VACUUM CONTROL SYSTEMS AT THE NAC CYCLOTRONS

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Summary. A modular microprocessor-based system being used for control of the vacuum pumping stations at the NAC cyclotrons[1] is described. The microcomputer-system consists of a set of Euro-card sized modules plugged into a bussed back-plane. The set may typically consist of (i) the processor module containing a Z80 CPU running under the CP/M 2.2 operating system, 64 kbytes of RAM, timer and peripheral ICs; (2) a 128-kbyte bubble memory module containing the compiled software; (3) a number of 32-bit relay output modules for driving contacters for vacuum valves and pumps; (4) a number of 80-bit opto-isolator input modules for reading the binary status of valve position limit-switches, binary setpoints from pressure-, temperature-, waterflow- and rotational-speed transducers as well as digital data from vacuum meters; (5) a 32-channel eight-bit analogue-to-digital converter module for digitizing analogue voltages from vacuum and temperature gauges; (6) an interface module for bi-directional data transfer to a CAMAC mailbox memory module for communication with the central control computers as well as for data transfer between the vacuum control system's front-panel and the processor and (7) front-panel modules.

System Philosophy

During the commissioning of the vacuum control system of the solid-pole injector cyclotron in 1981, it became apparent that we should standardize on general programmable hardware suitable for all subsequent vacuum control stations.

Modifications to interlock relations and control procedures for a system which are implemented in terms of discrete electronic components are inconvenient, time-consuming and costly compared to equivalent changes in software, while retaining the hardware unaltered for a microprocessor-based system. For this purpose we developed modular microprocessor-based systems for controlling, amongst others, the different vacuum pumping stations of the cyclotron facility.

Ease of maintenance is also achieved since we are using eight identical hardware systems with interchangeable modules and thus need to stock fewer spare modules and parts.

System Description

The hardware system is based on a nationally defined 64-line signal bus, viz. SABUS. All of the modules were designed and manufactured in-house, specifically for local control of stand-alone systems of the cyclotron facility.

Relay Output Module:

The 32-bit relay output module consists of four 8-bit latches (74LS374) driving 5 V DIL reed relays with normally-open contacts. The relay contacts connect via PC-board headers and flat ribbon connectors to backpanel connectors and cable to larger relays and contacters for activating a vacuum pump or valve upon closure of the contact. Using flat ribbon cable and connectors compared to individual wiring simplifies the assembly of a system and is time-saving. On the module the output from a retriggerable one-shot, with 0.2 second time-out, is used to enable the tri-state output from the latches. The one-shot which is triggered each time a latch on that module is addressed, acts as a watchdog timer ensuring that the program must update data on the module at least every 0.2 seconds, otherwise the pumps and/or valves controlled by that module, are deactivated and revert to their normally safe state i.e. pumps switched off and valves closed. This watchdog timer and usage of normally-open relay contacts which must be actively closed to switch a pump on or open a valve, act as fail-safe precautions.

Opto-isolator Input Module.

The 80-bit input module contains 40 dual opto-isolators (MCT6). The opto-isolators' transistor outputs are multiplexed byte-wide to an input gate on the data bus. The forward diodes require an input current of 10 mA per input. This is being sourced by an internal 24V dc power supply and limiting resistors. The inputs are divided into four groups of 20 each. Each group connects via a PC-board header and ribbon cable to the back-panel connector. From the backpanel, cables connect to the different input sources, such as the 'open' and 'closed' position limit-switches of each vacuum valve; the contacts indicating the binary setpoint status for pressures, temperatures, water-flow and turbo-pump rotational speed; interlocking outputs from other systems as well as digital output from vacuum meter gauges. Since the transfer frequency of the opto-isolators is 150 kHz, sufficient wait states are introduced in the program by the module when data are read from it to ensure that valid stationary data are read.

A-to-D Module.

The 32-channel analogue-to-digital converter module uses two ADC0816 ICs. It is used in the mode to convert 5V unipolar input voltages from vacuum meters to 8-bit digital values with conversion times of the order of 100 microseconds per channel. In the program module for the analogue vacuum gauges, the 8-bit digitized value is used as index into a lookup table. The lookup table consists of 256 sixteen-bit integers. For each integer element in the table, representing a pressure value, the first byte contains the BCD representation of the two digit mantissa, while the second byte contains the BCD representation of the exponent and its sign. The lookup table was generated by interpolation from the calibration curve data supplied by the manufacturers of the vacuum meters. Digitizing and converting the 32 analogue voltages to floating point pressure values takes less than 10 milliseconds.

Since each of the binary inputs or outputs or analogue inputs is identified in terms of its address, a cross-reference file is used in the software to relate a variable by name to its address in the micro. This is convenient when actual wiring of the physical variable to the control system is done, since correct address specification can be tested once wiring is completed.

Interface Module

This SABUS module interfaces the SABUS microcomputer and the CAMAC 3885 bus for connecting to the CAMAC Auxiliary Crate Controller and the CAMAC mailbox memory module, by means of which communication is provided between the SABUS CPU and the CAMAC system, used as network for the central control computers of the facility.

The module also has a parallel bus interfacing the SABUS microcomputer to peripherals, such as the local and remote-control mimic panels of a vacuum station. The bus consists of eight bi-directional data lines, three output control signal lines, a write strobe signal line and four status input signal lines. All signal lines are optically isolated from the SABUS power supply and are provided by means of RS-422 drivers and receivers, thus allowing the remote control panel to be in excess of 100 meters away from the local control panel. The module also contains two interrupt controller ICs (Am 9517A) and a real-time clock (MSM 5832). The three control signals are used as address selection code for different registers in the peripherals on the bus, while two of the four status signals are connected to the interrupt controller and used to interrupt the microcomputer when data are available at either the local or remote-control mimic panels in response to an operator activating a key.

Front-panel Modules

These modules are not standard SABUS modules and are specific to the vacuum control system. Each consists of a mother PC board containing the RS-422 drivers and receivers to interface to the parallel bus described above, 2 kbytes of RAM (HM 6116), 16 byte-wide latches and LED driver circuitry for the data to be displayed, a 32-character alpha-numeric display (NSM 1416) and a 20-character keypad with keyboard encoder.

The four daughter PC boards are the only ones which differ from one vacuum control system to another as they are laid out to be specific to suit the mimic panel of the particular system. They contain the numeric displays (up to sixteen 6-digit numeric displays NSA 1198) for pressure/temperature or rotational speed readings and discrete LEDs (up to 256) for indicating the status of pumps, valves and setpoints.

The data to be displayed are transferred from the SABUS to the 2 k RAM and thereafter continuously clocked out of the memory to the latches, in groups of sixteen bytes, and the appropriate LED driver enabled for a 2-millisecond display time while the clock is stopped. The eight outputs of a latch are connected on a one-to-one basis via current-limiting resistors to the eight display segments (a,b,c,d,e,f,DP) of a common-cathode numeric display NSA 1198. The corresponding digit pins of the 16 numeric displays are connected in common to the emitter of the power transistor switched by the one-of-eight selector. This is repeated for 6 of the digits on the displays. Each of the other two-digit selectors is connected to the cathodes of a group of 128 discrete LEDs in common, while the anodes of the LEDs in each group are connected on a one-to-one basis to the outputs from the latches. The seven-segment numeric display and the discrete LEDs can be considered as equivalent to a matrix consisting of 128 rows (16 latches by 8 bits) and 8 columns (digits). In the RAM the four least-significant address bits specify the latch or the number of the numeric display, while the next three address bits specify the digit of the displays, with the two groups of discrete LEDs being the ones with the highest address. Since the time for clocking the data from the RAM to the 16 latches is 32 microseconds, while the display time for each of the 8 digits is 2 milliseconds, one has a display duty cycle of 12.3%. Since no seven-segment decoders for the numeric displays are implemented in the hardware, the codes for generating the seven-segment symbols have to be done in the software and then transferred to the RAM on the display module at the appropriate address. For the 32-character alpha-numeric display 7-bit ASCII code is latched and decoded in the ICs themselves.

A copy of the data transferred to the display memory is kept in the main memory and compared for changes. Only when a change occurs will it be updated.

Since the 256 bytes of memory content is imaged one-to-one upon the array of LEDs, in a way dependent upon the actual physical connection, the software was written to include a cross-reference file specifying the RAM address and bit position of each LED. This provides freedom of choice to the person doing the lay-out for the PC boards.

Software

The software providing the necessary interlocking for the safe and correct operation of the vacuum components as well as the procedures to control them, is programmed in Pascal using a popular Pascal compiler to provide Z80 executable code. Provision is made for manual control of individual vacuum components as well as automatic sequences for evacuating or venting of combinations of sections of the vacuum system by means of interrupt-driven keyboard-initiated operator instructions. When a request is prevented because of an interlock requirement, the appropriate message informing the operator of the nature of the problem is displayed.

Before entering the main program loop the interrupts for keyboard requests from the local and remote control panels and the second and minute pulse trains from the real-time clock are enabled. In the main loop the binary status inputs from the opto-isolator cards are continuously monitored for a change of state, and the relay output latches refreshed to retrigger the watchdog timer, while the A/D inputs are digitized once a second. If a change of state in the binary inputs or a change in the digitized values is detected, all interlocking equations are checked, the appropriate binary status is generated for the relay outputs, and the display is updated, if necessary. If a keyboard interrupt occurs the code is read, analysed and the appropriate action taken, while informing the operator whether his request is being carried out, has succeeded or which particular interlock inhibits its completion.

The system was designed to provide interference-free and fail-safe operation.

References

1. A H Botha et al., Commissioning of the NAC separated-sector cyclotron. This conference.