Experience with the TRIUMF Main Tank Vacuum Control System

S. Sarkar†, J.C. Yandon, W. Sievers, P. Bennett, D.P. Gurd†, P. Harmer, J. Nelson.
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada. V6T 2A3.

Abstract

The TRIUMF Main Tank Vacuum Control System was upgraded in 1984. The earlier system, which consisted of a collection of hardwired relay logic boxes housed in three standard instrumentation racks, was replaced with a compact and flexible microprocessor-based control system. The user interface, previously distributed over the three racks, was consolidated into a single hardwired control and mimic panel. Since 1984, the Main Tank Vacuum System has undergone a series of changes in configuration and vacuum pumping hardware with necessary changes being implemented in the control system logic. Corresponding changes to the user interface were sometimes difficult to implement and in time exhausted the spare input / output capacity which had been built in to the panel. The availability of inexpensive personal computers with adequate graphics capability and the ease of modifying, or adding to a programmable user interface precipitated the retirement of the hardwired panel and its replacement by a PC-based graphics user interface. System configuration, safety considerations, the hardware and the software implementation using the 'C' programming language are described. The evolution of the control system and its performance, both over the years and in adapting to the vacuum system changes, are discussed.

I. INTRODUCTION

The TRIUMF Main Tank Vacuum System (MTVS) pumps the cyclotron vacuum tank from atmospheric pressure to an operating pressure of $4*10^{-8}$ torr [1]. The pressure is measured in the range from 760 to 10^{-3} torr by broad range Pirani gauges and in the range from 10^{-3} torr to 10^{-8} torr by broad range ionization gauges. The pumping system is composed of a number of pump groups, shown schematically in figure 1. Each group is a sub-system consisting of pumps, valves, vacuum gauges and pump condition indications.

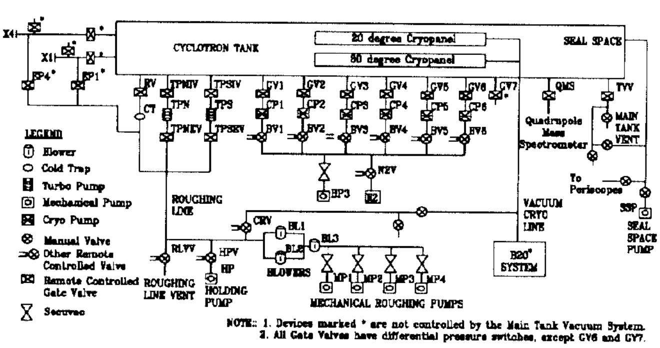

Figure 1: The TRIUMF Main Tank Vacuum System

The mechanical pumps (MP1-4) and Rootes blowers (BL1-3) reduce the pressure from atmosphere to 10^{-1} torr. The turbo pumps (TPN and TPS) further reduce the pressure to 10^{-3} torr. The cryogenic pumping system, consisting of six cryo pumps (CP1-6) and two cryo panels, brings about the final reduction in pressure to $4*10^{-8}$ torr.

The pumps operate efficiently over limited but overlapping ranges of pressures and are used in stages, to pump down the cyclotron tank from atmospheric pressure. Inadvertent operation with out of range, fore or backing, pressures can cause pump damage or contamination of the vacuum system. Pressure measurements are used to monitor the operation of the vacuum system and to provide interlock setpoints for the safe operation of the pumps. Temperature measurements are used to monitor the operation of the cryo systems and utilize RTDs, thermocouples and hydrogen bulbs. Auxiliary devices such as the holding pump, the seal space pump and the N_2 purge system are used to maintain backing vacuum, to maintain tank seal at low pressure and to regenerate the auxiliary cryo pumps respectively.

Prior to 1984 the function of providing system status information and protective device operation interlocks for the MTVS devices was implemented by in-house built, relay-based logic boxes. Commercial gauge controllers and readout controllers used for pressure and temperature measurements usually provided a single mechanical set point contact closure for use in the interlock logic. All of these boxes were distributed over three standard relay racks. Interlock logic was determined in part by the logic boxes, in part by the point-to-point wiring of control signals between boxes at the rear of the racks and in a small number of cases by an operator forming a part of the loop. Though only simple interlocks could be implemented with the relay logic, verification, documentation, addition and change of logic were cumbersome processes. System operation was through control switches and status indicators on the boxes spread over the three racks.

The control system was upgraded in 1984 to address the limitations of the earlier system. A concurrent goal was to produce a compact, generic vacuum control system design to eliminate the need to individually 'engineer' controls for the various beamlines' vacuum systems at TRIUMF. A relatively compact control system would allow the inclusion in centralized controls of devices previously left with independent manual controls and local readouts only, due to limits in the rack space allocated to vacuum system controls.

II. CONTROL SYSTEM

The use of a microprocessor based architecture for interlock controls and the use of 'C' as the programming language for these processors were both new at TRIUMF in 1983, though it has been commonly used since.

† Presently at SSC Laboratory, 2550 Beckleymeade Ave., Dallas, TX., 75237.

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Considerations of safe operation of a microprocessor based Main Tank Vacuum Control System (MTVCS) were addressed: by specifying the use of hardwired first level protection of all devices with potential for major damage - such as the use of differential pressure switches to interlock all Cyclotron Tank gate valves, and by requiring the MTVCS microprocessors to re-evaluate MTVS interlocks and regenerate all device operation permissives quicker than every 200 mSec.

Figure 2 is a block diagram of the MTVCS as it stands today. Two TRIMAC [2] 8085 based CAMAC Auxiliary Crate Controllers (ACCs) were used for control of the MTVS based on an estimate of the number of analog and digital points to be monitored and controlled, the update rate requirements specified above and expected system growth. The two TRIMACs were functionally partitioned to handle analog signal

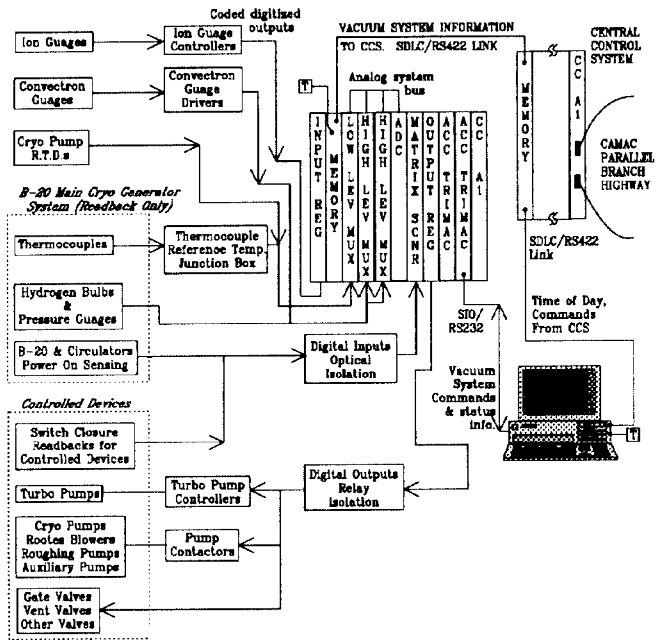

Figure 2: Main Tank Vacuum Control System Block Diagram.

processing and to carry out digital I/O and control operations. Communications between the Trimacs is via a shared (reflective) memory also accessible to the TRIUMF Central Control System (CCS). This allowed monitoring of vacuum control system and for remote operations described later.

A. Hardware

Features which make this system robust, compact and flexible, allowing generic application, are the use of a matrix scanner with opto-isolation (instead of relays) for inputs and the use of a general purpose analog input system.

High density (large number of I/O points per crate) was achieved by using single slot form factor Joerger Quad (24 bit) output registers and GEC Canada 256 (upgradeable to 512) point matrix scanner for digital output and input respectively.

The matrix scanner is itself a Z-80 microprocessor based module which provides features useful for interlock control systems. Input debounce processing, logic sense and masking are each software selectable on a per point basis. Further the (A) CC can read instantaneous point status, be interrupted (LAM) or polled (test LAM) for time tagged point status changes, read from a queue of time tagged point status changes or a mix of these modes under software control. These facilities have many implications for interlock system implication one of which is the use of time tagged point status information for diagnostics and trending in large systems.

Analog signals were interfaced using the Quantrol ADC and MUX system which can handle a maximum of 256 analog channels and can interface to a range of analog signals with integral first line signal conditioning. Signal conversion and linearization were done in software. Together this reduced the need to use various external boxes to interface and 'linearize' the different analog inputs.

B. Software

Prior to 1984 existing microprocessor-based systems at TRIUMF were programmed in assembly language. Migration to higher level languages such as FORTRAN was being explored. 'C' with its' rich set of bit manipulation primitives was a natural choice for the implementation of interlock control systems. The 'C' preprocessor allowed specification of interlock logic in an english like, human readable form which were easy to understand and modify. The facility for data structures and pointers allowed for the generation of software routines useable for classes of devices. Structures provide the natural grouping of related information while pointers associated with these structures allow easy manipulation of these related information eg. a device analog pressure has associated with it the type of gauge used, linearization and data conversion information, physical location, set points and associated units.

The Digital TRIMAC program was structured such that by changing Camac configuration data, by generating English language equivalents for device state information (utilizing preprocessor directives) and by using these equivalent statements in interlock logic specification the program could be easily 'ported' to control other vacuum systems.

In the Analog TRIMAC an ASCII file was used to define all analog channels to be scanned by the system and to specify channel details such as conversion factors, units, filtering to be done on the raw signal. Changes to the analog system required only this file to be updated. The Analog TRIMAC program was translated in to FORTRAN to deal with early version 'C' compiler problems. The natural device structuring possible in 'C' was unimplementable in the FORTRAN version. Subsequent updates to the Analog TRIMAC program entailed changes to multiple tables and keeping track of table data relationships.

III. USER INTERFACE

A generic (vacuum) interlock control system design capable of supporting configuration changes requires a soft or reconfigurable user interface. Intended implementation target, a low cost 'Personal Computer' (PC), with adequate graphics display resolution, would run tasks to receive system status information from the TRIMAC ACC, generate & update graphics display and send vacuum system control commands merged from keyboard and mouse to the TRIMAC ACC for execution.

In 1983 an established PC meeting the above requirements was unavailable. User acceptance of the soft user interface concept was low.

A. local Interface

Initial user interface was implemented using a conventional hardwired mimic and control panel. The Main tank vacuum system devices were drawn on the panel with multiple LEDs used to indicate status of the device. Push buttons placed in proximity were used for device control functions. Spare buttons and LEDs had been added to the panel to cope with vacuum system additions and changes. These were able to carry through for a number of years but changes or additions were usually difficult since to the control system were made difficult due to the need to

By 1987 the hardwired display had been in service for 3 years and was out of space for additions. Reliability was low due to mechanical wear out. Modifications were becoming costly. A backup panel was estimated to cost $5K and at this time it was cheaper to implement a PC based user interface. The user interface was replaced in 1988 with a 'soft' interface consisting of IBM PC/XT with a floppy disk and a EGA display. The hardwired panel, retained as backup only, was removed in 1989.

B. Remote Operation

The MTVCS was designed with remote operations capability with commands / status communications from and to the CCS via a shared CAMAC memory. This feature has been used to date only for remote monitoring of the system. The importance of this feature was for addressing the design goal of a generic vacuum control system design capable of addressing all vacuum systems at TRIUMF. In particular the secondary channel controls require centralized vacuum system controls because of shared pumping system but require distributed operator controls or consoles at each of the channel operational areas. The remote vacuum system control commands were to be funneled in to the MTVCS via the CCS. This would be useful in cases such as secondary channel controls were 'soft' user interfaces at the various counting room locations could control beam line vacuum system devices by communicating with the CCS computer to send information to this control memory allowing independent control stations for a central vacuum control system.

IV. IMPLEMENTATION

The entire system was implemented in 1.2 years elapsed time with 4 man-years of effort. This included 1 man year spent in verifying existing system and making bridge connectors to allow upgrading of system with minimum disruption of operation. Software effort totaled about 6 man-months equally divided among software design, development and coding.

There were initial teething problems with the early 'C' compilers available. The situation improved in time, with the availability of stable and relatively complete implementations of the 'C' language cross-compilers for the Intel 8085 processor running under DOS on an IBM PC.

V. SYSTEM UPGRADES

Initially the Main Tank Vacuum System utilized 5 diffusion pumps along with associated liquid nitrogen (LN2) cold traps to maintain operating vacuum. The diffusion pumps and LN_2 traps were replaced one at a time by cryo pumps, an additional turbo pump was added and the Roughing system pumping configuration was changed in a series of upgrades.

Hardware and Software changes to the control system associated with the above upgrades required on average 1~2 man-months of effort spread over 3 months of which the software component was typically 15-20 man days. The system has proven very flexible. Minor additions and changes are made routinely and easily.

The Soft user interface initially programmed in BASIC was later converted to 'C'.

VI. CONCLUSION

We started out with the goal of providing a flexible and compact control system. The MTVCS has been able to provide an interlock and control system for 256 input and 182 output points for a cost of about $27000, including additional cabling costs required because the vacuum system was being upgraded. It has worked well since 1984 and has been able to adapt to a changing system with relative ease and with little additional expenditure. The Rad Hard valve controls and the Extraction Probes housing vacuum controls for beamline 1 and beamline 4 were incorporated using two TRIMACs and a few I/O modules housed in the same CAMAC crate. In 1991 control programs for the Rad Hard valves and the Extraction Probes were transferred to the MTVCS digital TRIMAC. The current system utilizes one and a half racks including space for some gauge controllers. In the nine years of operation the system has proven highly reliable.

VII. ACKNOWLEDGEMENTS

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