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Department of Control Engineering

Specification for the microprocessor control of pressure within a pilot distillation column

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Introduction

This report is the first of a short series the object of which is to aid the development of a microprocessor system for the control of the pressure within the pilot distillation column installed in the Department of Control Engineering. The system is intended to replace an existing scheme (1,2) based on the use of a VIDAC analogue computer whilst retaining existing proprietory analogue control loops for the regulation of the supply of heat and coolant to the plant. The set-points of these controllers are to be manipulated by the microprocessor in response to a measured pressure error in a cascade-(or hierarchical) manner to maintain the balance of heat input and output to and from the plant thereby achieving control of the pressure therein.

The basic strategy is fully described in its analogue realisation in references 1 and 2 which also describe undergraduate and postgraduate experiments currently carried out on the system. It is intended that the microprocessor system should provide all the flexibility currently available to students (for system structure and parameter change) using the existing VIDAC scheme and that the experiments should be enhanced by the provision of disc data storage and retrieval facilities to back-up the use of existing analogue recorders. A number of safety interlocks are to be provided in the control software and interface hardware to prevent excessive pressure build-up within the column and to warn of significant falls in pressure which can spoil experimental results through the ingress of air.

Considerable care has been devoted in the design of the man/machine interface to ensure that students and researchers have a full appreciation of the operational state (status) of the process at all times: As well as making all relevant continuous signals available on meter and recorder display, alarm and status lamps will indicate whether the control is open- or closed loop as selected (or as overridden by automatic trips) and whether the control system is in saturation. Proportional-plus-integral control is to be employed and the necessary steps taken in the controlling software to avoid integrator wind-up during periods of either open-loop control or closed-loop control saturation.

Because the control is necessarily remote from a process which occupies three floors of the building, closed-circuit television display of all the crucial plant areas is to be made available at the man/machine interface to ensure absolutely that the process actuators (valves, heaters, pump motors etc.) corespond properly at all times to the computer or remote manual commands applied and that the liquid levels remain in a healthy state under their local controllers despite the severe changes in liquid composition which can occur in the course of experimentation. Direct acting remote shut-down facilities are also to be provided at the man/machine interface.

2. Theoretical Control Considerations

Fig. 1. illustrates the general arrangement of the column and shows a liquid mixture supplied at a feedrate F at a point halfway up the column. F is usually regarded as an uncontrolled process disturbance the variations in which are determined in practice by upsteam plant. In the laboratory environment a valve is provided as shown merely to simulate these variations. The reboiler level H_b is at present controlled by bottom produce flow rate W and the accumulator level by the total outflow L+D from that vessel. (The level controllers are simple proporietory bistable relay types triggered by capacitive electrodes as indicated). The remaining three manipulable flow variables are therefore:

$q_i(t)$ = the rate of heat supplied electrically to the reboiler

L (t) = the reflux flow rate

or D (t) = the top product flow rate

and $q_o(t)$ = the rate of heat extraction from the column via the condensor.

q_i and L (or D) are generally used for control of the top and bottom product compositions (inferred from boiling point measurements $x(n), x'(m)$ made near the top and bottom of the column as indicated) leaving $q_o(t)$ for the control of column pressure $P(t)$. This pairing of input and output variables is largely arbitrary however and it is intended that future schemes will permit alternative couplings, e.g. $P(t)$ might set $q_i(t)$ leaving $q_o(t)$ for composition control. For this and other reasons which will become apparent some variables are to be routed through the microprocessor which are not immediately essential for pressure control.

2.1. Process Equations

To a first approximation the rate of build up of pressure within a column is proportional to the imbalance of heat input and output so that

$$dP(t)/dt = k_p\{q_i(t) - q_o(t) - \Delta q_o(t)\} \tag{1}$$

where k_p is the process gain (approximately constant) and $\Delta q_o(t)$ is the net heat loss from the plant other than via the condensor. In a well designed plant $|\Delta q_o(t)| << |q_o(t)|$

Now heat extraction $q_o(t)$ is only indirectly manipuable by adjustment of cooling water flow rate $v_w(t)$. In fact the condensor can be approximately described by the model

$$(1+T_h d/dt)\ q_o(t) = k_c v_w(t) \tag{2}$$

where k_c and T_h are nearly constant and $v_w(t)$ is again indirectly set by a proprietory two-term (P+I) control loop so that

$$\{1+(T_c+1/k_b)d/dt\}\ v_w(t) = (1+T_c d/dt)\ v_{wd}(t) \tag{3}$$

where $v_{wd}(t)$ is the adjustable set-point, T_c the time constant and k_b the integral gain of the coolant controller. T_c is given by

$$T_c = k_a/k_b \tag{4}$$

where k_a is the proportional gain of the coolant controller.

The input variable to be directly manipulated by the microprocessor is therefore $v_{wd}(t)$, though the measurement of $v_w(t)$ used by the local proprietory controller is to be fed-back to the computer for monitoring purposes.

Combining process equation (1) to (4) we get, if $D \equiv d/dt$

$$P(t) = \frac{k_p}{D} \{q_i(t) - \Delta q_o(t) - \frac{k_c(1+T_c D) \quad v_{wd}(t)}{(1+T_h D)\left[1+(k_b^{-1}+T_c)D\right]}\} \qquad (5)$$

from which it is clear that a steady state can only be achieved when the contents of the brackets {} become zero. If $v_{wd}(t)$ were manipulated only by proportional action, i.e.

$$v_{wd}(t) = -k_1\{P_r - P(t)\} \qquad (6)$$

where P_r is the desired reference pressure and k_1 the proportional gain of the pressure control system, then it follows that, for constant $q_i(t)$ and $\Delta q_o(t)$,

$$\lim_{t\to\infty} P(t) = P_r + (q_i - \Delta q_o)/k_c k_1 \qquad (7)$$

$$\text{i.e.} \quad \lim_{t\to\infty} P(t) \neq P_r \qquad (8)$$

The steady state error in $P(t)$ may be eliminated partially by incorporation of feed forward control action based on a measurement of $q_i(t)$ so that the control law becomes

$$v_{wd}(t) = -k_1\{P_r - P(t)\} + q_i(t)/k_c \qquad (9)$$

or by the use of proportional plus integral action. It is the latter scheme which will be implemented initially but the measurement of $q_i(t)$ will be made available to the microprocessor nevertheless to permit feed-forward control at a later date.

2.2 Proposed Two Term Control Law

For run-up purposes, between tuning experiments and for open loop tests, manual control of $v_{wd}(t)$ via the microprocessor will be provided. Changeover to closed loop pressure control will take place on the operation of an auto/manual selector switch located on the remote man/machine interface. The control law will therefore be described by the following equations:

$$v_{wmin} < v_{wd}(t) < v_{wmax} \qquad (10)$$

where v_{wmax} and v_{wmin} are the maximum and minimum cooling water settings and, if

$$e(t) = P_r(t) - P(t) \tag{11}$$

$$\left.\begin{array}{ll} \text{then} & v_{wd}(t) = -k_1 e(t) - k_2 e_i(t) \\ \text{where} & e_i(t) = \int_{t_o}^{t} \{P_r(t) - P(t)\} dt \end{array}\right\} \quad , t > t_o \tag{12}$$

k_1 and k_2 being the proportional and integral gains respectively and t_o being the time at which automatic control is selected.

Furthermore

$$v_{wd}(t) = \text{manipulable (independent) variable,} \quad t < t_o \tag{13}$$

and

$$k_2 e_i(t) = -v_{wd}(t) + k_1 e(t), \left\{\begin{array}{l} t < t_o, \\ v_{wd}(t) = v_{wmin}, \\ \text{or } v_{wd}(t) = v_{wmax} \end{array}\right. \tag{14}$$

Equation (14) effectively prevents the uncontrolled wind-up of the integral action during periods of manual control and whilst the control system is in a state of saturation. It ensures bumpless transfer from manual to closed loop control and aids the large-signal stability of the closed loop system.

3. Hardware Details

In sections 3 & 4 of the report the following nmemonics are used to represent the plant and control variables and parameters.

PR $\equiv P_r(t)$ = pressure reference

P $\equiv P(t)$ = measured pressure

VWD $\equiv v_{wd}(t)$ = coolant demand

VW $\equiv v_w(t)$ = measured coolant flow

QID $\equiv q_{id}(t)$ = heat input demand

QI $\equiv q_i(t)$ = measured heat input

K1 $\equiv k_1$ = proportional gain

K2 $\equiv k_2$ = integral gain

E $\equiv e(t)$ = pressure error signal

PROP $\equiv k_1 e(t)$ = proportional action

XINT $\equiv k_2 \int e(t)dt$ (on auto control) = integral action

PMAX ≡ maximum permissible pressure

PMIN ≡ minimum " "

T ≡ time step

A/MSW ≡ auto/manual switch state (1 = auto, 0 = manual)

VENTSW ≡ vent valve state (1 = open, 0 = closed)

Fig. 2 illustrates the main interface hardware to be incorporated into the control system. At this state of development the diagram should be regarded as a functional specification only and the precise manner and choice of components used to realise these functions may ultimately differ in detail from those shown in the diagram. Relays for instance may be replaced by solid-state bistables and alarm lamps by light-emitting diodes. The data to be routed through the computer and monitoring of this data at input and output should however be as indicated. Reference signals PR, QID and VWD for instance (which are normally operator controls) are to be set up and adjusted on a specially designed man/machine interface (MMI) whereas control parameters e.g. K1, K2 etc are to be entered via a V.D.U. keyboard.

The interface hardware is to be divided between two interface panels -

(i) the man/machine interface (MMI)

and (ii) the plant interface

with some external coupling between the two. The M.M.I. basically allows the setting up and display of data generated by the process operator and the computer's immediate response thereto. Potentiometers allow the setting of PR, QID and VWD as shown and their settings may be displayed via a selector switch on the single input meter. Closure of the column vent valve is also effected from this panel but manual closure may be overriden by the computer in the event of a measured overpressure via overpressure relay OPR. The changeover from manual to automatic pressure control is effected by operation of switch A/MSW provided the vent valve switch has been closed; software detecting the operation of the two switches and energising auto/manual lamp relays AR or MR as appropriate. Lamps switched by relays HR and LR (high and low respectively) indicate whether ot not the closed loop control has saturated (in response to a large transients in, say, $q_i(t)$ or $P_r(t)$) and are operated by the controlling software.

Finally the M.M.I. provides facilities for demanding

(i) a log of the present controller parameters (PMAX,PMIN,K1,K2 and T) on the VDU screen.

(ii) the entry of new values of specified parameters via the VDU keyboard.

and (iii) the changing of the system parameters to the new values entered in (ii) above.

The logic commands to initiate the three subroutines "parameter log," "parameter entry" and "parameter change" are effected as shown in Fig. 3 via three bistables set by switches PLSW, PESW, and PCSW on the MMI and reset by logic outputs from the microprocessor on completion of these routines.

The plant interface is intended to display continuously the state of the plant as seen by the computer. It displays continuously on meters all analogue data digitised by the computer (QI, VW, PR, P and VWD) and routes into the computer the measured plant variables P, VW and QI. These inputs may be monitored via the selector switch on the input meter as with the manually input signals. All analogue inputs and outputs may also be routed via suitable connectors to a multi-channel recorder. Warnings of overpressure and under pressure are also displayed, via relays OPR and UPR on the plant interface.

Fig. 2 and 3 show the microprocessor's analogue and logic inputs and outputs allocated to the functions described. Section 4 describes the software response to the input signals received and the consequent effect on the output lines.

4. Software

Fig. 4 outlines the main features of the control program. After first being initialised and the initial parameters read in the program then enters a loop around which the computer cycles repeatedly once per pre-specified time step T. The control program is intended to continue running throughout an entire sequence of experiments despite parameter change, reference change, reversion to manual control, alarm conditions etc. Different branches through the program may be taken however depending upon which of the above situations apply.

As a second phase, though not included in this report, it is hoped to be able to switch to alternative control structures e.g. pressure control by input heat manipulation or feedforward control as discussed in section 2, without necessarily stopping the program so as to permit the rapid comparison of control strategies.

In Fig. 4 however, only proportional plus integral control of pressure (via cooland adjustment) is considered along with the necessary switching operations outlined in section 3. The flowchart is self explanatory and covers

(i) the reading of analogue and logic data from the M.M.I. and plant interface.

(ii) the testing of the vent valve and auto/manual switches.

(iii) the calculation of VWD or the priming of the integral action in the event of manual control.

(iv) the testing for saturation of VWD, and for over and under-pressure and the raising and resetting of the appropriate logic lines for lamp indication and, in the event of overpressure - vent valve release.

(v) outputting to the M.M.I. and plant interface digital to analogue converters (DAC's)

(vi) the storing of process variables on disc for off-line retrieval and display.

(vii) the calling of the parameter log, entry and change routines.

The parameter log routine is clearly initiated by the setting of logic input line 3 from the appropriate demand switch on the M.M.I. via a bistable as indicated in Fig. 3. The bistable is reset and the associated indicator lamp extinguished by the routine itself on completion of the demanded log via logic output line 7. The routine causes a single line log on the V.D.U. screen of all the system parameter values (PMAX, PMIN, K1, K2 and T) in present use by the control program.

The parameter entry routine is similarly initiated and also resets its initiating bistable on completion. Again a bistable output lamp indicates that parameter entry has been demanded and is in progress. The routine requests the operator via the V.D.U. screen to enter the parameters' nmemonics to be changed and the new values required via the keyboard. This done the entry routine is completed. It is the function of the parameter change routine to actually effect the updating of the parameters to the new values entered whilst retaining the original values of the parameters for which no change was entered. The parameter change routine incorporates an abort option which allows the operator to retain all the original parameter values if be decides not to proceed with the update despite having entered new values. Again a switch set bistable initiates the routines which itself resets the bistable as Figs.3 and 4 indicate. The three parameter routines are to run at a lower priority than the control routine although triggered by it and must not delay the looping around the main control sequence.

5. Future reports

The development of the system here proposed will be recorded as appropriate in future reports which will include the results of specimen dynamic experiments carried out on the entire system.. The reports are to provide a basis for the preparation lecture and laboratory excerise sheets for the forthcoming S.R.C.

vacation school to be held in the Department of Control Engineering at the University of Sheffield on 21-26 September 1980.

A second laboratory exercise involving the use of the microprocessor interfaced to D.D.C. back-up stations on the distillation column is also to be developed. A report specifying the system requirements is in preparation. The system will have much in common with that developed by Edwards, Bennett, Moore(3,4) in 1972 on the CONPAC 4020 computer.

6. References

(1) Edwards, J.B. "The control of pressure in a binary distillation column." System Laboratory Note, Dept. of Control Engineering, University of Sheffield, 1976.

(2) Edwards, J.B. "On controlling the pressure in a pilot distillation column," Master's Course Case Study Specification, Dept. of Control Engineering, University of Sheffield, 1976.

(3) Edwards, J.B., Bennett, S. and Moore, N.G.: "The computer control of a distillation column in a near industrial environment." Proc. of I. Chem. E. International Conference on "Design, Decision and the Computer", London. 1972. pp 6:19 to 6:29.

(4) Moore, N.G. "The computer control of a pilot distillation column," Ph.D. Thesis, Dept. of Control Engineering, University of Sheffield, 1974.

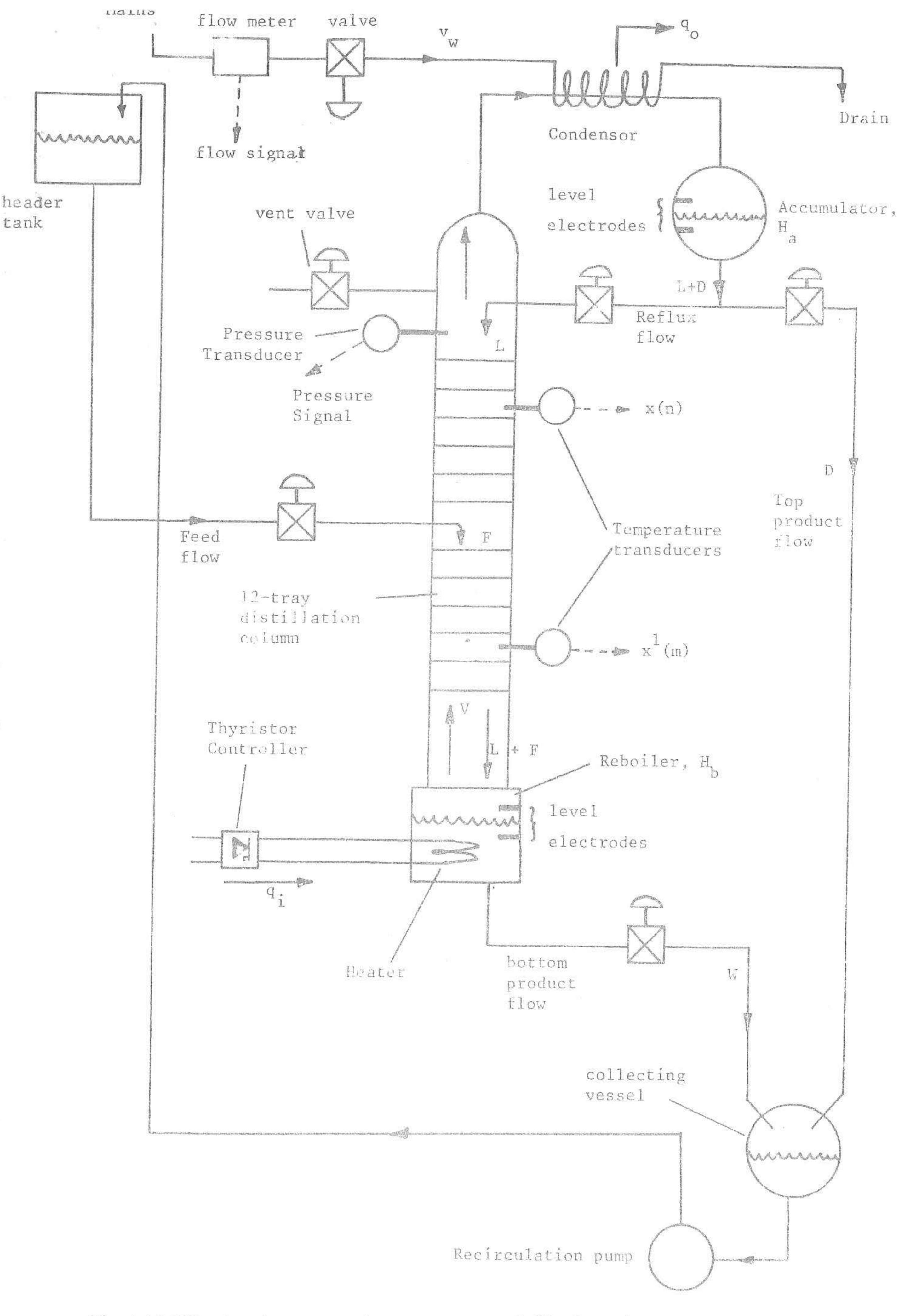


Fig.1(.) Illustrating general arrangement of distillation column and instrumentation.

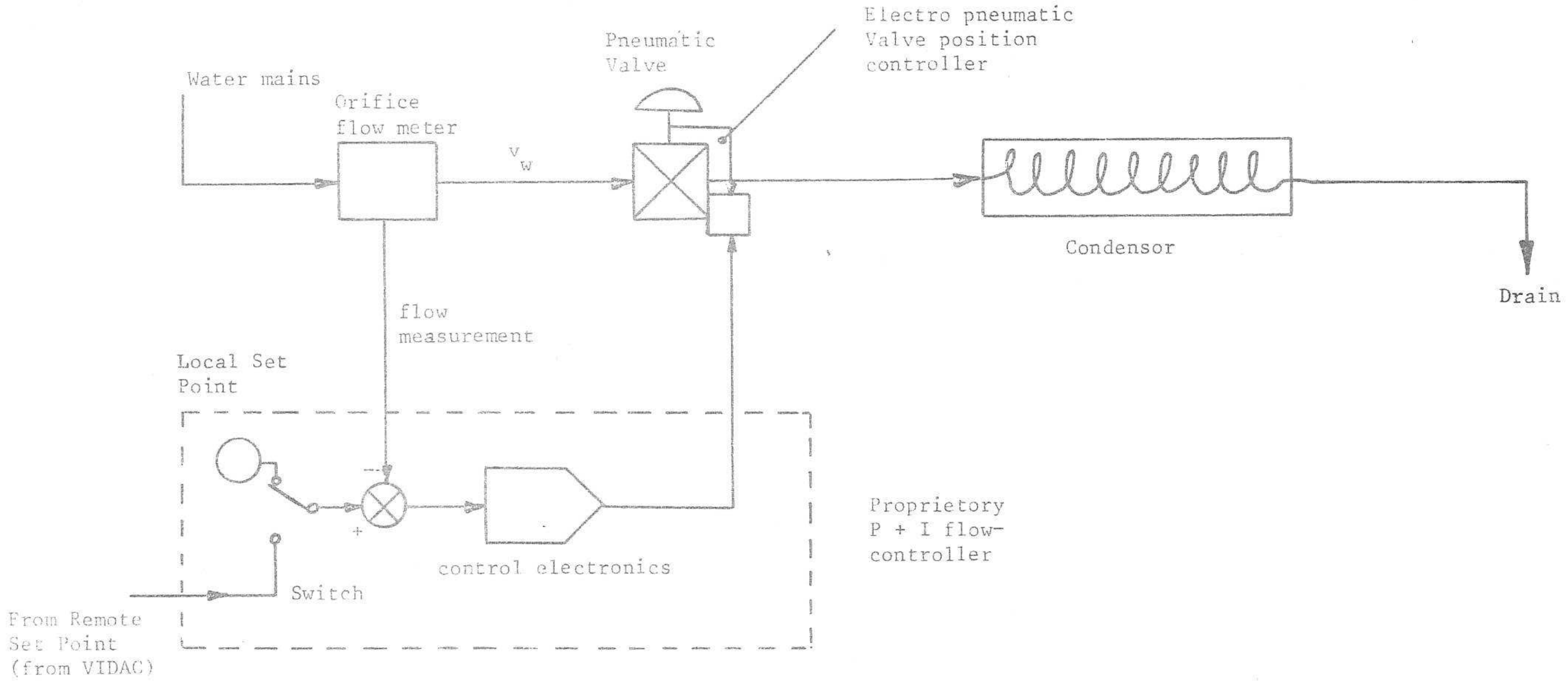


Fig. 1b Showing Cooling Water Flow Control System

Fig. 2.
Main interface hardware

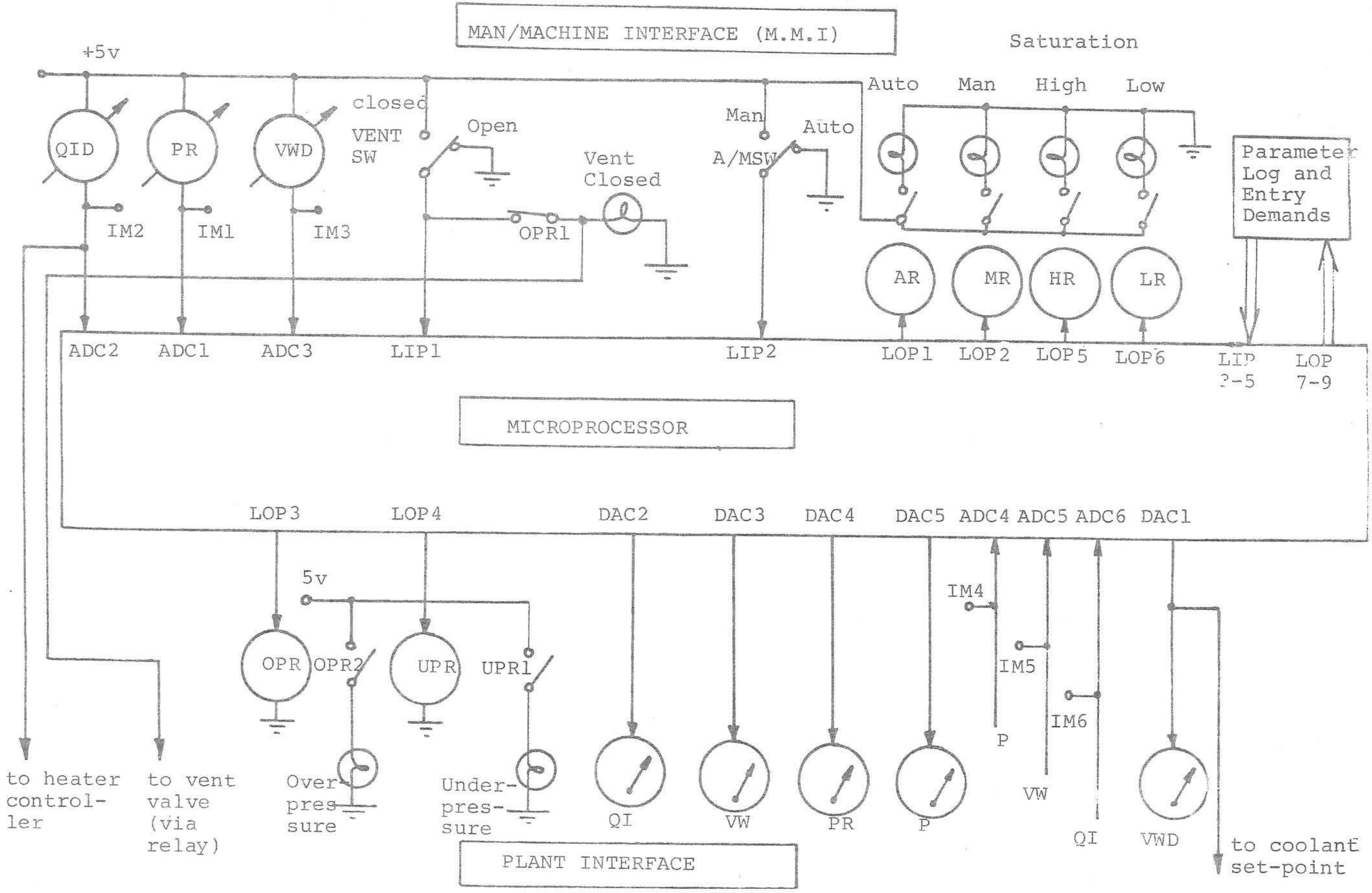


Fig. 3 Parameter Log and Entry Controls on M.M.I.

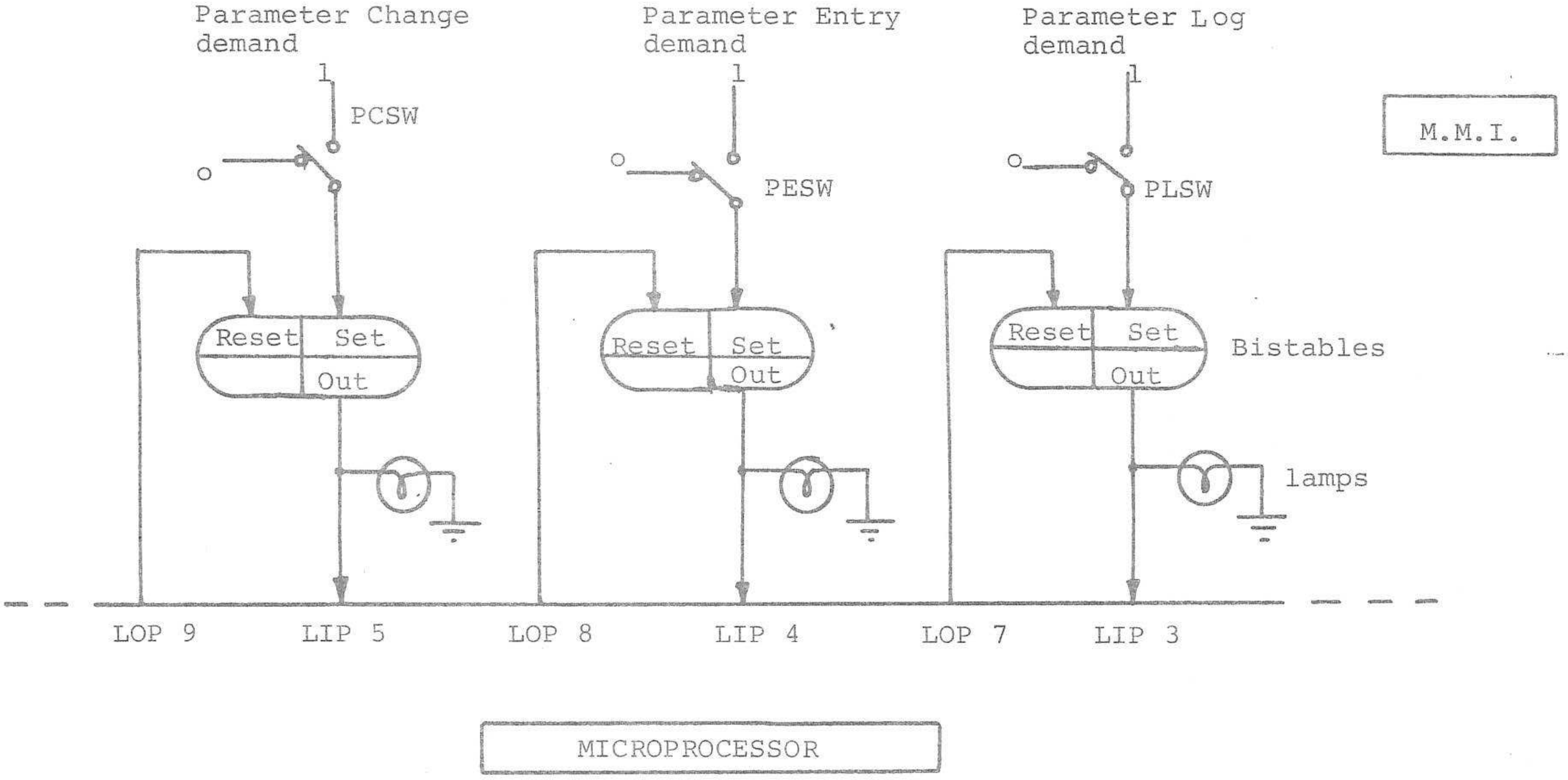


Fig. 4. Functional Flowchart. (sheet 1)

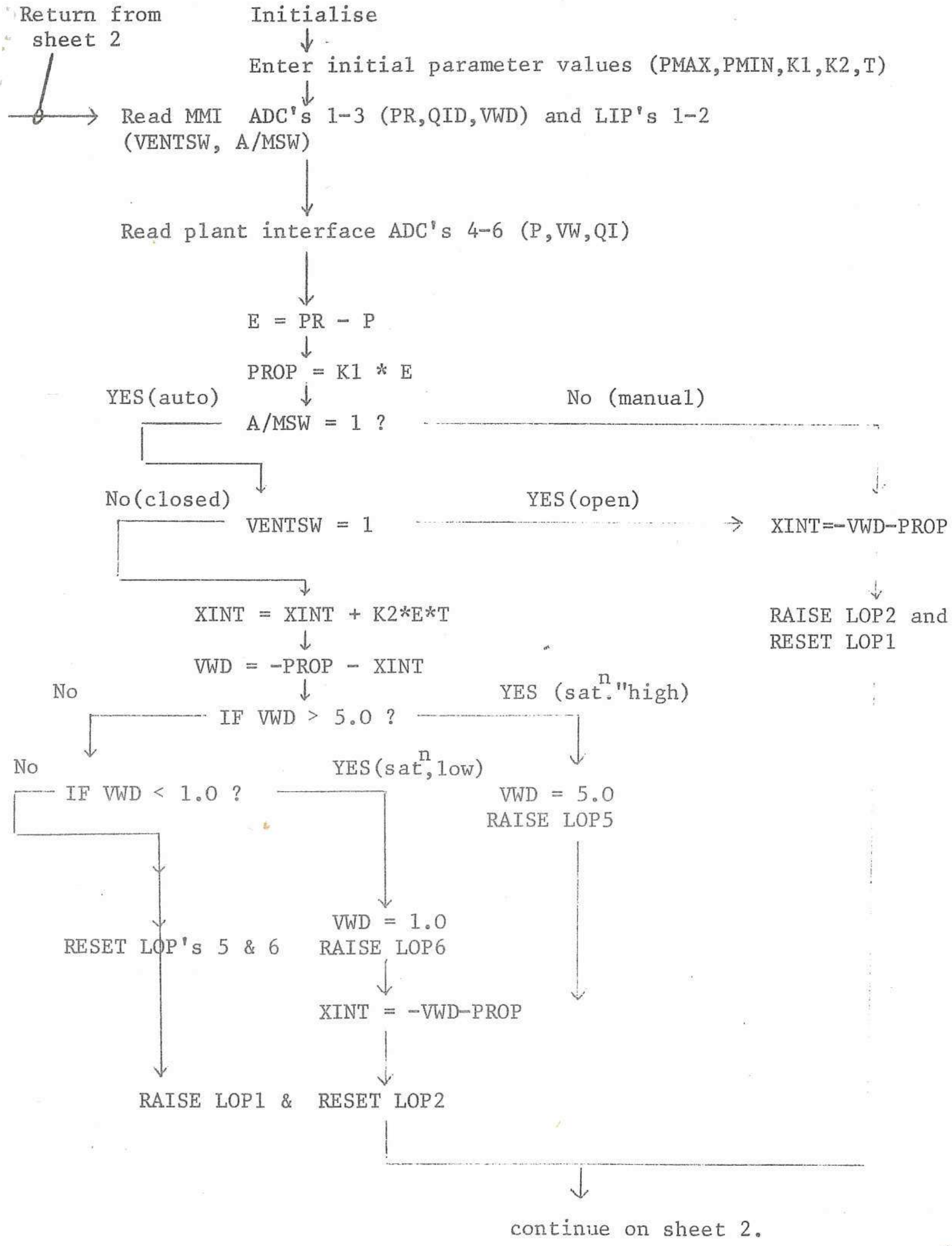
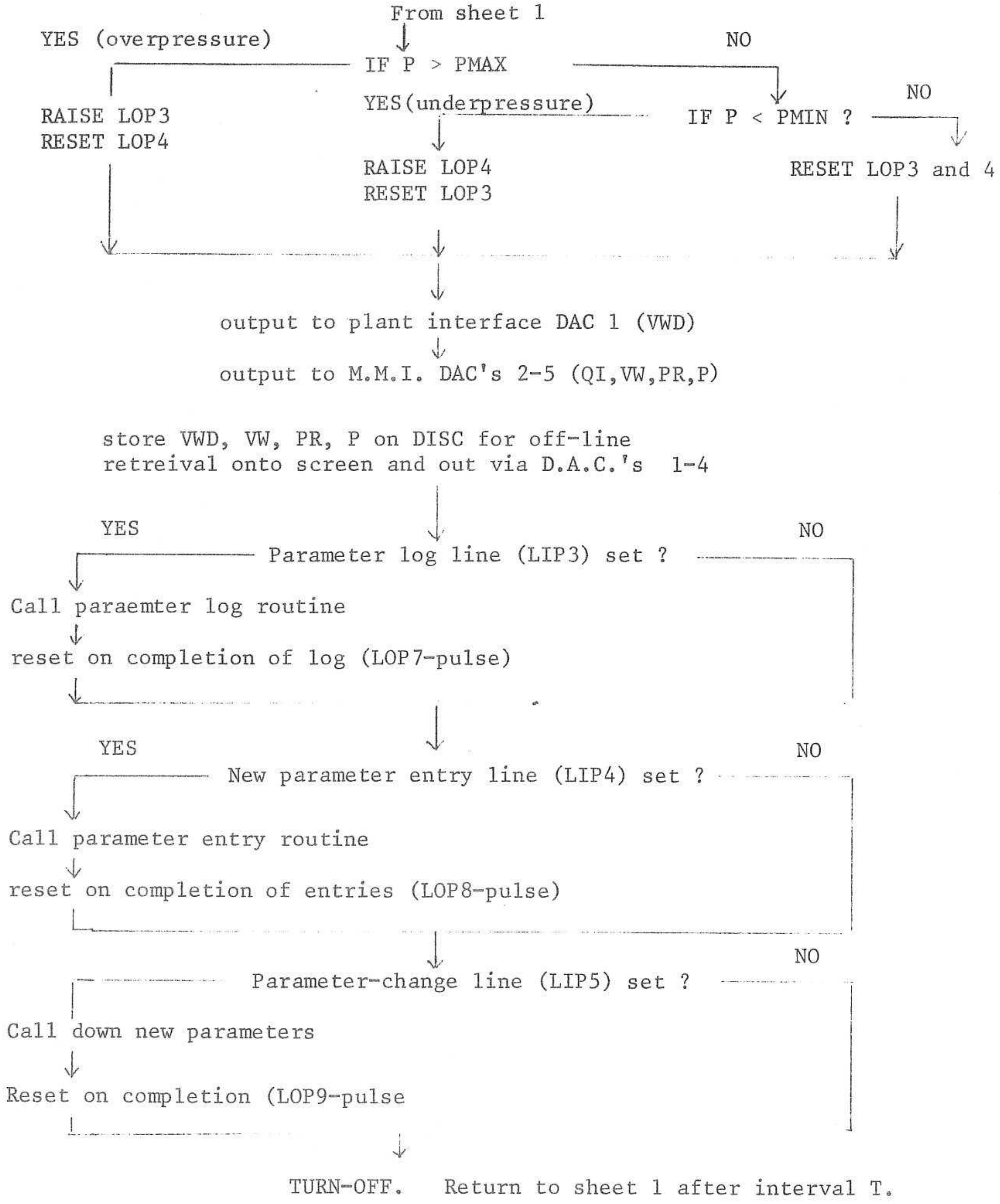


Fig. 4. Functional Flowchart (sheet 2)



(note all signals in the range 0 to +5 Volt,

analogue signals in the range +1 to +5 Volt).

Fig. 11 Comparison of rig and simulation performance (level road)