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A Thermocouple Telemetry System Replacement for the DIII-D Neutral Beams

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Abstract— **The DIII-D neutral beams thermocouple telemetry system was recently replaced with a new system to reduce signal noise. The original system, which utilized multi-channel ice point reference devices and a Computer Automated Measurement and Control (CAMAC) standard interface, provided unreliable data due to excessive signal noise. This obscured the actual temperature rise and fall on beam system components. A new telemetry system was sought to improve data reliability, and reduce operational risk to beam system components. A prototype system was configured using commercially available data input/output (I/O) modules that feature built-in thermocouple reference junction temperature compensation and an Ethernet interface. The prototype system was installed and connected to a group of beam system thermocouples. Using the application programming interface supplied with the I/O modules, test code was developed within the MS Windows® operating system to monitor the acquired data. Performance and reliability of the prototype system were observed over a six month period of DIII-D experiment operations, and data was compared to that acquired with the original telemetry system. The measured reduction in signal noise prompted the implementation of this upgrade in all DIII-D neutral beams systems. A Linux version of the code was developed and integrated as a procedure for data acquisition during neutral beam operations. Data obtained from the replacement system showed reduced signal noise. In addition, the replacement telemetry system provides improved performance and data acquisition capability. The resistance and lifetime of the hardware in electrically noisy and high radiation exposure environment however, remains an issue.**

Keywords: thermocouple, CAMAC, telemetry

I. INTRODUCTION

The design of the DIII-D neutral beams protection systems consist of fast interlocks, permits, and monitoring systems. Fast interlocks, which have a response time of less than 10 milliseconds, protect the system during a beam shot. The permits, in conjunction with alarms, provide for proper arming during the "get-ready" procedure, and firing when ready. In addition to these two systems, a thermocouple monitoring system provides another layer of protection by informing the beam operator, through plots of waveforms, of the temperature rise on different beam components. These systems work hand in hand to form a robust protection system. Over many years of operations, equipment has slowly aged and degraded in performance. The original neutral beams thermocouple system suffered from excessive signal noise. The data obtained were obscured by noise and became nearly useless. A replacement thermocouple data acquisition system was sought to replace the original system.

II. ORIGINAL SYSTEM OVERVIEW

The original system consisted of thermocouples wired to four ice point reference (IPR) units per beam line and interfaced to CAMAC modules. Fig. 1 shows how the thermocouples and ice point references were interfaced to CAMAC. As shown in the figure, the signal conditioning and data acquisition (DAQ) hardware were located in a CAMAC crate some distance away from the thermocouples. The long cable length from the thermocouples to the crate made the signal more susceptible to noise and loss. Over the years the hardware had degraded to the point that the signal was saturated and distorted by noise for all four independent systems on the four beam lines.

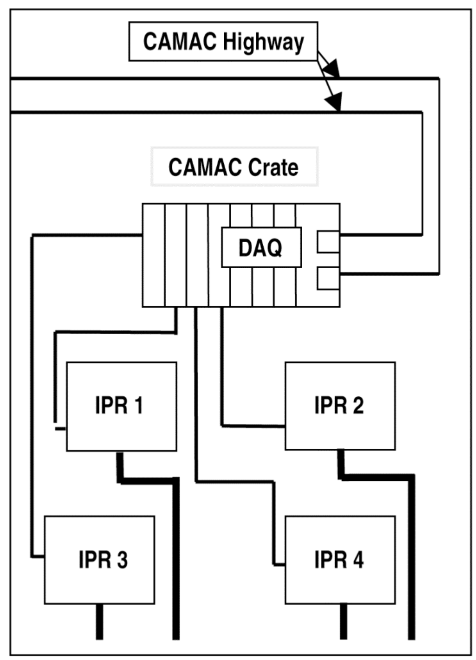

Figure 1. The configuration of the original thermocouple system. The ice point reference or IPR boxes were mounted on the side of the beam line. The thermocouple cables were attached to them and to the signal conditioning and DAQ modules of the CAMAC crate. The heavy lines in the diagram represent thermocouple cables.

III. REPLACEMENT SYSTEM OVERVIEW

In contrast to the original system, which contained the signal conditioning and data acquisition hardware in the same CAMAC crate and at a distant location from the thermocouples, the replacement system consists of modular units located close to the thermocouples. The proximity of the I/O modules to the thermocouples is one of the advantages the replacement system has over the original system in regard to noise performance. The relatively small size of the modules and the type of the interface, being Ethernet based and using Ethernet cables and connectors, allowed the replacement system to be installed in a short time and with ease.

Fig. 2 shows the topology of the system.

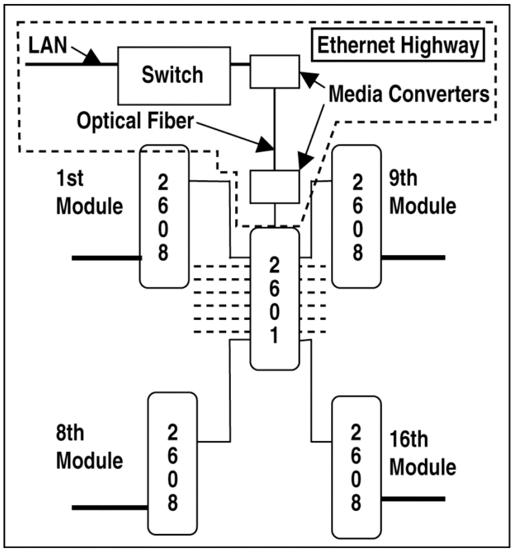

Figure 2. The configuration of the replacement thermocouple system. The thermocouple cables are attached to the 2608's that contain thermocouple reference junction compensation, signal conditioning and A/D circuitry. The heavy lines in the diagram represent thermocouple cables. The media converters change fiber to copper. They are required for highvoltage isolation.

The modular units shown in the figure above are commercially available hardware from Sensoray Co., Inc. The main module, a Sensoray 2601 model, provides up to sixteen ports for I/O modules. The Sensoray 2608 modules are electronic thermocouple input modules with built-in thermocouple reference junction temperature compensation. The advantage of built-in compensation are the ease of calibration, reduced copper telemetry path, elimination of several noise injection points, and a gain of valuable real estate on the beam line. The Sensoray 2608 modules plug into the main module by RJ45 cables that also provide power. The main module, also called the gateway for the I/O modules, has an Ethernet interface. A computer running the thermocouple data acquisition software communicates with the main module via Ethernet. The Ethernet interface allows multiple computers to communicate concurrently with the I/O modules through the gateway. An advantage of the Ethernet interface is the capability to communicate concurrently with the modules through the network from multiple computers having access rights.

Communication between the Sensoray 2601 and the LAN network switch is through optical fiber. The optical fiber is required for isolation. It also provides noise rejection.

IV. THE DAQ SOFTWARE

Once a prototype hardware system was selected, the next phase of the replacement system evaluation was to develop code for testing and monitoring the system. The test code was developed with the supplied application programming interface (API) that supports both the C and Visual Basic programming languages. The test code or application was developed in Visual Basic in the Microsoft Windows® operating system. The test application assisted in troubleshooting and the understanding of the hardware. The supplied API allowed rapid application development.

With the hardware installed and the test code complete, the replacement system was observed over a six-month period of DIII-D experiment operations. The acquired data showed reduced signal noise compared to that of the original system.

Thermocouple software consists of two parts, the scanning code and the graphical user interface (GUI). The GUI of the original system was maintained but the scanning code was rewritten to support new hardware. Like the original scanning code, the function of the new scanning code is to acquire data from the I/O modules and populate a database. The acquired data are displayed on multiple GUIs that represent different components of the beam line, such as the calorimeters, the bending magnet pole shields, the drift ducts, and the collimators. On the GUIs are text boxes that display the peak temperatures of the thermocouples. Fig. 3 shows an example GUI of a calorimeter with boxes that represent thermocouples.

V. MEASURED SIGNAL NOISE REDUCTION

The measured reduction in signal noise was apparent in plots of signals of the replacement system versus the original system. In the plot of temperature rise of the original system, the thermocouple signal was affected by large noise spikes. The measured peak temperatures would reach extreme values that were up to two times beyond expected range for some components of the beam line. Values of up to 726ºC were measured, as shown in Fig. 4, for components that were expected to reach a maximum value of 300ºC, based on engineering study.

The plots of the temperature rise of the thermocouples can be displayed by double clicking on the boxes. From the plots the operator can see the thermocouple temperature rise trends. During a beam shot, an operator closely monitors the temperature of the thermocouples by checking the peak temperatures and plots. The plots verify that the peak temperatures resulted from real temperature rise, not noise. Fig. 5 shows a plot of a thermocouple signal after a beam shot. A ramping plot that smoothly reaches a peak indicates a reliable thermocouple signal. The final version of the thermocouple scanning code was ported to Linux and integrated as a procedure for data acquisition during neutral beam operations.

VI. MEASURED SIGNAL NOISE REDUCTION

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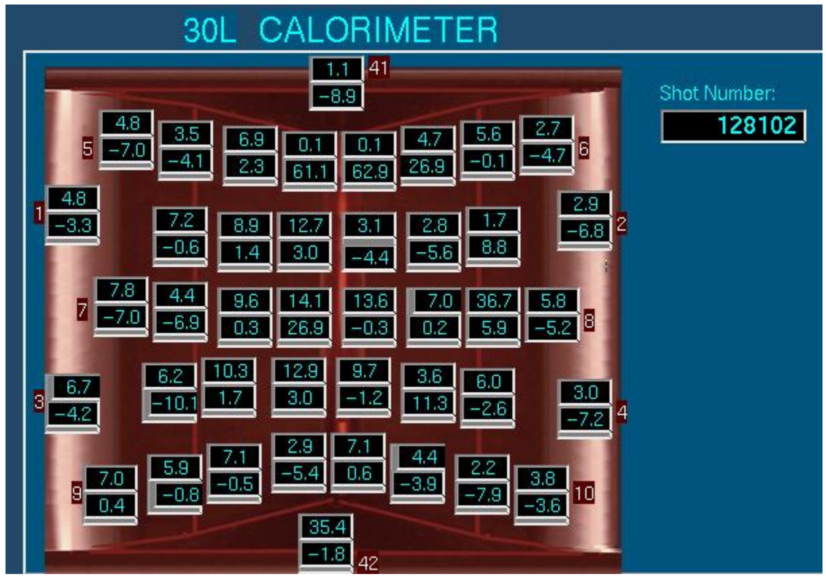

Figure 3. One of the graphical user interface of the thermocouple software. There are two boxes for each thermocouple; the upper box displays the peak temperature rise, and the lower box displays the baseline temperature.

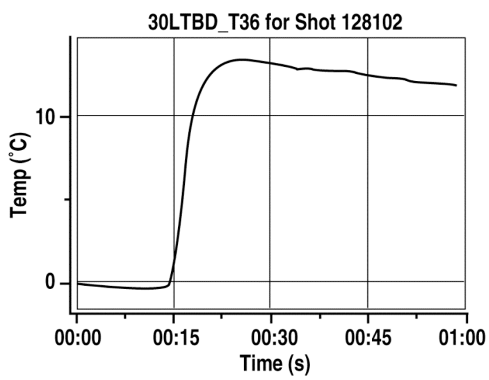

Figure 4. An example of a good thermocouple signal. In additiion to monitoring the peak temperature rise on the GUI, an operator also checks the plot of the signal.

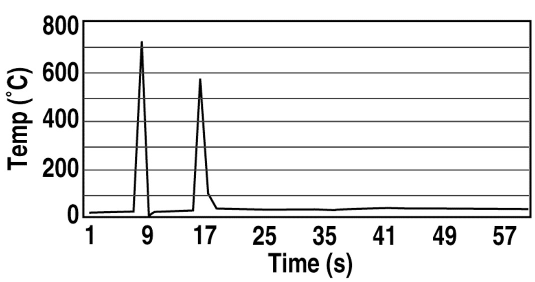

Figure 5. A plot of a thermocouple signal of original system. On some components, such as the magnet poleshields shown here, the peak temperature would reach up to more than twice the expected peak temperature.

The noise pickup by the original system was seen in the majority of thermocouples, and was evident in all beam lines.

In comparison to the original system, the replacement system produced a smoothly rising curve that reached a peak as shown in Fig. 6 for a thermocouple. The peak values measured by the replacement system reached values in the expected range on different components of the beam line. This reduction in signal noise was demonstrated in the majority of the thermocouples for all four beam lines. For a six-month period, the data obtained from the replacement system consistently showed reduction in signal noise.

The replacement system not only exhibits reduced signal noise but also provides improved performance and data acquisition capability. As mentioned earlier, the ability to access the I/O modules from more than one computer simultaneously is another advantage of the replacement system over the original system. The bandwidth of the telemetry of the replacement system is also higher than that of the original system. These benefits result from the use of Ethernet for data transmission instead of the CAMAC highway. Some of the configurable features of the I/O modules are a variable sample rate of 1 to 10 samples per seconds and the ability to set the thermocouple type.

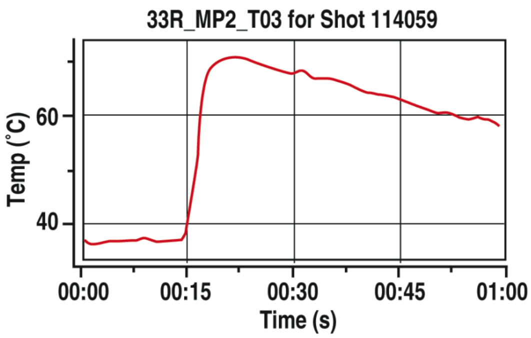

Figure 6. After the installation of the replacement system, the plot of a thermocouple signal shows a waveform that rises gradually and reaches a peak in the expected range. The signal closely matches that of a good signal shown in Fig. 4.

VII. SYSTEM RELIABLITY

Currently, the replacement system continues to produce reliable thermocouple temperatures and plots in an electrically noisy and high radiation exposure environment. However, as observed with other solid-state digital electronic devices, the lifetime tends to be shorter than that of older, discrete component electronic devices in this same environment. Some symptoms of deterioration are sporadic lockups that require power cycling, regular hardware faults, and eventual failure. Remedies being considered include relocation of the hardware to a less severe environment and better electrical and radiological shielding of the new system's modules.

A similar system, also configured with Sensory modules, has been holding up quite well in a similar environment but at a location approximately five meters from the tokamak. In comparison, the current system is approximately two meters from the tokamak. By implication, the closer proximity of the current system to the tokamak exposes it to a higher level of EM fields and radiation. These results indicate that once the Sensoray modules are relocated outside of the machine hall away from the intense EM fields of the DIII-D coil sets and radiation during a plasma shot, their survival rate will improve.

VIII. CONCLUSIONS

The noise pickup as observed and measured by the peak values of the thermocouples and their plots pointed to shortcomings in the original thermocouple telemetry systems. A test setup with new hardware that featured Ethernet based telemetry showed reduction in signal noise in the acquired data. The reduction in signal noise, as measured by the acquired values of the thermocouple temperatures and plots of their temperature rise, was consistent in a majority of the thermocouples. This prompted the replacement of the original thermocouple systems on the four beam lines.

The replacement process required installation of hardware based on a different telemetry protocol than that of the original system and development of test codes for monitoring the reliability and understanding the features of the main modules and I/O modules. Design features of the modules, such as the use of Ethernet cables for interfacing and powering the I/O modules, facilitated the installation. After the installation of the hardware, test code was developed with the supplied API in the Microsoft Windows® operating system. The test code enabled the operator to monitor performance of the system and reliability of the acquired data. During a six-month period of DIII-D experiment operations the replacement system exhibited dependable performance and uniform noise reduction in the majority of the thermocouples. The final version of the test code was ported to Linux and integrated as a procedure for data acquisition. Remaining challenge is long-term system reliability in a radiation environment.

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[1] Sensoray Co., Inc. 7313 SW Tech Center Dr. Tigard, Oregon 97223, USA.