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AUTOMATION OF A CRYOGENIC FACILITY BY COMMERCIAL PROCESS CONTROL COMPUTER*

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INTRODUCTION

To insure that Brookhaven's superconducting magnets are reliable and their field quality meets accelerator requirements, each magnet is pre-tested at operating conditions after construction. MAGCOOL, the production magnet test facility, was designed to perform these tests, having the capacity to test ten magnets per five five day week. This paper describes the control aspects of MAGCOOL and the advantages afforded the designers by the implementation of a commercial process control computer system.

Magcool Description

The magnet test facility is more complex than most cryogenic systems. It has all the conventional components (compressors, purifiers, cold boxes) plus complicated supply and return headers that permit as many as five superconducting magnets to be cycled through cooldown, test and warmup steps asynchronously.

Figure 1 shows a simplified process flow schematic of the system. A normal magnet testing cycle consists of five functional steps. They are:

Pump and Purge - replaces air in magnet with purified helium
Cooldown 1 - cools magnet from room temperature to 90 K
Cooldown 2 - cools magnet from 90 K to 10 K
Test and Measure - magnet cooled to 3.9 K, quenched and field measured.
Warmup - Magnet warmed to room temperature

*Work performed under the auspices of the U.S. Department of Energy.

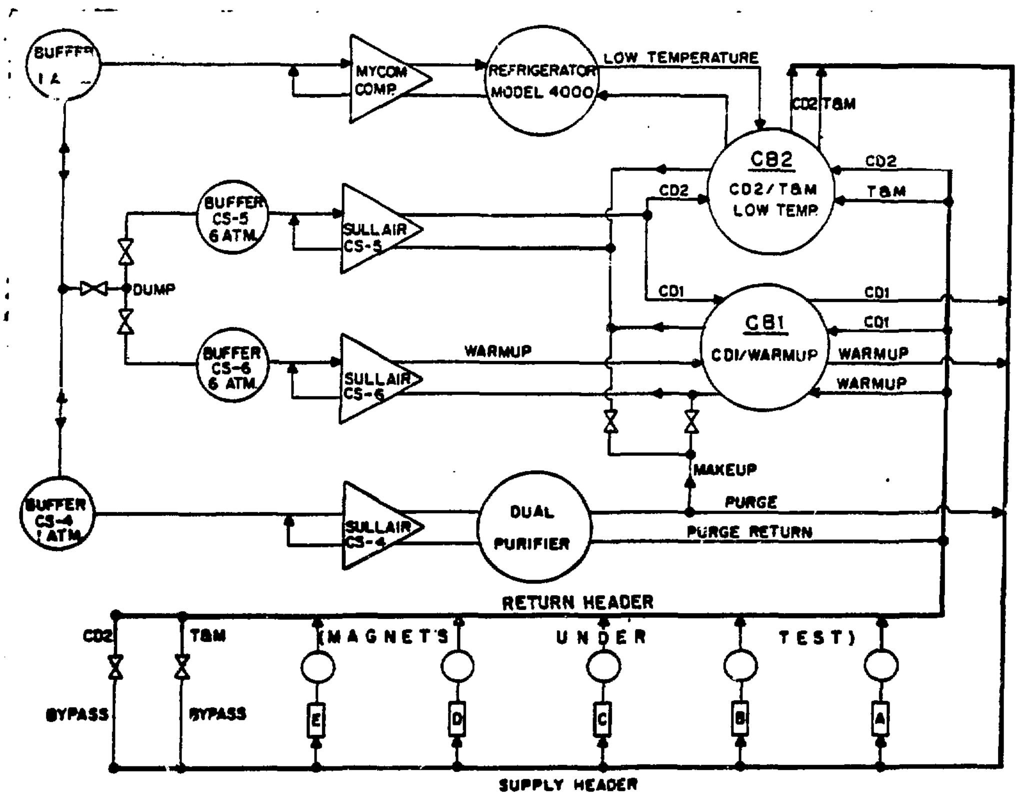

Fig. 1. Simplified MAGCOCL Process Flow.

Cold Box 1 (CB1) contains heat exchangers to perform cooldown 1 and warmup tasks. Cold Box 2 (CB2) contains the precooler/subcooler and heat exchangers for cooldown 2 and the subcooled helium test and measure functions. Supply and return headers consist of a group of parallel transfer lines plus over one hundred stop and control valves that permit a magnet in any test stand to be connected to selected hardware so that the load can be cycled through the five functional test steps. Process I/O consists of a total of over 350 points which include 30 analog outputs used for direct digital closed loop control. Liquid nitrogen shielding is used to reduce heat leak to the portion of the system that operates at or below liquid helium temperature.

Instrumentation and Control Philosophy

Unlike most cryogenic systems which go through a series of steps to get to operating conditions, many of MAGCOOL's functions are continually dynamic and parallel in nature. During the early design stages of the system it was clear that control would be difficult and would require at least two, probably three operators per shift if the usual analog panel approach was used. Operator error was a worry because with five magnets cycling through five functions in five test stands many tens of valves would have to be manipulated on a per shift basis. At best, errors would only lose time but some process variables have strict operational limits that set magnet maximum cooldown and warmup rates to keep internal stress within safe limits. Clearly, a computer based control system that could protect the magnets from operator error and over stress would be beneficial. The decision was made to minimize operator intervention, reduce operatore error and manpower requirements by totally automating the system. The philosophy was extended by designing MAGCOOL instrumentation to inter-specifically to computer I/O and to rely on the digital system to all control, alarming and logic sequencing without aid of analog meters or controls except where they were embedded as part of commercial auxiliary equipment.

Buy or Build

There is always a temptation when embarking on a project such as MAGCOOL to buy a digital processor, color CRT and I/O cards from suppliers and construct one's own system. In theory, the designer has the option to add "state-of-the-art" features such as fast data highways, distributed microprocessors and extended graphic packages to tailor the electronics to the exact needs of the process system. An alternative approach is to purchase a commercially supplied process control computer system and modify it, where necessary, for cryogenic control. The advantages realized by this approach are:

1. A commercial process system should be a bug-free field-proven product. A mature system, the design a result of many iterations.

2. The process engineer can concentrate on cryogenic application software and not be burdened with hardware and software systems development.

3. Implementing a commercial system will, in the end, be less expensive than constructing a custom system in-house.

4. Probably most important, software and hardware system documentation and support is the responsibility of the supplier, not the users.

Approximately fifteen manufacturer's quotes were evaluated and surprisingly almost all could furnish systems useable for cyrogenic control tasks. The only cryogenic process variable that presented problems was high accuracy temperature measurement, solved by interfacing our own microprocessor to the system via a 20 ma serial communication loop. Commercial system architecture ranged from the very simple to distributed processors using peer to peer local area network communications. Anaconda Advanced Technology's CRISP system was selected.

System Description

Hardware consists of a 256 kilobyte PDP 11/34 floating point processor, LA 120 printer, dual hard discs, appropriate I/O hardware and a high resolution 80 character by 48 line color graphics terminal. Two cabinets of I/O gear are electrically separated from the processor by use of opto isolated buss drivers. D.E.C.'s RSX-11M monitor was supplied which is a powerful multiprogramming operating system ideally suited for real time control applications.

For application programming Anatec's CRISP high level process control language was provided. The process engineer uses CRISP to declare I/O points, perform logic, arithmetic, timing and counting operations and program closed loop DDC control strategies. All application software is resident in battery backed memory to protect from power or disc failure. The operator interface consists of the color graphics terminal upon which piping schematics, process variables, loop controllers, system trends and alarms are dynamically displayed in a paged format (Fig. 2). All CRT pages are easily built from the operator's keyboard by use of a menu of standard process or user configured symbols. Screen dynamic variables are linked to the CRISP data base to provide automatic refresh every 600 ms. Existing displays can be modified or additional CRT pages can be constructed on line. The number of CRT pages is only limited by available disc space.

Control System Organization

CRISP furnishes all the necessary tools but it is up to the designer to mould these features into a control system that the operator will accept and feel comfortable with. The operator must not become frustrated or intimidated while trying to interact with the process through the keyboard.

Control system design was divided into operator systems and application software. Operator systems included display design, alarm routines and deciding what convenience should be furnished

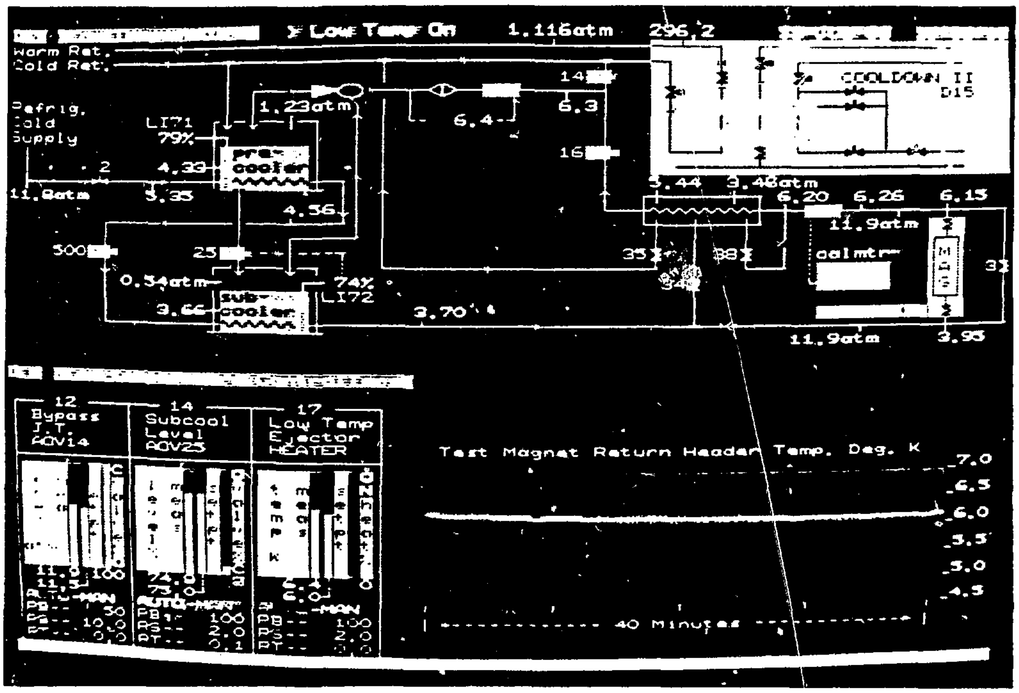

Fig. 2. Typical CRT Display.

to the operator so that he has flexibility while keeping the system safe from error. Application software, which was divided between utility and functional CRISP subroutines, proved to be the easier of the two tasks. Utility programs sequence and control compressors and purifiers, and perform gas handling duties which the operator has to initiate to get started but thereafter rarely looks at. Functional subroutines program the magnets through their five test stages.

To minimize intervention, the operator only has to start and stop the various functional subroutines to step the magnets through their test cycles. Figure 3 shows the magnet test stand function control CRT page. Software interlocks prevent out of sequence or other test stand tasks from being activated. Once the subroutine is installed, all valves and controllers are automatically initiated and sequence through to the completion of the functional step. When warmup is done the subroutine turns itself off and automatically puts the magnet into a safe depressurized install-remove state.

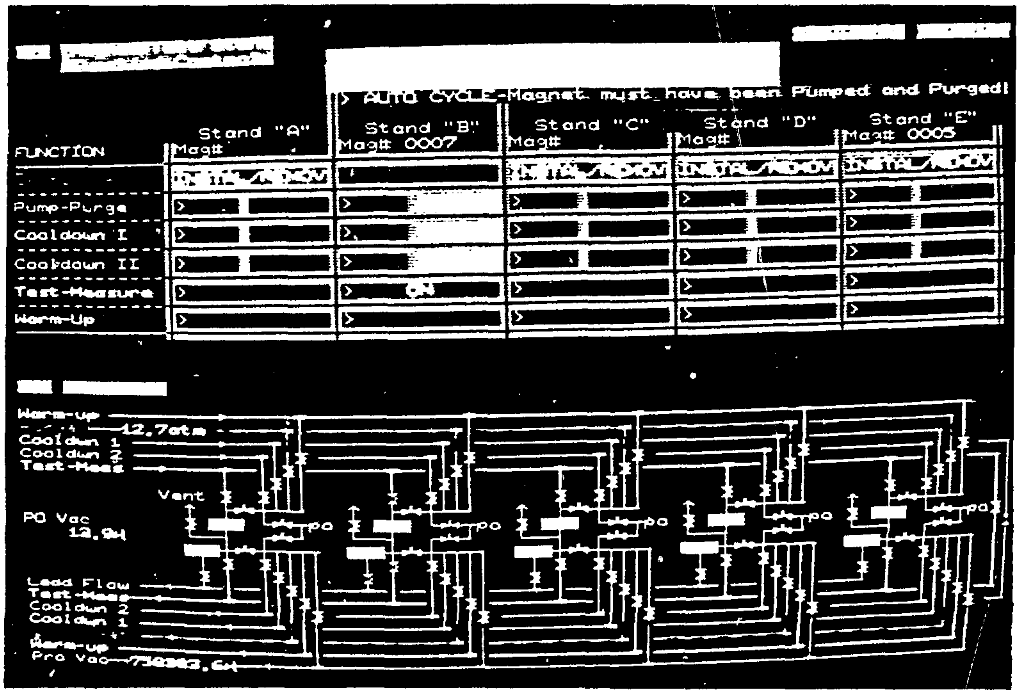

Fig. 3. Test Stand Function Control Page.

If problems with hardware or software arise, the operator has the option to abort automatic and go to semiautomatic or full manual control. However, the system is so logically complex that this feature is rarely used. Time can be better spent by going off line, debugging in the manual mode, repairing the problem and coming back on line in automatic. Comments were heavily used throughout source code programming to aid in understanding the logic at some future time. CRISP logic and graphic displays took one man-year to complete. Of the total, four man-months were devoted to applications programming and the remainder spent on CRT display and operator system interface design.

Operating History

The control system was programmed and connected to MAGCOOL hardware during mechanical installation. Software was debugged by turning off computer I/O scan and setting dummy process variables from the operator's keyboard.

MAGCOOL was brought on line last February. Compressor controls, gas management and purifier reactivation utility programs worked as expected with only minor PID control loop parameters needing adjustment. A day later a test magnet was pumped and purged and started into cooldown 1. Even though cooldown 1 is logically very complex and difficult to control, CRISP performed beyond expectations. Basically, all software and hardware of the remaining functions executed equally well with only a few minor changes that were accomplished on line. The system not only worked but exceeded expectations on the first try.

Summary

To date over ten magnet test cycles have been programmed through "MAGCOOL". The system has seen a few power and hardware failures plus some leaking valves but is flexible enough in design to absorb problems and continue to perform. Operators now prefer the CRT and keyboard to the analog panel and want to know more of the details of programming the system.

While many control engineers will argue that abandoning analog black boxes in favor of digital control is risky, MAGCOOL's operating record has shown that operator error has been sharply reduced, one man operates the entire system and a vast improvement in magnet test cycle time has been realized as compared to our older analog system which performs the same tasks on a single magnet.

Using a commercially available process control computer system for cryogenic control can save time, manpower and money; all steps in the right direction.