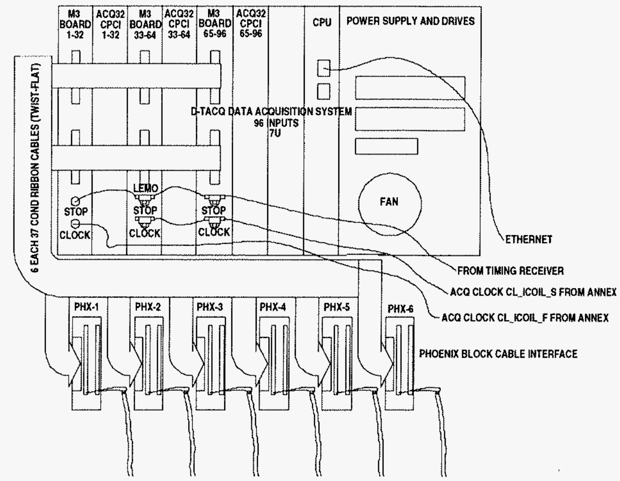

Fig. 2. I-Coil acquisition computer assembly.

A clean environment is maintained for the I-Coil acquisition system by installation in a sealed and air-conditioned rack. The computer and expensive digitizers are protected from heat removal failure by the system diagrammed in Fig. 4. When in-cabinet temperature exceeds 92°F, the input power to the UPS will be interrupted. Subsequently, the UPS will send a message to the computer to shut down. The UPS will run out in about 7 min, giving the computer time to shut down but not enough time to raise the cabinet temperature more than 2–3°F above 92°.

IV. COIL PROTECTION INTERLOCKS DESIGN SOLUTION

Fig. 5 shows the equipment protection interlock systems for the I-Coils. The design meets requirements for equipment protection as stated earlier.

The referenced requirements from Fig. 5 are:

1. Water flow must be adequate to each coil for shot setup to be allowed to proceed.
2. Water temperature at outlet must be acceptably low for each coil for shot setup to be allowed to proceed.
3. Coil temperature must be acceptably low for each coil or the shot shall be aborted.

The bases for these requirements are derived from the mechanical design of the coils and interfacing components [4].

The isolation transformer and the long deionized water path satisfy the requirement for 5000 V of isolation between the coils-power cables and instrumentation.

V. CONCLUSION

Deployment of the data acquisition system was successful although at first perceived risky. It meets requirements at a reasonable cost of about $375 per channel. We look forward to the use of other cPCI solutions with capabilities beyond waveform digitization. These capabilities would include functional replacement of other traditional CAMAC modules that perform digital I/O, timing, counting and others.

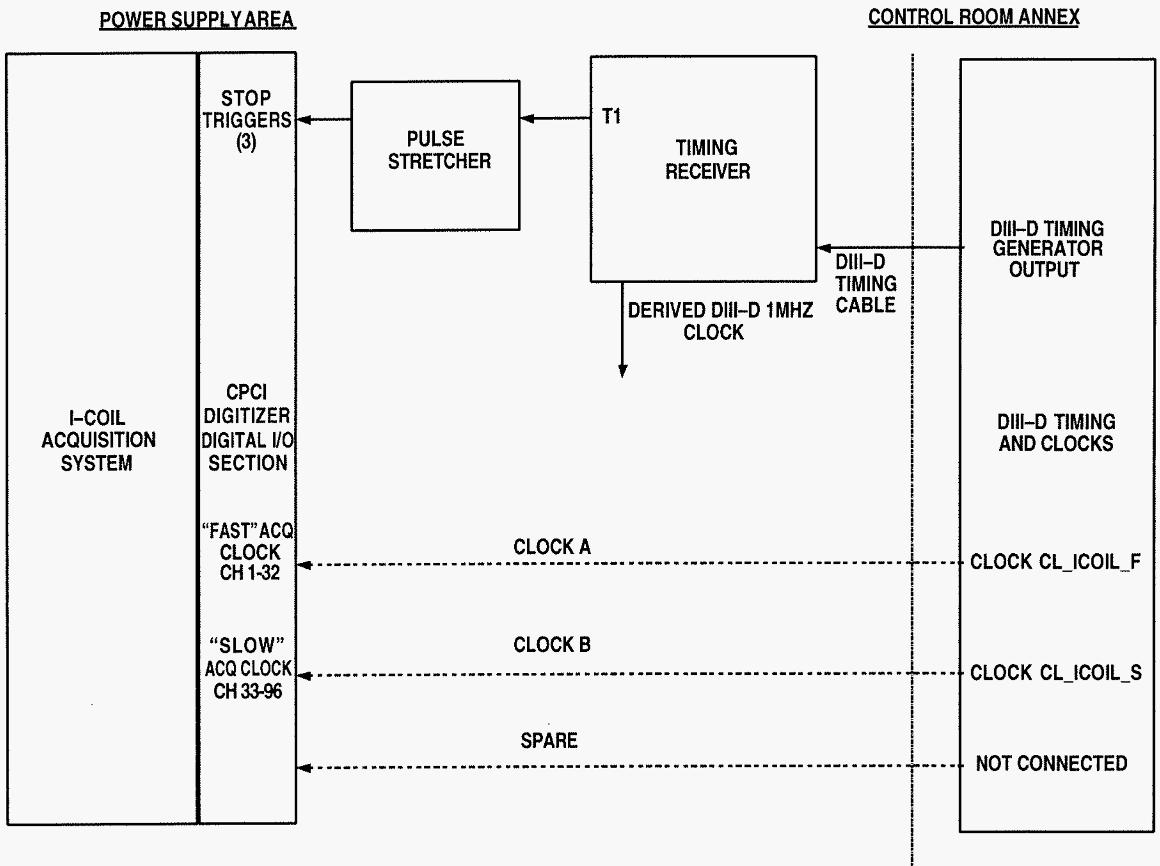

Fig. 3. Digitizer clock and stop trigger connections.

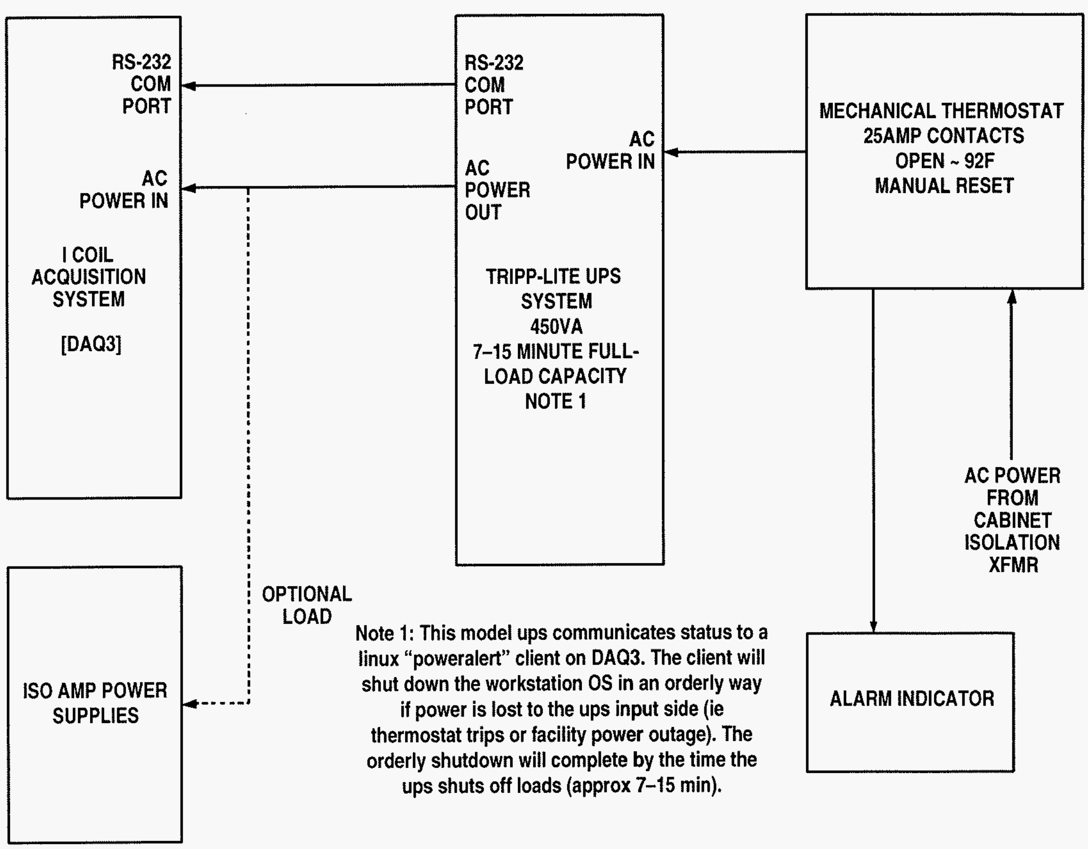

Fig. 4. I-Coil acquisition cabinet over-temperature protection interlock.

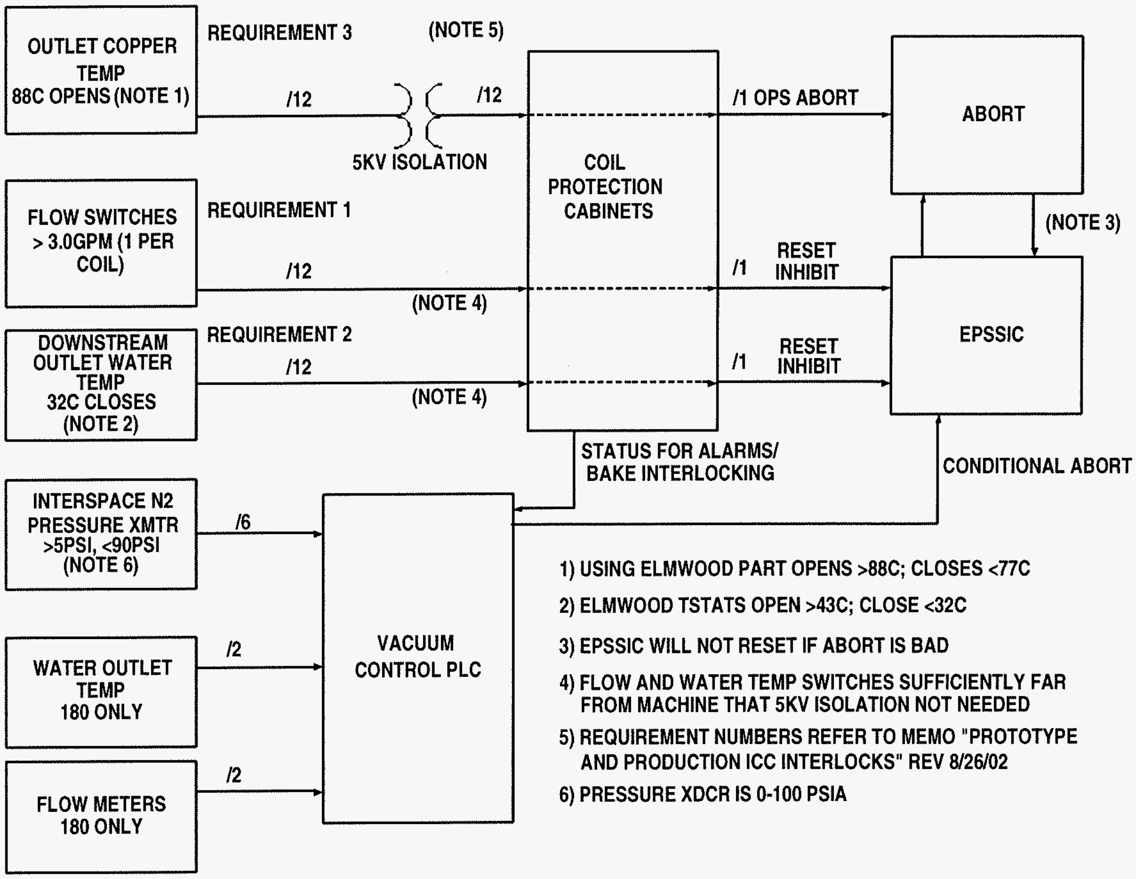

Fig. 5. I-Coil protection interlocks block diagram.

The equipment protection interlocks are traditional hardwired systems with off-shelf components. The reliability of such a system is easy to define and quantify. The system is also maintainable by a much wider range of personnel with diverse technical training.

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