DISTRIBUTED ENGINEERING CONTROLS FOR THE DELPHI GAS SUPPLY SYSTEM

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1. SYSTEM REQUIREMENTS

The DELPHI detector complex at LEP requires 12 precision gas mixtures. The detector is 100 m underground; a total distance of about 350 m from the gas supply building, which is situated on the surface for safety reasons. On the three separate detector control platforms, flammable gases are metered to and from each chamber channel as a precaution against gas leaks. A total of 12 mixers, 13 distribution systems and 2 regenerating purifiers report to user groups, gas and experimental operators and safety systems (fig. 1).

Fig. 1 The disposition of the DELPHI gas system modules

Because of the multiplicity of the units it was decided from the beginning to standardise design in terms of functional modules. Each module is run and monitored by a microprocessor. Control connections – both "horizontally", between modules of one supply system and its users; and "vertically" between all modules and operators, safety systems etc. – are provided by a Local Area Network. The process controllers themselves are blind, i.e. without monitors and keyboards. Graphics facilities and keyboards are provided by 4 dedicated supervisor stations on the LAN [1,2].

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2. THE COMMAND STRUCTURE

It is of great importance to be able to understand both the nature and the source of commands in complex engineering systems. In a truly distributed control system such as this, commands are issued not only by the operators or a master computer: the modules themselves may issue commands to other modules on their own supply in certain fault conditions.

STRINGLISH is designed to provide both clarity and traceability of commands. Each command is sent as a packet in the format

DESTINATION SOURCE COMMAND VARIABLE VALUE.

Transmission is by strings of ASCII characters separated by blanks; the resulting command is an English sentence which can be directly read on any network monitor, and which can be recorded to form an operating log.

Incoming command strings are unpacked by cutting at the blanks. After checking that the source is authorised, the command, together with the variable and value arguments, is passed via CASE statements to procedures which take the appropriate control action. All programming is in Omegasoft PASCAL.

3. PROCESS CONTROLLERS

The system consists of Mixer, Distributor, Purifier and Supervisor modules. Each is controlled by a dedicated microprocessor and the programs are standardised as far as possible for ease of development and maintenance. Bilateral Manual and Network RUN and STOP controls are provided. When running, the micro records key parameters and tests for values outside their operating range. Small excursions result in warning messages; for large excursions the program stops the module and also stops the other modules on its detector supply.

Each module is designed for the maximum autonomy. The program checks the operating values every few seconds: every 30 minutes the current values are recorded in a dayfile and these are maintained in local memory for 64 hours (which conveniently covers the interval Friday 18h00 to Monday 10h00!).

The micros used are Motorola M6809E type running in the standard G64 bus: typically a process controller consists of the M6809, a network interface card, one ADC and one or two PIA's.

The system has been developed using Utnet, a CERN designed Local Area Network implementation of the X25 standard. We are now converting to the DELPHI choice of Cheapernet, following the design of a single card G64 Cheapernet station (fig. 2).

Fig. 2 The CERN Cheapernet-G64 interface card, length 160 mm

4. GAS MIXER MODULE

4.1 Operating modes

The active element in each gas stream is a Bronkhurst HITEC Mass Flow Controller; each MFC is connected to a control card on a slot-addressed auxiliary bus driven by the G64 micro (fig. 3). Four modes of operation can be selected.

Fig. 3 The DELPHI gas mixer – heavy lines represent gas flow, lighter lines represent analogue voltage

- (a) Direct manual control by potentiometer.
- (b) Ratio mixing. The component gas flows are slaved to the flow of carrier gas. The mixture ratios are set manually.
- (c) Direct flow control, set by the micro via a DAC (which duplicates the action of the potentiometer in mode 1).
- (d) Micro-ratio control. As in mode 2 the component gases are slaved to the flow of the carrier gas; but the component gas ratios are controlled by the micro via the DAC. The program integrates the flows for 1 minute, then calculates small corrections to the DAC settings to maintain the precision of the gas mixture.

Mass Flow Meters have an absolute precision of about $\pm 1\%$ of full scale flow, and an intrinsic resolution of about $\pm 0.3\%$.

Modes 1 to 3 therefore have a mixture precision of about $\pm 1\%$: the self correction of mode 4 gives a stability of $\pm 0.1\%$ over long periods.

4.2 Constant pressure supply

For flexible operation, with variable gas demand but maximum mixture precision, the mixer is usually operated as follows.

The mixer is set to mode 4 – micro ratio. The flow control valve of the carrier gas is held fully open: the carrier gas then passes to a pressure regulator which maintains a constant 200 mbar outlet pressure fig. 3. The carrier gas flow, measured by the MFM, slaves the MFC's of the component gases to pass the correct proportions. As the flows of component gases rise the flow of the carrier gas falls (at constant demand) until the correct equilibrium is reached. The micro makes running adjustments to maintain the mixture precision. This set-up has the following advantages.

- (a) Constant output pressure: individual chamber gas flows can be varied independantly of other channels, which are unaffected.
- (b) Variable demand but high measurement precision ($\pm 1\%$ absolute, $\pm 0.1\%$ stability).

4.3 Mixture feedback

For chamber systems requiring the highest absolute precision (e.g. TPC), absolute mixture measurements from analysis instruments can be fed into the program to give second order feedback correction of the mixture.

4.4 Vapour Injection

Direct injection of vapours is more precise than bubbling a proportion of gas through liquids. Vapours, e.g. ethyl or isopropyl alcohol are introduced in the gas stream by a HITEC liquid mass flow meter. This is slaved to the carrier gas flow in the same way as the component gases. In fact the vapour concentration is controlled by treating the liquid flow as a vapour flow for calculation purposes. The liquid is dripped from a capillary tube onto a porous metal cone in the gas stream: concentrations up to 3.5% of methyl alcohol have been produced in this way.

5. GAS DISTRIBUTION MODULES

All flammable gases are metered on the supply and return sides of each detector channel. Supply manifolds are mounted with 24 dual thermal flowmeters (fig. 4) which measure power needed to maintain a platinum film resistor at a

Fig. 4 Gas distribution module

constant temperature of 60°C in the gas stream [3]. The flow range is from 1 to 60 nℓ/hr when calibrated with Argon. Each channel is addressed digitally, which opens analogue switches to connect the "in" and "out" voltages via a bus to the G64 ADC card. The voltage has a parabolic relationship to the flow which is calculated from a third order polynomial fit to the parabola. The polynomial coefficients are known for each standard gas mixture. Alarm warnings are generated if the difference between input and output gas flows exceeds 5%; at 7.5% the distribution unit is stopped and a command is sent via the LAN to stop the mixer.

Optional sampling systems switch the returning chamber gas streams in succession to Herman Moritz 1501E oxygen meters and MCM Dewmatic hygrometers. Instrument readings are recorded and can be used to trigger alarms.

Two large distribution systems are equipped with Reichle blower compressors which raise the gas to + 200 mbar gauge pressure for recycling via the purifier modules. Input and output pressures are monitored, stopping the compressor in case of regulation failure. Passive venting via large bubblers is available as a last resort on both inlet and outlet connections.

6. PURIFIER MODULE

This is a twin column purifier (fig. 5) with automatic regeneration, run by a G64 process controller [4]. In the service column the gas stream passes upwards over 2 litres of Uetikon 3Å molecular sieve to remove water; then over 2 litres of BASF R3-11 active copper reagent, which oxidises to remove oxygen. After a preset time interval, (or alternatively when the outlet O₂ or H₂O levels rise to e.g. 5 ppm), the service and standby columns are interchanged. The used column is then regenerated as follows:

- (a) The cylinder is electrically heated while Argon counter-flows to remove H₂O.
- (b) When the internal temperature reaches 120°C, the Argon flow is changed to an Argon + 7% Hydrogen mixture, which reduces the Copper Oxide to Copper.
- (c) After 5 hours of regeneration, thermostatically controlled to 200°C, the heater and Ar/H₂ are turned off. Argon flow is restored during cooldown.
- (d) Finally the cylinder is recharged with chamber gas and waits in a standby condition.

Energetic reduction reactions can cause the temperature to rise: at 260°C the regeneration process is interrupted while the cylinder cools down.

Fig. 5 Twin column gas purifier with automatic regeneration

The purifier can reduce a gas stream from 2500 ppm O_2 to < 1 ppm O_2 at $1 \text{ m}^3/\text{hr}$. Typical TPC operating conditions at $2.2 \text{ m}^3/\text{hr}$ are:

Purifier intake:	O_2	4 ppm,	H_2O	100 ppm;
Purifier output:	O_2	0.3 ppm,	H_2O	6 ppm.

7. SUPERVISOR STATION

This is a G64 development system running under FLEX, with a colour monitor and keyboard. The Supervisor runs a suite of graphics programs loaded from EPROM to a virtual disk in RAM.

The "front page" program is an interactive menu which displays the run-state (i.e. RUN, STOP, WAIT, DISCONNECT etc.) of each gas system module. If an alarm is active, the run-state is flagged in red. All modules are polled every few minutes to update the display.

On selecting a gas module by use of the cursor a graphical image of the module is displayed. The current dayfile of all parameters is displayed within the image and refreshed every few seconds. By calling a sequence of dayfiles from the module's memory a graphical reconstruction of past events can be displayed. The history of particular variables, i.e. mixture percentages or channel flows, can be plotted against time; the screen image can also be printed out.

The Supervisor also provides for simplified STRINGLISH dialogues: the destination and source addresses are provided automatically and the operator has only to type the command-variable-value section.

The supervisor facility has proved invaluable in the development of this large distributed control system – no operator should be without one!

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