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G. L. CAMPBELL
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DIII–D CRYOGENIC CONTROL SYSTEM UPGRADE

G.L. Campbell and J.J. Gilgallon
General Atomics, P.O. Box 85608
San Diego, California 92138-5608

Abstract: The helium liquefier and distribution system at the DIII–D tokamak facility has been upgraded with the addition of a programmable logic controller, color graphic operator interfaces and analog data acquisition system. This new system provides extended monitoring, control capability as well as centralized datalogging, trending and alarm reporting. Other objectives included offsite (remote) monitoring and control via phone modem and a hardware basis for automation of liquefier operation and maintenance. It is now also possible to accomplish connection and coordination with other DIII–D control systems. It was required that most of the installation and checkout of the new control system be done during operating periods. For this reason, and reliability concerns, the upgrade hardware was designed and installed as an additional independent system rather than a replacement control system.

Introduction

DIII–D is a magnetic confinement fusion research facility operated by General Atomics Company (GA) for the U.S. Department of Energy. Auxiliary plasma heating systems include four dual ion source neutral beam injectors (beamlines) providing 14 MW total injected power, ECH heating, and ICRF heating.

The beamlines use nitrogen and helium cooled cryopanels to handle the approximate 200 Torr-liter gas load from the sources and neutralizer during a pulse. The pumping speed for hydrogen of these panels is approximately 1.6 million liter/second, sufficient to prevent gas loading of the tokamak during beam injection. Beamline cryopanels are cooled by flow of LN_2 and LHe at typical rates of 100 and 120 liters/hour respectively. Helium liquid is delivered from a dewar by coaxial transfer pipes surrounded by the liquid nitrogen flow and insulating foam outside shell. Pneumatically operated valves at each beamline control LN_2 and LHe flow through the panels. The nitrogen is vented after exiting the beamline but the helium is returned to the liquefier system via the coaxial transfer piping. Helium gas is purchased and liquefied for the DIII–D project by a system (Fig. 1) composed of a Koch Process Systems model 2800 helium liquefier, six screw compressors, and GA built wet expander and 3.8 K heat exchanger [1]. The liquefier supplies all the needs of the beam injectors as well as ECH gyrotron magnet cooling and several diagnostic cryostats. Normal operation and maintenance of the system requires the support of one full time engineer and three technicians. The original cryogenic system controls are non-centralized and dedicated to each major component; liquefier, heat exchanger, wet expander, and beamline flow/temperature controls. No interprocess communication is used. Key parameter recording and alarm generation is done by a 48 channel datalogger. Alarms occurring during nonworking hours are reported via telephone by a programmable voice calling unit.

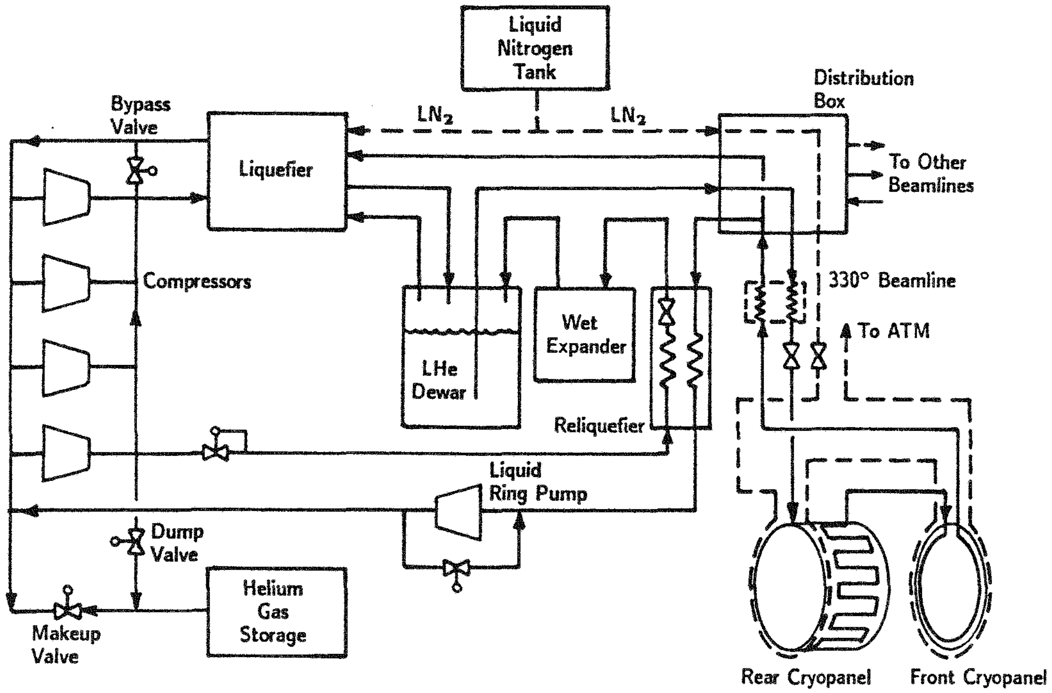

Fig. 1. DIII–D cyrogenic system.

Objectives

One of the most attractive reasons for centralizing the cryogenic control systems is to allow off-site monitoring and control. This will eliminate the need for engineers and technicians to travel from home to correct minor control problems and will shorten the on-duty time for exceptional operations such as startup and shutdown.

It was also considered that operation and diagnosis of systems would be more easily accomplished using a central hierarchial color graphic display. Such a system also makes practical the use of graphical trend plotting and broadens the scope for datalogging. The problem of acquiring the data and status from the several parts of the cryogenic system suggested the use of a programmable controller (PLC) which in turn provides the hardware base for system automation.

Finally, as the cryosystem is required to be operational for almost all DIII–D experiments, the upgrade was designed as an alternative and parallel entity sharing original sensors and actuators (Fig. 2).

Process Sensors and Actuators

The hardware in the original control systems provided most of the analog and discrete signals necessary for central monitoring and control. The majority of these signals were also available from electronic transmitters. Electronic sensors were added where only pneumatic or mechanical means had been employed. The total count of about 250 analog sensors include silicon diodes, thermocouples and vapor pressure bulbs; gas flow rates; engine speeds; pressures; valve positions; and heater power. Discrete state signals are obtained from compressors, valves and panel switches.

Analog and discrete outputs from the new and original controls are presented to switching systems that the operators use to select which controller is operating a device. The new control system can automatically relinquish control to the old system upon detection of a fault or control problem.

Operation of the Joule-Thompson flow control valves in the Koch liquefier was redesigned using an intelligent stepping motor controller and linear variable differential transformer (LVDT) position sensing arrangement. This enhances operation of the original control system and allows much simpler interfacing to the upgrade hardware. Similarly the liquefier engine speed control scheme will be redesigned to provide setting via 4 to 20 mA current rather than the synchronous motor-potentiometer used presently.

Sensor Acquisition

Two different techniques are used to acquire analog sensor data for the cryogenic control upgrade. Sensor signals intended for use in PID control loops and others that require rapid update for control or operator confidence are conditioned and connected directly to programmable controller I/O. The number of such sensors is kept as low as possible due to the high cost of PLC analog inputs and the outboard signal conditioning often necessary for thermocouples and other low level or non-single ended signals. Remaining analog sensors are connected to an STD Bus microcomputer using configurable signal conditioning and A-D conversion cards. Thus these signals are acquired at much lower cost and are linearized/conditioned on the A-D converter card or by the microcomputer program. The disadvantage of this approach is the slower speed at which the data is available to the PLC. The STD computer is interfaced to the PLC with a GA built dual port memory board mounted within the STD bus.

Digital signals are handled exclusively by the PLC with a variety of I/O modules. PLC I/O at the beamlines is isolated using high speed (826 KBaud) fiberoptic modems. A fiberoptic modem set also connects the cryo upgrade PLC with the DIII–D vacuum control system PLC.

Operator Interfaces

The upgraded cryogenic control operator interface hardware consists of one IBM AT microcomputer (offsite station) connected via phone modem to the PLC and one Nematron

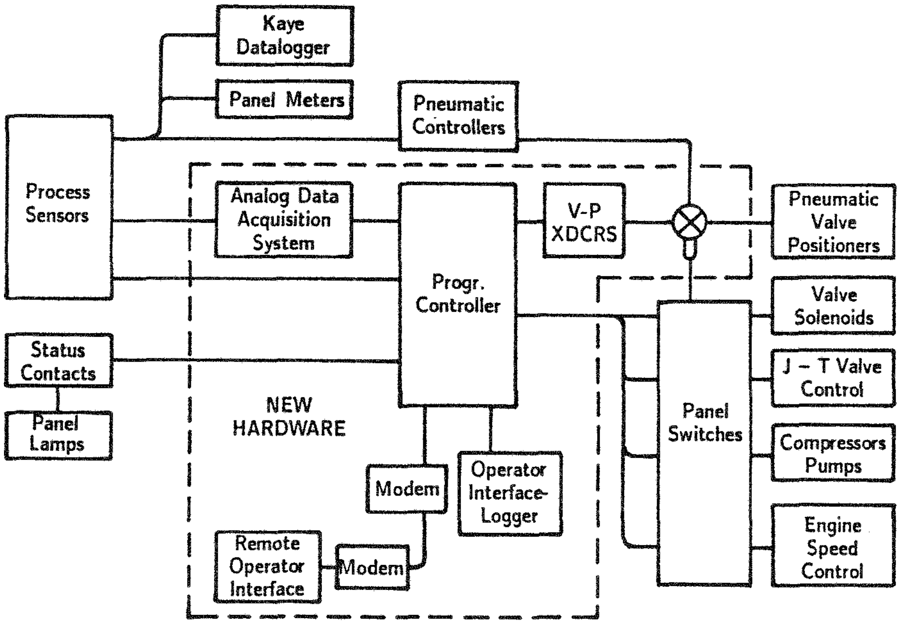

Fig. 2. Cryogenic system control hardware configuration.

industrial AT compatible microcomputer at the cryogenics control area. The Nematron is connected to the PLC I/O processor with a 19.2 KBaud synchronous RS232 link while the offsite operator must run at 1200 Baud asynchronously. Both of the operator interfaces run Genesis control software supplied by Iconics. The onsite unit is also equipped to be the graphics and control development station and has archiving and trending capability. The offsite AT is used only for monitoring and control.

Displays are organized in an inverted tree structure. At the top level is a system overview screen (Fig. 3) with information sufficient to indicate quickly whether the cryosystem is "OK" or "NOT OK." Status is shown by color changes within blocks for liquefier temperatures TT 7 to TT 17, beamline panel temperatures (30, 150, 210, 330), and 3.8°K heat exchanger temperatures TI 146/TI 127, liquid nitrogen, helium, and gaseous helium storage levels are indicated by bargraph and numeric attachments. Compressors 1 to 6 and liquid ring pump on/off status is also displayed. The next level divides the subsystems and shows more numerical values for process sensors (Fig. 4). Lower level displays are used for control and PID loop details, often simulating existing hardwired control panels (Fig. 5). A P&I diagram format is generally used in the higher level displays.

Loop Control/Integration

Having established a hardware foundation for automatic control, work is progressing to implement the lowest level PID loop control in the PLC. In most instances this will replicate the function of existing pneumatic process controllers but adding the means to change setpoints and modes from offsite. Higher levels of control can be achieved which will reduce operator burden and increase system efficiency. Operating modes which demand constant attention and frequent manual intervention can then be automated.

Operating Experience

The new cryogenic control system in its current state allows monitoring and limited operation from the offsite operator station. Full capability has been realized at the local level for trend plotting and alarm reporting as well as system status display. Hardware installation and connection is complete but the new system has not been used regularly for process control. This is due to the need for some additional programming work and extensive strategy planning for some of the higher level loops.

During the checkout phase of the project much more time was spent than was anticipated on calibration of sensors. As work progressed the desirability of other improvements was recognized. Though not central to the control system upgrade, many of these improvements were performed.

Operator familiarity regarding the new hardware has not been actively dealt with at this point. The operators currently use the display, logging and alarming capability but formal training has been deferred until full remote and local control capability is realized.

Conclusion

The upgrade of the DIII–D cryogenics control system has achieved the initial design objectives of remote monitoring and control, enhanced data collection and display, and provision for a hardware base to automate the process. Ongoing software development will integrate the separate processes involved in helium liquefication and delivery, resulting in a system which is easier to operate and maintain.

Acknowledgment

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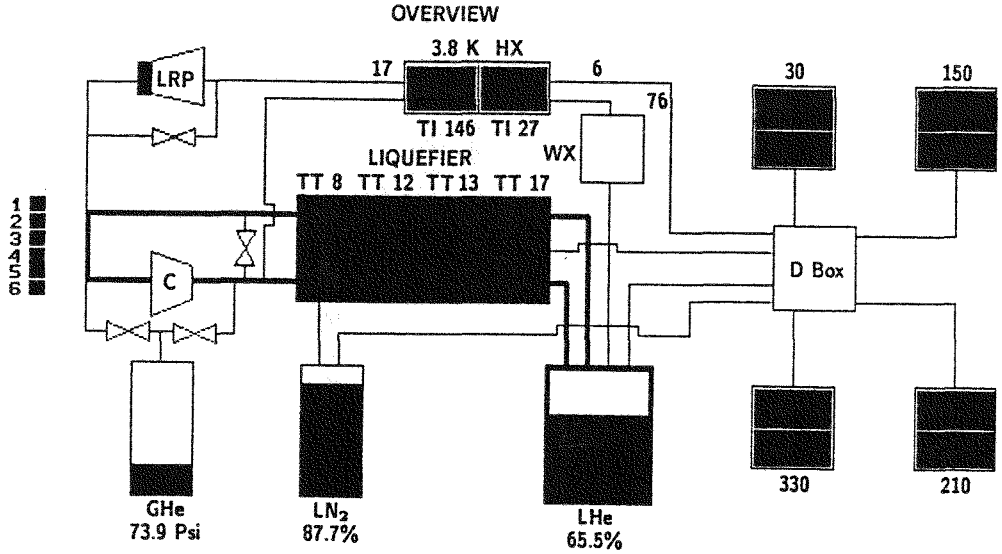

Fig. 3. System overview graphics template.

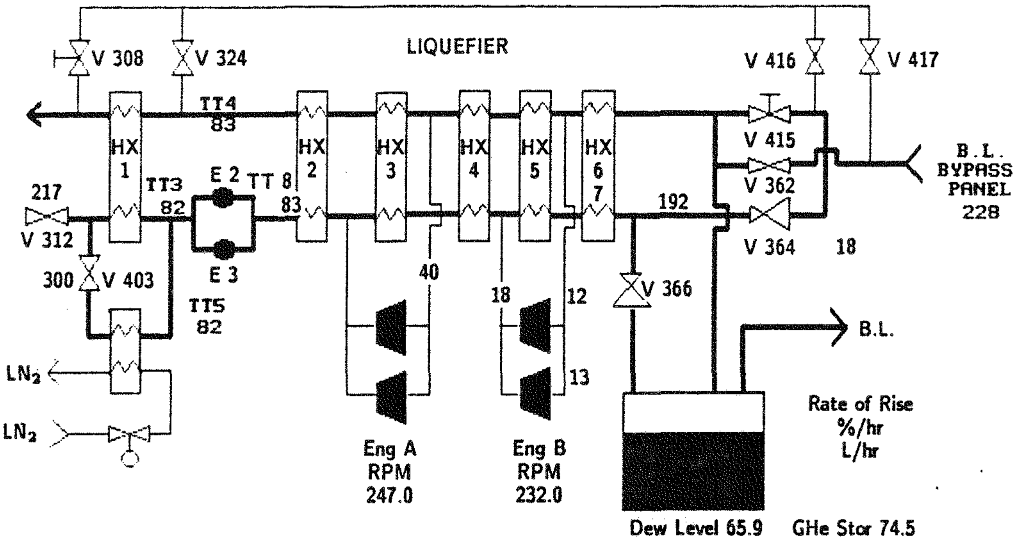

Fig. 4. Typical subsystem detail graphics template.

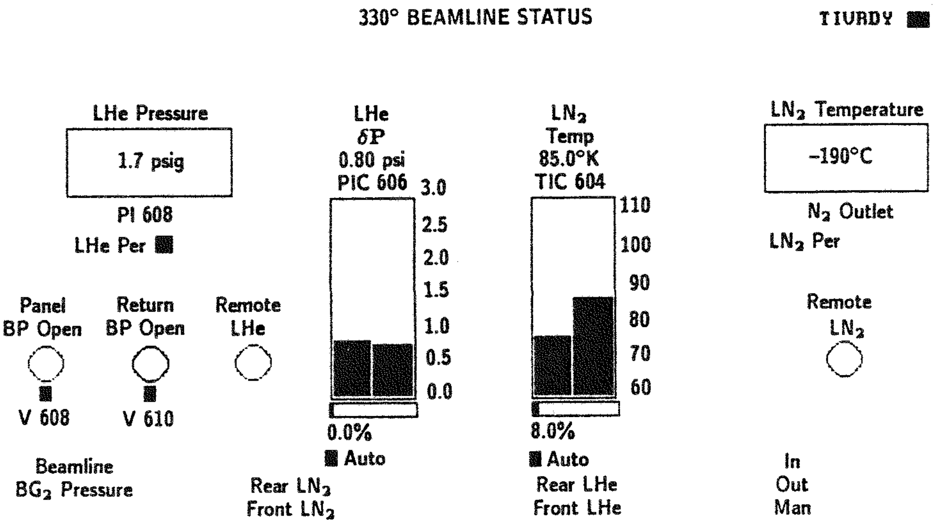

Fig. 5. Graphics simulation of hardwired control panel.