CONTROL OF THE TEVATRON SATELLITE REFRIGERATION SYSTEM

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INTRODUCTION

The six kilometer ring of superconducting magnets which forms the Fermilab Tevatron is cooled by a Central Helium Liquifier (CHL) which provides liquid helium (and nitrogen) to 24 satellite refrigerators distributed around the ring.[1] The system is controlled by 31 independent microprocessors operating over 400 servo loops. The central computer system provides monitoring, alarms, logging and changing of parameters.

DESCRIPTION OF CONTROL SYSTEM

The satellite refrigerators are designed to operate as independent entities without attending personnel. Accordingly, it is appropriate to have distributed local control and monitoring, and also to provide remote monitoring and control capability for central operations personnel.

Local control is achieved by means of 24 individual self-cycling microprocessor systems which allow automatic local operation of each refrigerator.[2] This includes operation of 14 control loops, each consisting of a controlled variable (temperature or pressure at a given point) and a process variable (valve position or engine speed). In addition, there are a number of other monitoring points giving a total capability of 112 digitized analog signals and 64 bits of digital status. For the Tevatron refrigerator system, this capability

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* Operated by Universities Reasearch Association, Inc. under contract with the U.S. Department of Energy

is comparable to the total number of monitor points for the entire 400 GeV conventional accelerator.

The intelligence to control each satellite is provided in an Intel standard multibus chassis. The microcomputer, memory expansion, and ADC/DAC board are commercially available units modified to this specific system. Also resident in the chassis are Fermilab designed actuator driver boards, a digital status and control board, and temperature resistor interface boards. Communications with the host computer system is accomplished with a CAMAC 080 (PIO/CMA Interface) module through a high speed link running around the ring.

INSTRUMENTATION

Nearly all of the refrigerator instrumentation is sent back through the local microprocessor and data link to the central host computer for monitoring, alarming, and data logging capabilities. Each refrigerator has 64 analog to digital (A/D) channels, 48 resistor thermometer channels and 64 digital status bits. Battery backup circuits allows for system monitoring for up to four hours in the event of a power failure. The A/D channels enable pressure, flow, temperature, and gas analysis measurements throughout the system.

Pressure Measurement

Pressures and differential pressures throughout the system are measured using a capacitance type transducer manufactured by Setra Systems, Inc. High accuracy models are used to measure pressures in the 300K helium process stream in the compressor buildings. Errors in these readings could result in suction and discharge pressure oscillations due to compressor buildings regulating each other.

Flow Measurement

Flow rate measurements are made with venturi or orifice plate flow meters with differential pressure transducers for remote readout. Orifice plate flow meters are used exclusively for warm gas measurement while liquid helium flows are measured with venturi flow meters.

Remote readout of warm gas flowmeters allows operators to continuously monitor the refrigerator, compressor, and storage flows in order to: Calculate liquefaction rates, detect high helium losses, detect poorly tuned refrigerators, calculate refrigerator loads, and detect low compressor throughput due to suction strainer plugging.

Temperature Measurement

Temperatures throughout the heat exchanger and magnet strings are measured by vapor pressure thermometers, carbon and platinum resistor thermometers. Vapor pressure thermometers (VPT) consist of a cold volume within the flow stream with a capillary tube leading out to a pressure transducer. The VPT volume is charged with an appropriate gas for the expected temperature. Vapor pressure curve fits can then be used to convert to temperature. A backup VPT was installed at the locations used as control points. VPT's can be very accurate, although the range is quite limited.

Carbon resistors[3] are used to measure the magnet single phase temperature every 30 meters. Each Allen Bradley 1/8 watt, 18 ohm resistor was individually calibrated at temperatures between liquid helium and room temperature. The resulting data was curve fitted to assure an accurate magnet temperature profile. A backup resistor was installed at each location.

Platinum resistors by Lakeshore Cryotronics are used to measure temperatures between room temperature and 50 K. They offer the advantage of having a linear response over this range.

Compressor cooling water and oil temperatures are measured with National Semiconductor's LM-135. Encapsulated in epoxy, they offer a simple and reliable means of measuring the temperatures of these fluids.

Gas Analysis

Online gas analysis equipment is used to monitor helium gas purity. This equipment is used during system purification as well as normal operation to detect system problems. Contaminants being monitored include water vapor, nitrogen and oil mist.

Water vapor is continually monitored by Panametrics Model 600 dewpoint analyzers. Gow-Mac thermal conductivity cells analyze for nitrogen between 50 and 500 ppm. Low levels of nitrogen (0-50 ppm) are monitored by an inhouse-built arc cell. Oil mist is monitored downstream of the screw compressors and oil removal system by a PPM Inc Model C 20 A.

CONTROL VALVES

Each refrigerator has twelve electric actuated flow control valves. Each compressor building has one such valve, and BØ has three additional valves which are used for inventory control. The cryogenic valves used in the system are inhouse designed bellows valves. Valve plug flow characteristics differ by function within the system from linear to three orders of magnitude equal percentage.

The latter is necessary to allow adequate regulation of helium flow in the gas or liquid phase.

Two different 24 volt electric actuators are used throughout the system. A Barber Coleman actuator is used within the accelerator tunnel. The design of this actuator suited the space and radiation constaints within the tunnel. A less expensive, inhouse modified Industrial Devices Corp. actuator was used in the other locations.

Each actuator has a 1.4 cm stroke and a LVDT position readback. Seating force for most of the actuators is 890N. Some of the Industrial Devices Corp. actuators were modified to allow 1780N which was necessary to seal a high pressure valve. Control of the actuators can be done locally, remotely, or automatically via the microprocessor control loop software.

EXPANSION ENGINE CONTROLLERS

For an expansion engine to achieve a specified flow of gas or liquid for cooling, its speed must be controlled by an external source.[5] The expansion engine drive is a speed regulated dc motor which acts as either a source of power of a load to the engine. The liquid expander incorporates a 2 hp motor/generator while the larger 30 K gas expander uses a 7.5 hp motor/generator. Each motor can be operated between 200 and 1800 rpm. External cooling fans were added to the motors to prevent overheating at low rpm.

Each motor/generator has its own electronics package for motor regulation. The liquid expander motor is regulated by a General Electric 6 VHR Statotrol regenerative drive. A General Electric 6V7F3229 speed variator is used to regulate the gas expander motor. Each engine controller incorporates safety interlocks to shut the engine down in case of a malfunction to provide personnel safety. It also provides local and remote readouts for motor speed and power as well as status data. The controllers have been interfaced to the microprocessors to allow regulation of refrigerator temperature or pressure.

CONTROL LOOPS

Each refrigerator has 12 active microprocessor based control loops which tune the refrigerator to one of its four operating modes: satellite, liquefier, refrigerator, and stand-by. Two additional control loops are incorporated during magnet cooldown. Each compressor building has nine active control loops. Three additional loops are used for inventory control. A maximum of 20 control loops are available in each compressor and refrigerator microprocessor. Spare control loops are often used during specialized operations such as heat exchanger derime, magnet warmup, and mobile purifier operation.

Each control loop can operate as an open or a closed loop.[6] Closed control loops are of the Proportional - Integral - Derivative (PID) gain type. Input variables (either a pressure or temperature within the system) can be manually changed upon failure of the primary device.

Sample times for the control loops were first chosen to be 20% or less of the involved time constant. Further tuning of the various gains is being performed with the aid of a data logger and real time plotter. Choosing gains has been a difficult task since gains optimized for steady state operation are often not appropriate for upset conditions, such as turning on or off the magnet ramp.

Software has been written to allow control loops to be controlled by a higher level program. This program can activate or inactivate control loops, change set points and various output variable constraints. Programs of this type have been written for automatic magnet cooldown, fast magnet quench recovery, and compressor suction regulation.

CONCLUSION

Now that the Fermilab Tevatron accelerator system is operational, more control loop work will be required to optimize the refrigeration system. As higher energy levels are reached in the accelerator, stable refrigerator operation will be required at near design level capacities. Optimizing the refrigerator control loops and quench recovery scheme will help minimize the accelerator down time.

REFERENCES

1. J. Theilacker, et al., in: "Advances in Cryo. Engr., Vol. 29," : Plenum Press, New York (1984).
2. J.R. Zagel, et al., IEEE Trans. on Nuc. Sci. NS-28:2153 (1981)
3. M. Kuchnir, in: "Advances in Cryo. Engr., Vol 29," Plenium Press, New York (1984)
4. J. Theilacker, et al., IEEE Trans. on Nuc. Sci. NS-28:3257 (1981).
5. G. Mulholland, et al., A Report on the A-Sector Test Cryogenic Experience of the Fermi National Accelerator Laboratory Superconducting Accelerator, Fermi TM 1130, Aug (1982)
6. M. Martin, et al., IEEE Trans. on Nuc. Sci., NS-28:3251 91981).