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The RC 4000 DATA LOGGER and COMPUTER SYSTEM for the PULAWY II Plant.

A/S REGNECENTRALEN
VALBY DIVISION - COPENHAGEN
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1. DATA LOGGING TASKS.

The prototype of the RC 4000 computer is intended for installation in a chemical plant constructed by Haldor Topsøe in Pulawy, Poland. The plant is composed of 13 wide-spread units: 3 gas preparation units, 3 ammonium units, 4 nitric acid units, and 3 ammonium nitrate units. The end product consists of bags with ammonium nitrate. The plant is operated manually by operators under supervision of the computer. The main tasks of system RC 4000 as defined by Haldor Topsøe are,

(1) Alarm Monitoring.
Every 5 minutes about 250 process variables will be scanned and checked against prescribed alarm-limits. Alarm conditions are brought to the attention of the operators by visible alarm signals followed by a print-out of the process variables to be corrected. Under alarm-free conditions the variables will be scanned at the rate of 30 points per second, and the complete scan thus typically lasts 8 seconds. In case of alarms the scanning rate drops to 1 point per second limited by the alarm strip printer.

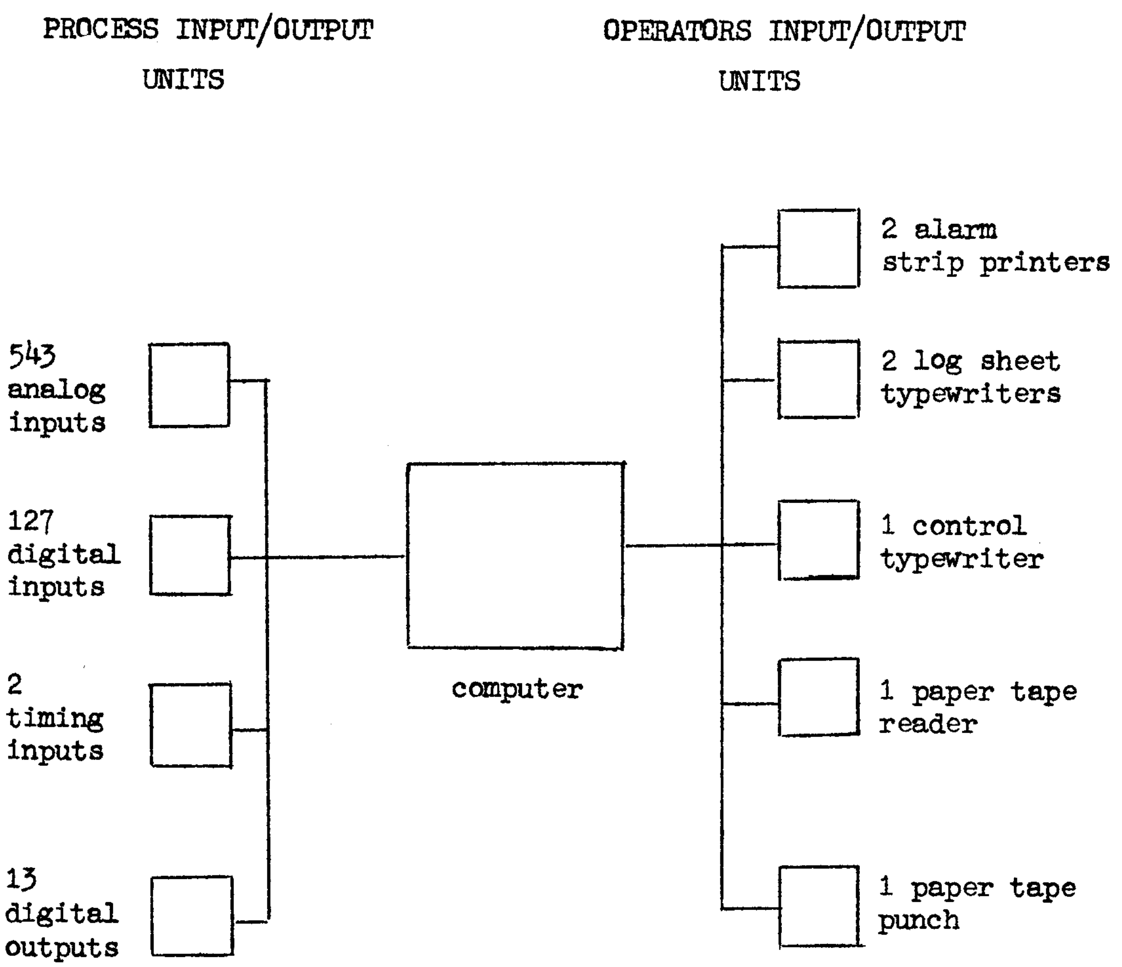
(2) Data Logging.
Every hour two records of about 300 process variables each are typed out simultaneously at a rate of 1 - 2 points per second. The entire scan therefore typically lasts 2.5 minutes. The operator can also at any time request trend logging of a single variable.

(3) Process Evaluation.
An important function of the computer is to perform the guarantee test of the entire plant by providing management with regular information about production and consumption figures. This balance report is printed every 8 hours.

(4) Self-checking.
From the above it is clear that the RC 4000 exercises supervisory rather than direct control of the plant since all process corrections are made manually by operators. In the event of hardware malfunction or programming errors the plant can still be controlled manually while the computer system is repaired. The minimum safety demand is that the computer is able to detect and report such malfunction. In idle intervals the computer will therefore perform self-checking of basic hardware functions such as the instruction logic, the adder, the analog to digital converter and the registers.

2. SYSTEM CONFIGURATION.

The following figure shows the configuration of peripheral devices as defined by Haldor Topsøe,



(1) Analog Inputs.
An analog-to-digital converter is connected to 543 input signals derived from such sources as thermocouples, resistance thermometers, pH analyzers, and flow transducers. The selection of an input point is performed by a relay multiplexer with a switching rate of 30 points per second.

(2) Digital Inputs.
Discrete events such as the number of bags with end product and the kilowatthours consumed are counted in 1-bit registers. These registers must be read and cleared by the computer every second. The on-off status of various contacts such as alarm indicators will also be registered and sensed by the program.

(3) Timing Inputs.
Two inputs, which cause program interruption every second and every 1/50 second, are used to control timing counters in the store. Together with operator input this is used to keep track of real-time.

(4) Alarm Printers.
Two strip printers (50 lines per minute) are provided for the printing of alarm values.

(5) Typewriters.
Two typewriters (14 characters per second) print out the log sheets. A third typewriter is used for communication with the operator.

(6) Paper Tape I/O.
Programs and process constants are input from a paper tape reader (1000 characters per second) and output on a paper tape punch (18 characters per second).

(7) Digital Outputs.
These outputs will drive alarm lamps in the process control room.

3. PROCESS CONTROL PROGRAMS.

The main duty of the computer is to scan the analog and digital input terminals from the plant regularly and perform certain control tasks. The control tasks are,

(1) Pulse Collection
(2) Flow Integration
(3) Balance Computation
(4) Data Logging
(5) Alarm Scanning
(6) Trend-logging
(7) Operator Communication
(8) Self-checking.

These tasks are coordinated by a real-time monitor.

Real-time Monitor.

This executive program keeps track of the real-time in order to start task programs at scheduled intervals (or immediately on request from the operator). The real-time monitor also contains a number of utility routines which are shared by the task programs. These routines handle all input-output requests and perform certain multiprogramming functions.

Control Task Programs.

For each task program a start time and a period of repetition is defined. The following is a short description of all tasks. For each task a completion time is specified. It should be noted that this is not the sequential execution time which would be obtained if a task was run to completion single handed - it is the real-time it takes to complete the task in the multiprogramming system.

Pulse Collection.

All digital registers are read and cleared. Each pulse is added to a 24 bit counter in a data table. To prevent the loss of information the registers should be read every second.

task period, 1 sec.
completion time, 40 msec.

Flow Integration.
All flows are measured by the A/D converter and summed in a data table as 24 bit integers. Also registered is the time elapsed since the last execution. From this the integrated flow values are computed.

task period, 5 min (10 min).
completion time, 18 sec.

Balance Computation.
Material balances are computed from the integrated flows and the pulse counts. The balance computation also measures a few analog inputs (ammonia levels) and accepts laboratory data from the control typewriter. The balance computation is performed in two phases: In the reset phase data values are transferred from the pulse table and the flow table to a balance table. Following this the pulse and flow tables are cleared in order that the integration tasks may start again. In the print phase the calculated balances are printed on one of the log typewriters.

task period, 8 hours (24 hours).
completion time, 5 msec (reset phase), 2.5 min (print phase).

Data Logging.
A log of all analog inputs is printed on the log typewriters in the computer room. All measurements from plant units 1 - 5 are printed on typewriter 1, whereas those from plant units 6 - 13 will go on typewriter 2. The analog values are converted to engineering values and typed out. The converted values are tested against low and high limits. Normal values are printed in black, alarm values in red.

task period, 1 hour (30 min, 2 hours).
completion time, 0.25 min (scan phase), 2.5 min (print phase).

Alarm Scanning.
The digital sense inputs are scanned and examined for alarm signals. Also the analog inputs are scanned and tested against low and high limits. Alarm values are printed simultaneously on the two strip-printers placed in the control rooms. A panel with light indicators controlled from the digital outputs will show in which of the plant units 1 - 13 an alarm condition exists.

task period, 5 min (10 min).
completion time, 18 + 1.2×A (A = number of alarm prints).

Trend-logging.

This program is only started by the operator. The program reads a selected analog input and prints the converted value on the two strip-printers.

task period, determined by the operator.
completion time, 1.2 sec.

Operator Communication.

The operator may at any time type a command to the process control system on the control typewriter. The operator can perform the following actions,

(1) Manual input of laboratory data for the balance computation.
(2) Setting of the start time and the period for each of the task programs above.
(3) Selection of an analog terminal for trend-logging.
(4) Repetition of the print phases of data logging and balance computation.
(5) Setting of the on-off status of the 14 plant units. Data input from a non-operative plant will neither be integrated, logged, nor checked for alarm.
(6) Changing of alarm limits for analog terminals.
(7) Changing of scale factors for analog terminals.
(8) Correction of the hour and date.

Self-checking.

In idle intervals this program will check the basic hardware functions such as the instruction logic, the adder, and all registers. If hardware malfunction is detected, a message is typed on the control typewriter.

4. REAL-TIME MONITOR PROGRAM.

The real-time monitor consists of a clock routine and a multiplexer routine. The clock routine is started every second by an interrupt signal from the main clock. It will scan a time table defining the start time and the period of each task program. If real-time exceeds scheduled run time of a task program the clock routine will set a flag bit for that program. When the time table scan is completed the interrupted program is resumed.

The multiplexer routine scans the flag bits regularly on a rotating basis and allocates time slices to the active programs in the following way, every 20 miliseconds the current task program is interrupted by a timing pulse. The multiplexer will now search for another program with the flag bit set and will start it. After another 20 milliseconds the multiplexer switches to a third program, and so forth. Thus, if there are N active tasks each will receive 20 milliseconds of computing time every N×20 milliseconds.

This time-sharing scheme would merely slow down all tasks by a factor N if they were only performing computations. Fortunately the Pulawy tasks spend most of their time waiting for the slow peripheral units. It is this input-output time which is shaved among other tasks. When a task program requests an input-output operation the real-time monitor will immediately switch to another task program as soon as the operation has been initiated.

When a task program is completed it will call a monitor routine asking it to turn its flag bit off. After this the task will not receive any more time slices until the next scheduled run.

A conflict arises when several tasks demand access to the same device, for example, the A/D converter. This is solved by the simple principle of first come, first served. In the case of the typewriters ownership is regulated by means of the semaphores suggested by Dijkstra. (This is a general mechanism which prevent concurrent program from getting into an argument about shared facilities).

The system above also simplifies the handling of operator requests for immediate execution of a task. This can be done without reference to the time table by setting the flag bit directly.

5. Operators Input/Output Units.

5.1. Output Typewriters and I/O Typewriter

All 3 typewriters are of the IBM Selectric type. One is used for operators Input/Output to the program and 2 are used for typing-out logreports on preprinted formularies. The machines are supplied with an ALGOL-alphabet and are mechanically identical.

To ensure a reliable printing, the machines are supplied with a pin-feed mechanism which, together with holes in the paper, prevents the paper in beeing fed slantwise.

Paper dimensions:

Paper width	13 5/8	inches (amer.)
Distance between pin-wheels	13 1/8	-
Holedistance	1/2	-
Holediameter	5/32	-
Max writingwidth	12 7/8	-

Typing characteristics:

Type-distance 12 pitch, i.e.	max 154 char/line
Line-distance	3 or 6 lines/in.
Speed	14 char/sec

5.2. Tape Reader.

The tape reader is a GNT photo-electric tape reader model 4101. The 4101 is a high speed, bi-directional punched tape reader. As an input unit to RC 4000 it is only used as a uni-directional reader. The main specifications are as follows,

Speed:

Intermittent (step-by-step) operation max 500 characters/sec.

Tape Width:

11/16, 7/8 or 1 inch standard. 5, 6, 7 or 8 channels plus 1 for sprocket holes.

Tape Type:

The reader will accept max 25 per cent transmissive punched paper tape.

Alarm circuits give information to RC 4000 about open tape latch and tape out. A display panel shows the actual character.

5.3. Tape Punch.

The tape punch unit is based on an ADDO-X paper tape perforator. It is a solenoid-actuated motor-driven perforator capable of punching 5, 6, 7, or 8 channel tape at rates from 0 to 18 characters per second. In connection with RC 4000 the main specifications are as follows,

Speed:

Max 18 characters per second.

Number of Channels:

8 channels, one of which is used for parity bit.

Tape:

1 inch width standard paper tape

Hole size:

Code holes 0,072 inches in diameter
Feed holes 0,046 inches in diameter

Hole spacing:

0.100 inches apart both longitudinally and vertically.

The tape punch unit is equipped with a tape supply with tape-out switch and manual tape feed lever.

5.4. Alarm printers.

To the Pulawy project the RC 4000 will be equipped with two remote located alarm printers, one in each control room. The printers will be connected in such a way that they print the same data.

The printers are Addo-printers, model 19 - 0147 - 00 - 0550. The printers has been modified, and the new specifications are as follows,

Capacity:

10 data columns and 1 column for indication of high or low alarm limit excess.

Characters:

The type bars of the 10 data columns are provided with 12 characters, No. 5 from the right with characters 0 - 9, + and -; the others with characters 0 - 9, asterisk and dot.

In front of a line + and asterisk will not be printed.

In a special column, to the right of the data column, L, H or no character is printed. If L or H are printed the print colour is red, else black.

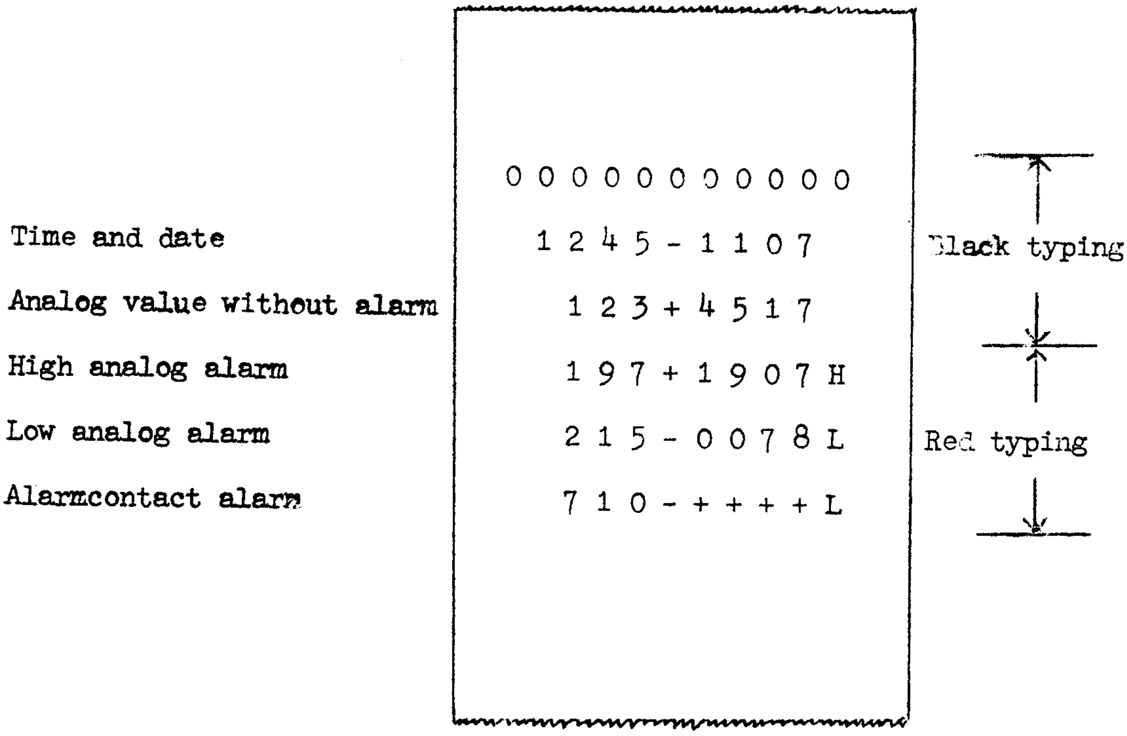
Printing speed,

max 50 lines/minute for a 10 columns line
Max 100 lines/minute for line skip.

Printing,

Max paper width: 88 mm / 3 1/2 in.
Standard paper width: 64 mm / 2 1/2 in.
Length of Tally Roll, approx: 33 m / 110 ft.
Selection lever for single or double line spacing.
Single line spacing: 4,23 mm / 1/6 in.
Double line spacing: 8,46 mm / 1/3 in.
Character width: 5 mm / 0,198 in. per division.

A sample of the print out is given below.



Example of stripprinter output.

6. Process Input/Output Units

6.1. ANALOG INPUT UNIT

(1) GENERAL.

The purpose of the ANALOG INPUT UNIT is to accomplish the connection between the CENTRAL PROCESSOR and the processparameters represented by analog voltages from different kinds of transducers. It means that the ANALOG INPUT UNIT should perform the following functions:

Multiplexing of the analog input channels (Relay-multiplex).
Selection of correct analog range.
Amplification of analog signal if necessary (according to selected range).
Analog to digital conversion.

Furthermore, signalconditioning of the following types are made: cold junction compensation for thermocouple signals, resistance to voltage conversion (resistancethermometers) and conversion of current-calibrated signals to voltage-calibrated signals.

The inputsignals are connected to two multiplex units, one of which is located in the computer room, while the other is situated in a remote building housing a control room.

(2) FUNCTIONAL DESCRIPTION.

The ANALOG INPUT UNIT consists of the following subunits,
ANALOG INPUT CONTROLLER UNIT (>>ANC<<),
RELAYMULTIPLEXER UNIT A and B (>>RMA<< and >>RMB<<),
AMPLIFIER UNIT (>>AMP<<), and the
DIGITAL VOLTMETER UNIT (>>DVM<<).

The ANC units control the other subunits in accordance with the signals received from the CENTRAL PROCESSOR (via the Low Speed Data Channel). These include a 10-bit relay address and a >>start<< signal. The relay given by the 10-bit address is activated when the >>start<< signal is received and after a delay of ca. 10 mS (i.e. max. settling-time of the relays) the analog to digital conversion (DVM) is started. The conversion time is exactly 20 mS, and during this time the analog voltage is integrated so that the conversion result will be given as the true average value within this interval. This means that unwanted noise at the power-line frequency will only cause a negligible error.

When the conversion is finished, relevant output-data from the conversion are available. These are in a 12-bit BCD format (3 decimal digits), and will stay available for transfer to the CENTRAL PROCESSOR untill the ANC unit is activated again.

(3) ANALOG RANGES.

In the transducers different levels of voltages could be generated (covers 6 decades). To achieve a reasonable accuracy for any of these it is necessary to have different analog ranges established by the transducer type, i.e. the terminal No. (= Relay address). To each range corresponds an analog busline, to which the associated input terminals will be connected in case the relay is activated. The 4 ranges used have following full scale values: $\pm$10 V, $\pm$1 V, $\pm$50 mV, and $\pm$20 mV.

The range to be used is selected by the ANC unit, as it is determined by the actual relay address. The 10 V and 1 V buslines can be connected directly, and the 50 mV and 20 mV buslines connected via very accurate amplifiers to the input terminals of the DVM unit.

The ANC also selects the correct range for the DVM - 1 V or 10 V (the 50 mV and 20 mV signals are amplified 200 times and 500 times respectively).

(4) ACCURACY - INTERFERENCE.

The accuracy of the digital output from the A/D converter is determined by the properties of both the A/D converter and the amplifier. Furthermore, interference from power lines (50 cps.) or from very high transients (switch circuits) could cause some error in the measured value.

A theoretical analysis of the effect of probable common mode noise (10 Vrms., 50 cps.) on the input cables shows that even for the lowest range it will be less than 0,002 per cent of full scale. It means that the accuracy mainly will be determined by the digital voltmeter and the amplifiers which in this case gives an accuracy better than 0,12 per cent at 25 degrees C and a temperature drift of ca. 0,01 per cent/degree C (per cent of full scale).

(5) RELAY MODULES - TYPE OF RELAYS.

The two relay multiplex units, RMA and RMB, consist of modules which can be equipped with up to 32 relays of a certain type. These are mounted on a large printed circuit board receiving drive-signals for the coils from another circuit board containing the necessary decoding and drive circuits. The five least significant bits of the relay address word select the relay with the number according to this, and the five most significant bits determine similarly the module number to be activated.

To each analog range corresponds a certain type of relay, and only one type will be present in each module. This means that the analog range is given by the five most significant bits of the relay-address, which further means that a decoding of these can control the relays, switching the four analog buslines.

For the 20 mV, 50 mV, and 1 Volt ranges relays with extremely low thermal offset and noise (< 5 µV) are used. They all contain 3 contacts, one for the shield and two for the signal wires. All contacts have very high insulation-resistance to case, so that the Common Mode Rejection will not be significant deteriorated due to leakage currents. For the same reason the common bus of a relay board is only connected to the outside busline in case the module is activated.

Relays with an extra set of break-contacts for output to conventional recording equipment are used in some of the modules.

For the 10 Volt range a more inexpensive relay-type is used. It is a reed-relay and the thermal offset and noise may of course be much greater than for the other types; after 5 mS, the total noise signal will be less than 1 mV. This relay has 2 make contacts for switching the two signal wires; - the shield is constantly connected.

(6) SIGNALCONDITIONING.

Signalconditioning is necessary for the thermocouple-inputs and the resistance-thermometer inputs.

All the thermocouple signals pass through a cold junction chamber (reference temperature: 0 degree C to + 0.1 degree C) before applied to the input relays.

The resistance thermometer inputs include circuits for resistance to voltage conversion as the inputs of the relaymultiplex must be voltage-calibrated signals. This is accomplished through a number of bridge-circuits; - one for each input, and a common, high precision power supply (10.00 Volts). To achieve a good compensation for the cable resistance, a 3-wire connection between the thermometer and the bridge is necessary, so that two wires are connected to one terminal and one wire to the other terminal of the resistance thermometer. It should be noticed that all 3 wires must have the same dimensions to get good compensation. Further possible errors due to >>self-heating<< of the thermometer should be taken into consideration.

(7) CABLING AND INSTALLATION.

All the analog signals from transducers are connected to their associated relay-module by means of cables that could be up to several hundred meters of length.

The thermocouple signals are connected to the relay multiplexers via the cold junction reference box. Some of these signals are via break-contacts on the relays passed to output-connectors and further by cables to conventional instruments. It means that these signals will go to the conventional instruments except for the short time (about 30 msec.) where the input relays are activated.

All low level signals go through twisted pairs with individual shield as far as possible. The main part of the 1 Volt and 10 Volt signals go through twisted pair in multicore cables with common shield.

6.2. DIGITAL COUNT UNITS.

The DIGITAL COUNT UNITS consist basically of a number of 1-bit >>registers<< arranged in groups of 23 which have common control circuit. Once every second the content of a register group is transferred to the CENTRAL PROCESSOR (via the Low Speed Data Channel) and after this the group is reset.

A true is transferred when a contact closure of a certain duration has been present between the input leads (twisted pair) in the 1-second interval before the time of data transfer. This means that counting of events (e.g. 1 kWh of energy consumed, 1 bag of end-product out from plant, etc.) with frequencies lower than 1 cps can be made by means of the DIGITAL COUNT UNITS and the CENTRAL PROCESSOR without occupying this more than a few microseconds every second.

The maximum counting frequency is determined by the relationship between the duration of the contact closure and the recurrence frequency of the >>sense<<-signal from the CENTRAL ROCESSOR.

In the PULAWY-datalogger is used 3 DIGITAL COUNT UNITS making it possible to count up to 69 independent events.

The input signals from the process (contact closures) go through a filter before it is applied to the count registers. With the input filter and clamp circuits used, a cable length of up to 500 m will give a reliable counting provided that the remote count contacts are isolated from the drive circuits and ground and also provided that extremely strong noise sources are not located close to the cable.

6.3. DIGITAL SENSE UNITS.

The DIGITAL SENSE UNITS consist of a number of filter and clamp circuits arranged in groups of 23, connected to a Low Speed Data Channel interface.

Each DIGITAL SENSE INPUT consists of two leads (twisted pairs) that through a cable is connected to an ALARM-contact. If this contact is closed the corresponding output is false, and in case the contact is open (or the cable is disconnected) the output is true (i.e. an ALARM-condition).

One group is sensed from the program at a time, and as the input-signals are static, the transfer of the data to the CENTRAL PROCESSOR can take place at any time as defined from the program.

With the filter and clamp circuits used a cable length of 500 m will not affect the reliability of the contact-sensing provided that the remote contacts are isolated from ground, and provided that extremely strong noise sources are not located close to the cables.

6.4. DIGITAL OUTPUT UNIT.

The DIGITAL OUTPUT UNIT comprises a 13-bit buffer register and 14 indicator-lamp drivers.

The corresponding display-lamps are placed in the control rooms.