327H-1

PROCESS CONTROL SIMULATOR PCS 327

Book One

CONTENTS

INTRODUCTION	SECTION 1
FUNCTIONAL DESCRIPTION	SECTION 2
SPECIFICATION	SECTION 3
INSTALLATION AND OPERATION	SECTION 4
BASIC THEORY AND EXPERIMENTS	SECTION 5
CIRCUIT DESCRIPTION AND MAINTENANCE	SECTION 6
APPENDIX 1	
APPLICATION NOTES	

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Notes on Process Control Terminology

The terminology in this manual and on the instrument panels is generally in accordance with the following standards :

U.K.	British Standard BS 1523 : 1960 Section 2
U.S.A.	American Standard ASA C85.1 - 1963

These standards are in the main in agreement with one another but there are a few detailed differences which might cause difficulty, to avoid which the following notes are provided.

BS 1523	ASA C85.1
'Set value'	'Set point' or 'Command'
'Desired value'	'Desired value' or 'Ideal value'
'Deviation'	'System deviation'
'Measured value'	'Actual value'
'Controlled condition'	'Controlled variable'
'Control signal' or 'Correcting condition'	'Manipulated variable'
'Overlap'	'Neutral zone'

327H-2

Although this Feedback manual was correct at the time of printing, components supplied may differ slightly from those described.

We endeavour continually to improve our equipment by incorporating the latest developments and components, even up to the time of despatch. Whenever possible we will include such new or revised information.

Component replacement

Whenever possible, replacement components should be similar to those originally supplied. These may be ordered direct from Feedback Instruments Limited or its agents by quoting the following information:

1. Equipment type
2. Equipment serial number
3. Component reference
4. Component value

Standard components can often be replaced by alternatives available locally.

INTRODUCTION

The Process Control Simulator PCS327 is a special-purpose analogue simulator employing integrated circuit operational amplifiers laid out in such a manner to allow the principles of process control methods to be taught at both technician and technologist levels.

Numerous variable interconnections together with a range of non-linear functions make the simulator sufficiently versatile to permit a detailed study of the dynamic responses of a wide variety of linear and non-linear processes and the application of proportional, integral, derivative, two-step, three-step (with and without overlap) control to the improvement of their performance.

At the same time provision is made for the process characteristics and controller configuration to be preset by the instructor and the full mimic diagrams concealed by simplified overlays; this helps to present the ideas of process control in the simplest possible terms to technicians whose acquaintance with process control methods will be of a more empirical nature.

The Simulator may be used at high speed for oscilloscope observation or at a low speed for meter or chart recorder observation, speed selection being achieved by independent controls on the Process and the Controller. When the Controller is set for low speed use it is suitable for the application of three-term control to the Feedback Process Trainer PT326.

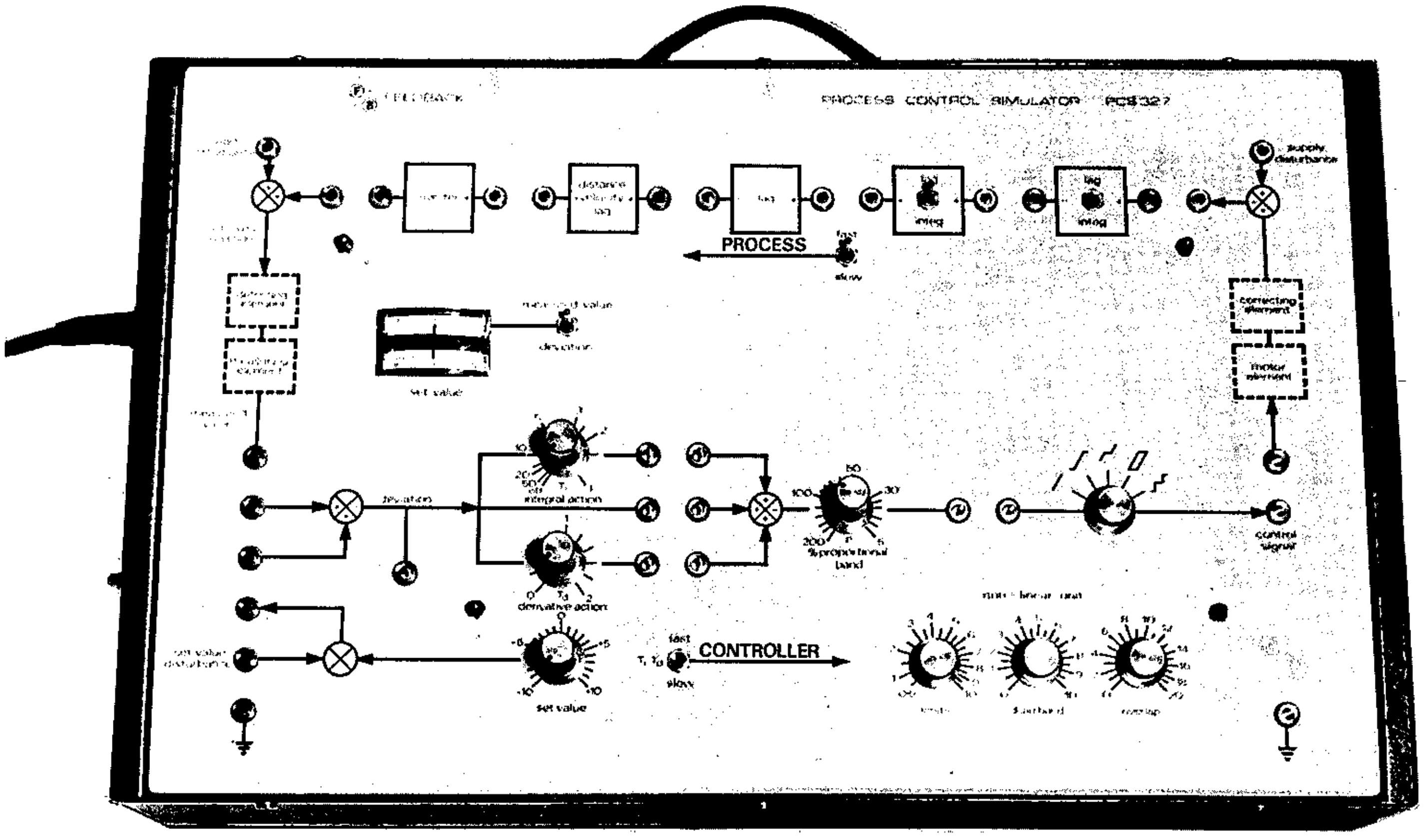
All control constants and simulated elements and signals are denoted by terms recommended in BS1523: Section 2, for process control systems, and the accuracy of calibration is adequate to provide close comparison between theory and practice. The equivalent USA standard is ASA C85.1 of 1968 (see the introductory note on terminology on facing page).

The equipment is fully compatible with all Feedback signal sources and all results may be observed on any laboratory oscilloscope with direct-coupled horizontal and vertical amplifiers.

Some additional features of the equipment are:-

- Simulated distance-velocity lag (transport lag)
- Self-contained power supplies
- Integrated-circuit reliability
- Student-proof design.

The manual is written at two levels suitable to the empirical and the analytic approaches, each section containing theoretical and practical material interleaved in a progressive manner.


PROCESS CONTROL SIMULATOR PCS327
PROCESS
fast
slow
lag
integ
distance velocity lag
supply disturbance
correcting element
motor element
measured value
deviation
set value
integral action
derivative action
deviation
% proportional band
control signal
CONTROLLER
non - linear unit

FUNCTIONAL DESCRIPTION — SECTION 2

2.1 General

Fig 1 shows the panel layout. A power on-off switch and indicator lamp are mounted in the left-hand side of the case.

The full-scale range of all input and output signals is ±10V.

2.2 The Simulated Process

The process comprises the following elements, any of which may be inserted or omitted from a complete process by the use of jumper leads.

1 simple lag of time constant 10 milliseconds
2 lags of time constant 10 milliseconds each convertible by toggle switches to integrators of time constant 10 milliseconds

1 distance-velocity lag of delay 10 milliseconds
1 inverter

With these elements any of fourteen different linear process characteristics of Type 0, 1 and 2 may be established. Every element produces a polarity inversion but the inverter may be included or not as necessary to produce the desired overall polarity.

In addition two summing elements are provided, one at the input to the process to permit introduction of a signal representing supply disturbance and one at the output for the introduction of a simulated load disturbance.

The elements shown dotted as:

Controlling element
Motor element
Detecting element
Measuring element

do not represent any hardware in the equipment but are included to show the position in the process where such elements would be found in practice.

An overlay, which can be rapidly fixed or removed, covers the whole of the process elements proper to present a single element containing the process selected by the instructor.

2.3 The Simulated Controller

The controller comprises the following elements:

1 Set-value control of range ±10volts
1 Comparing element
1 Integral action control scaled in integral action time
1 Derivative action control scaled in derivative action time
1 Proportional band control scaled in % proportional band

The comparing element generates the deviation 0 as the difference between the controlled condition and the set value and passes it to the three-term controller comprising the integral, derivative, and proportional controls. Each of the fundamental control terms may be monitored at the test point provided and one, two or three of the terms may be summed together before passing to the proportional band control.

To avoid problems due to integrator drift an OFF position is provided on the integral action control in which the integral term is held at zero. The complete path from comparing element input to proportional band control output is non-inverting to allow easy application to external processes such as the Feedback Process Trainer PT326.

The output of the controller proper passes to a switch-selected non-linear element described in Para 2.4. One of the switch positions completely by-passes this element and transfers the control signal direct to a socket from which it may either be connected by a jumper lead to the simulated process input or to an external process input. Similarly the controlled condition socket at the input to the controller can either be linked to the output of the simulated process or be fed from the output of an external process.

The set value control can also be disconnected entirely from the comparing element and an external set value input applied, if desired. The set value output is the sum of the steady value adjusted by the set value control and any disturbance injected into the set value disturbance input.

2.4 Non-linear unit

This provides a selection of idealisedbut typical non-linear characteristics. The location of the element is chosen (between the controller output and process input) to permit it to be considered in either of the two following lights:

a) as representing typical mechanical non-linearities such as backlash, hysteresis, deadband, etc occuring in any of the motor, correcting, measuring or detecting elements.

b) as representing various types of non-linear controller characteristic, e.g two-step and three-step with or without overlap.

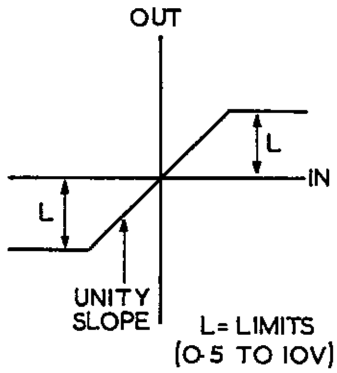
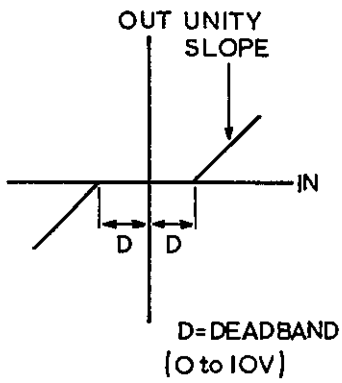
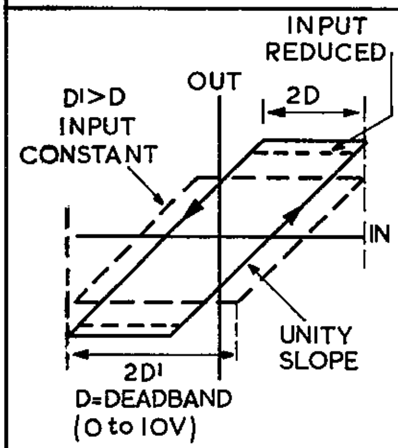
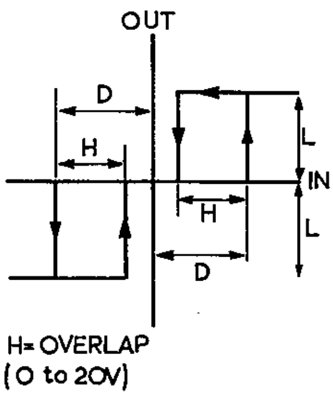
SELECTED CHARACTERISTIC	TYPICAL APPLICATIONS (a) PROCESS	TYPICAL APPLICATIONS (b) CONTROLLER
	i) MOTOR SATURATION ii) DIAPHRAGM VALVE LIMITS	i) FLAPPER VALVE LIMITS
	i) DEAD SPACE BETWEEN MECHANICAL LINKAGES	
	i) BACKLASH IN GEARS AND OTHER LINKAGES	
	i) H=D=0 IDEAL RELAY ii) H=0 IDEAL CENTRE STABLE RELAY iii) H=2D IDEAL POLARISED RELAY iv) H<D CENTRE-STABLE RELAY WITH OVERLAP L MAY BE VARIED TO SIMULATE DIFFERENT MAXIMUM INPUTS TO PROCESS	i) H=D=0 TWO-STEP CONTROL ii) H=0 THREE-STEP CONTROL iii) H=2D TWO-STEP CONTROL WITH OVERLAP (OVERLAP=H) iv) H<D THREE-STEP CONTROL WITH OVERLAP

FIG.2 NON LINEAR CHARACTERISTICS

The element comprises:

1 switch selector
1 limits control
1 deadband control
1 overlap control

The various forms of non-linearity provided, with the effects of the three controls and the applications under (a) and (b), are fully explained by figure 2 and need no further comment except that the backlash characteristic is valid for only a limited range of signal frequencies (4 to 40 Hz) and is therefore only usable with the simulated process in the FAST condition, whose normal frequency range this is. The non-linear unit may be isolated by the jumper links and inserted into any other desired position to demonstrate any special effects desired.

2.5 Controller overlay

An overlay, which can be rapidly fixed and removed, covers the whole of the non-linear unit and the controller excluding the comparing element. This permits a much simplified presentation of the control path whilst allowing the setting of the proportional, integral, and derivative terms and set value by the lecturer for simple demonstrations.

In addition the instructor may preselect and preset some non-linear control characteristic, e.g two-step with overlap, and indicate by the pointer provided on the overlay the type of controller currently set up.

2.6 Meter Indicators

Two centre-zero meters indicate the set value (lower meter) and either the measured value or the deviation (upper meter) according to the switch position selected. The sense of the meters is arranged to ensure correct polarities according to the equation

DEVIATION = MEASURED VALUE - SET VALUE.

SPECIFICATION

3.1 General

Input and output ranges	±10V at all points
Frequency response of basic amplifier configuration (e.g inverters)	Flat at full output to 25kHz
Minimum resistive load on any output for full range output	5KΩ
All outputs short-circuit-proof	

3.2 Process

Time-constant of simple lags	10ms (FAST) or 1s (SLOW)
Time-constant of integrators	10ms (FAST) or 1s (SLOW)
Distance-velocity lag	10ms
Useful frequency range of distance-velocity lag	0 to 30Hz

3.3 Controller

Set value range	0 to ±10V
Integral action time range (Ti)	(250ms to 5ms (FAST) (25s to 0.5s (SLOW) Corresponding to 4 to 200 repeats/sec. and 0.04 to 2 repeats/sec.
Derivative action time range (Td)	0 to 20ms (FAST) 0 to 2s (SLOW)
Proportional band range (P)	200% to 4% Corresponding to gain constants 0.5 to 25

3.4 Non-linear unit

Characteristics provided	1. Linear 2. Limits 3. Deadband 4. Backlash 5. Two and three-step (relay) with overlap.
Slope of linear portions	Unity
Limit adjustment (L)	0.5 to 10V
Deadband adjustment (D)	0 to 10V
Overlap adjustment (H)	0 to 20V
Frequency range of backlash characteristic	

3.5 Power Supply

Internal voltage lines	±15V
Line voltage	220-250V 50/60Hz or 110-120V

3.6 Dimensions

Width	Depth	Height	Weight
20.5in	11.5in	6.5in	
520mm	292mm	165mm	

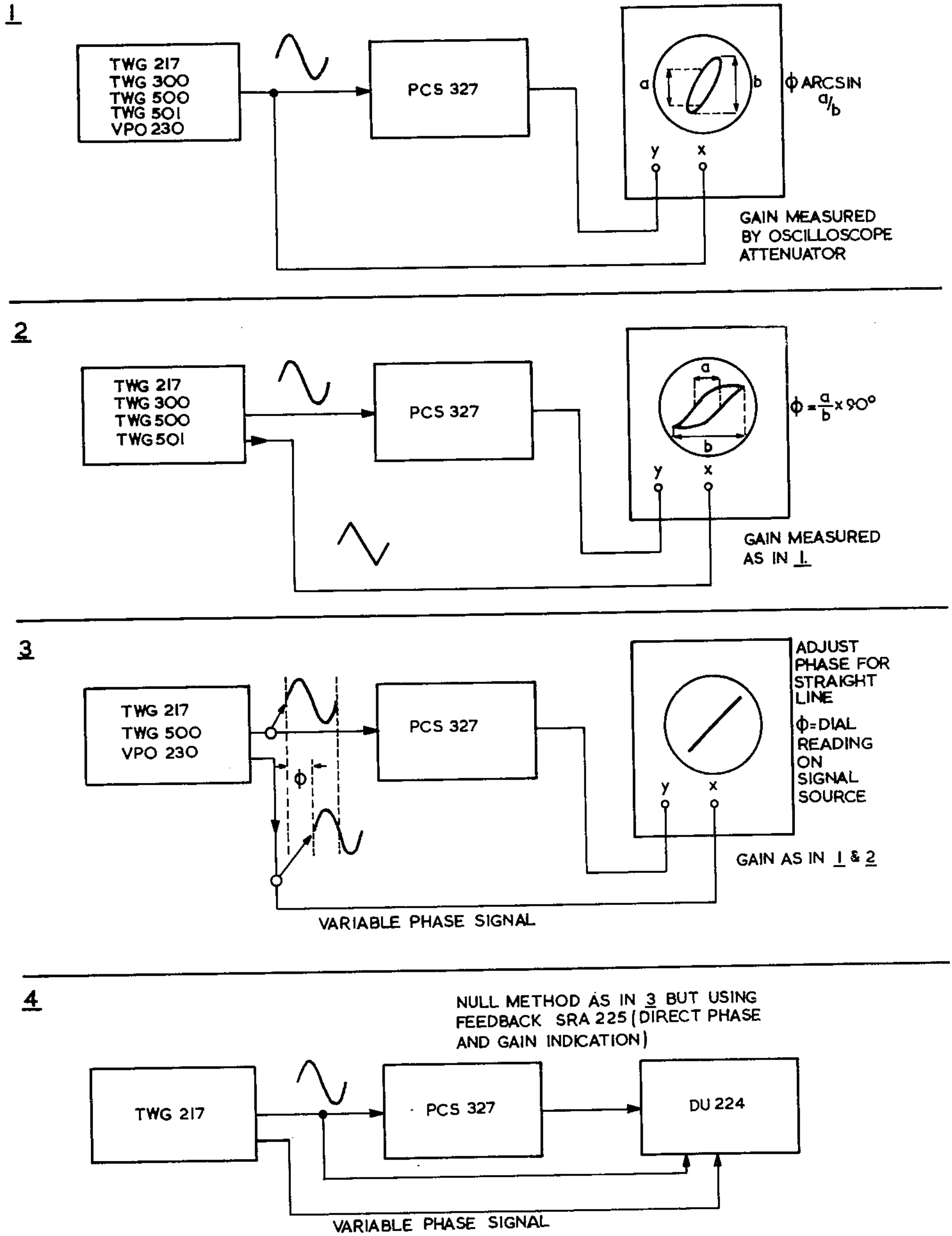
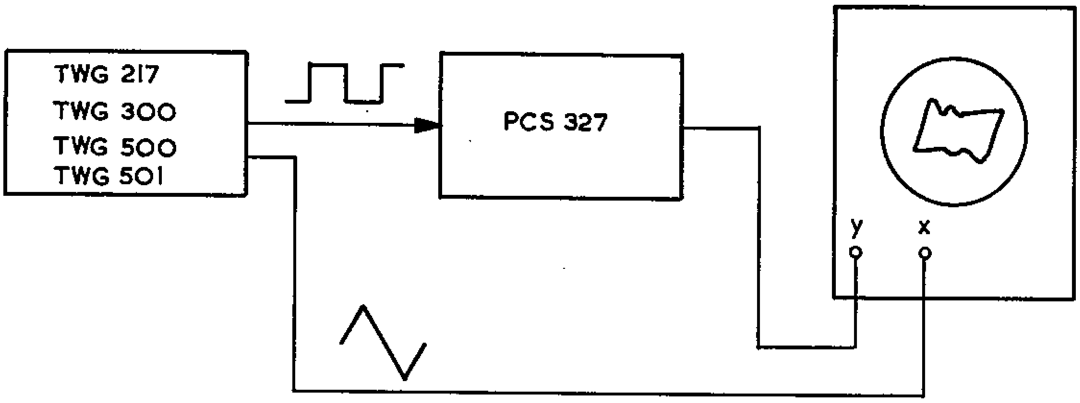
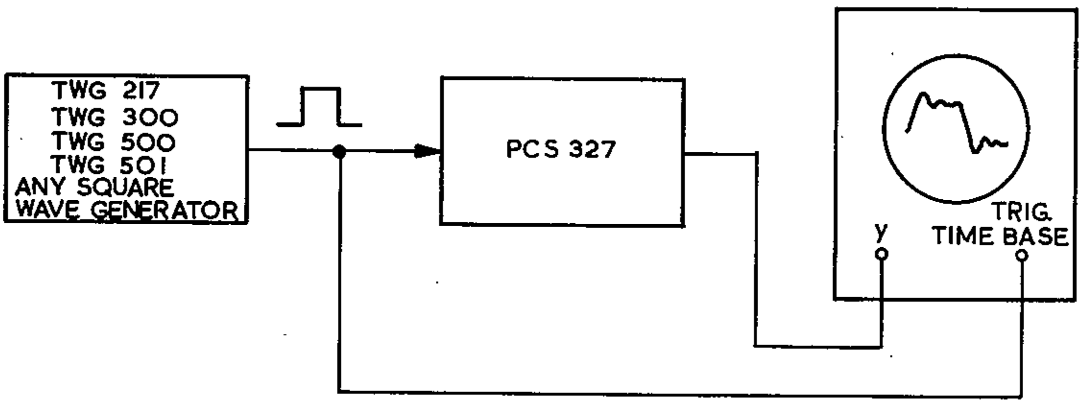


FIG. 3 FREQUENCY AND PHASE MEASUREMENT METHODS

1



2



3

AS 1 BUT USING FEEDBACK SRA225

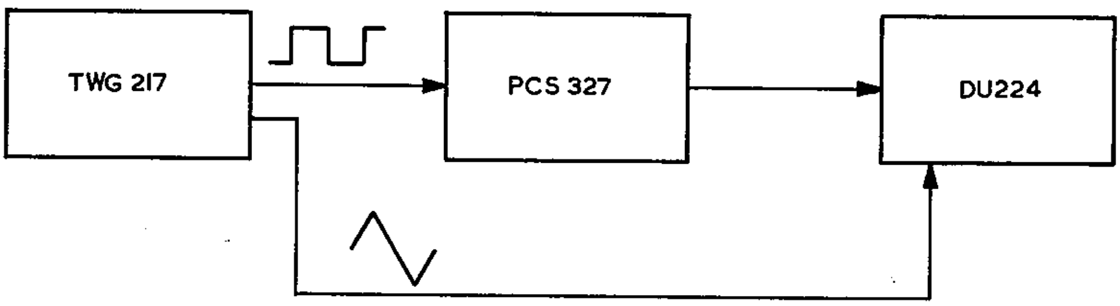


FIG. 4 STEP RESPONSE MEASUREMENT METHODS

4.1 Line voltage selector

Remove the front panel from the case to give access to the power supply and check that the fuse is correctly positioned for the line supply voltage to be used. Replace panel.

Indicator lamp should glow when switched on.

4.2 Amplifier zeros

The operational amplifier zeros are preset and will need adjustment only very rarely (see Maintenance Section).

4.3 Ancillary equipment

The PCS327 will require a source of sinusoidal and/or square input signals for frequency response and step function testing, together with an oscilloscope for observation of responses.

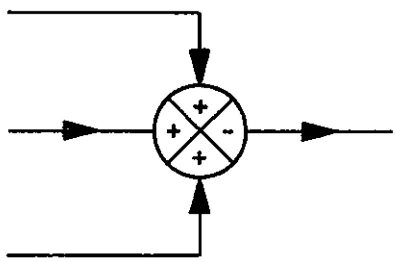
Suitable signal sources are Feedback TWG217, TWG500 or VPO230 (all provided with variable-phase outputs) or TWG300 or TWG501 (without variable-phase).

If a Feedback System Response Analyser type SRA225 is available (TWG217 + DU224) all essential observations, including step responses, can be made with this. Otherwise an oscilloscope having direct coupled horizontal and vertical deflection amplifiers will be needed.

Various methods of obtaining frequency and phase responses and step responses using the above instruments are illustrated in figures 3 and 4.

4.4 Setting up a Process

To set up a process simply patch the required elements in cascade, with the first input patched from the supply disturbance summing element output and the last output patched to the load disturbance summing element input. The inverter is included or not as necessary to ensure that the total number of polarity inversions round a closed loop is always odd. To simplify this, every element which produces an inversion is clearly marked to show the relative polarities of input and output. Summing points are similarly indicated thus:



Notice that for a summing point to behave as if it produced a difference (as required to generate the deviation term) it is sufficient for there to be an odd number of inversions in the loop (including the one produced by the summing point), thus ensuring overall negative feedback.

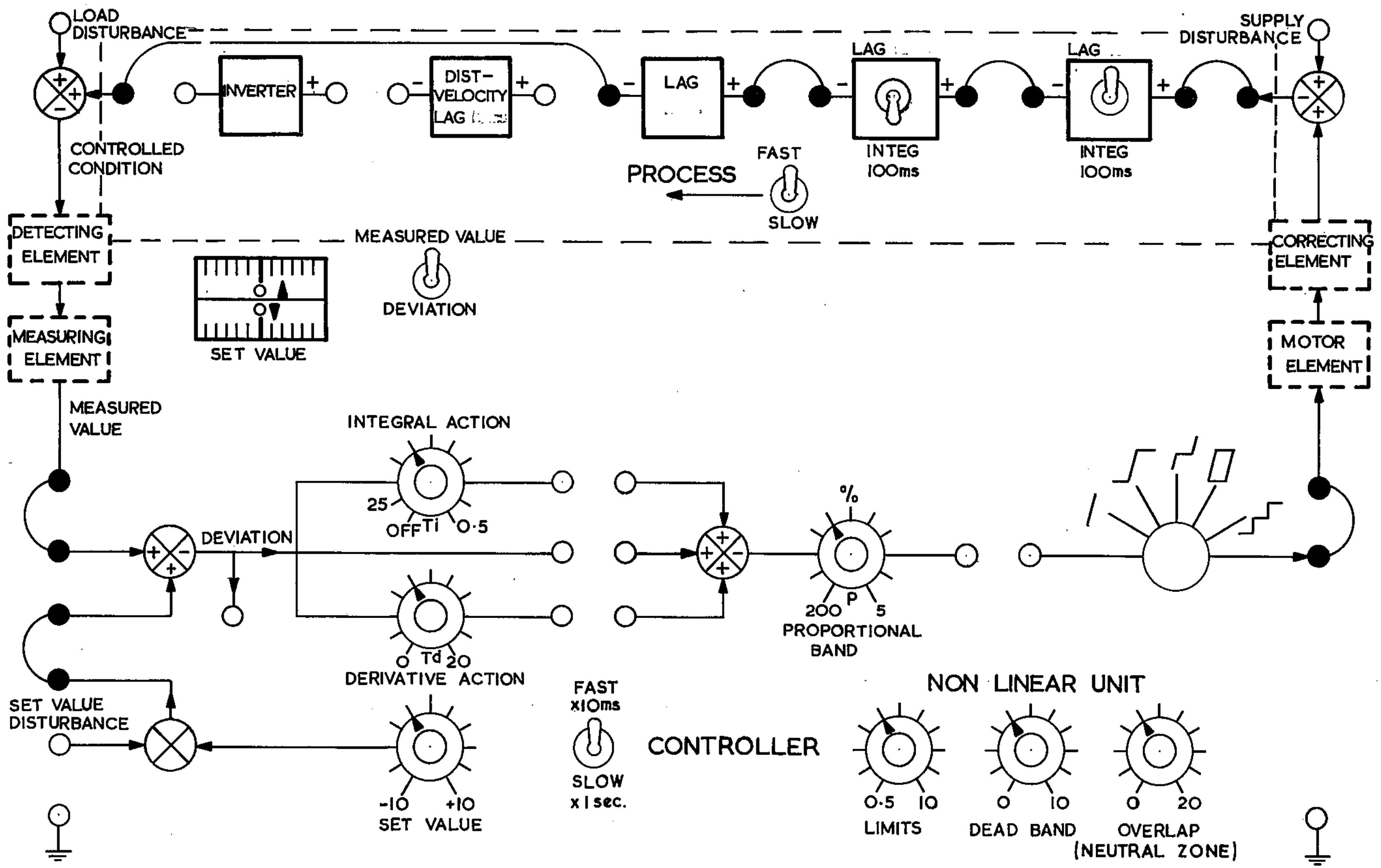


FIG. 5 TYPICAL PATCHING

4.5 Setting up the Controller

The three control terms are linked to the summing point as required for the experiment in hand.

The only other patching needed on the Controller is between the proportional band output and the Process input. This may be done either via the non-linear unit or directly, by-passing this unit, there being no difference in polarity as the non-linear unit produces no inversion.

The SET VALUE control output may be patched to the COMPARING ELEMENT input.

The settings of Ti, Td and P are the subject of the various experiments and are described in the appropriate places.

4.6 Example of a process

Suppose it is required to set up a process containing two simple lags and an integration. The patching would be as in fig 5. Note that the non-linear unit may be by-passed completely or included but set to give a direct through connection, as desired. Without the inverter there are seven inversions round the loop and since this is an odd number as required, the inverter is not included.

4.7 Setting up the Non-linear Unit

The variable quantities L, D and H associated with the non-linear unit are fully defined for each position of the selector by the diagrams in figure 2 and can be set to any desired values by reference to the scales provided on the calibrated controls.

In setting the relay characteristics it will be found that variation of L, which changes the effective output of the relay, has an effect on the degree of hysteresis or overlap such that reduction of L reduces the actual overlap for a given dial setting of H. The calibration of H is correct only when L is set to maximum.

If desired the selected characteristic can be displayed by coupling the input and output to X and Y deflection amplifiers respectively, of an oscilloscope and applying to the input a triangular or sinusoidal signal of ±10V peak, when direct observation of the effects of the controls may be made.

No special comment is necessary except on the backlash characteristic, where it will be noticed that, for a given input amplitude, increase of the value of H must be accompanied by a decrease in output amplitude and vice-versa.

4.8 Overlays

The overlays are secured to the panel by two quick-release spring fasteners on each. The Controller overlay is provided with replicas of the integral, derivative, and proportional control and set value scales.

The pointer provided on this overlay may be used to indicate the type of control currently in use.

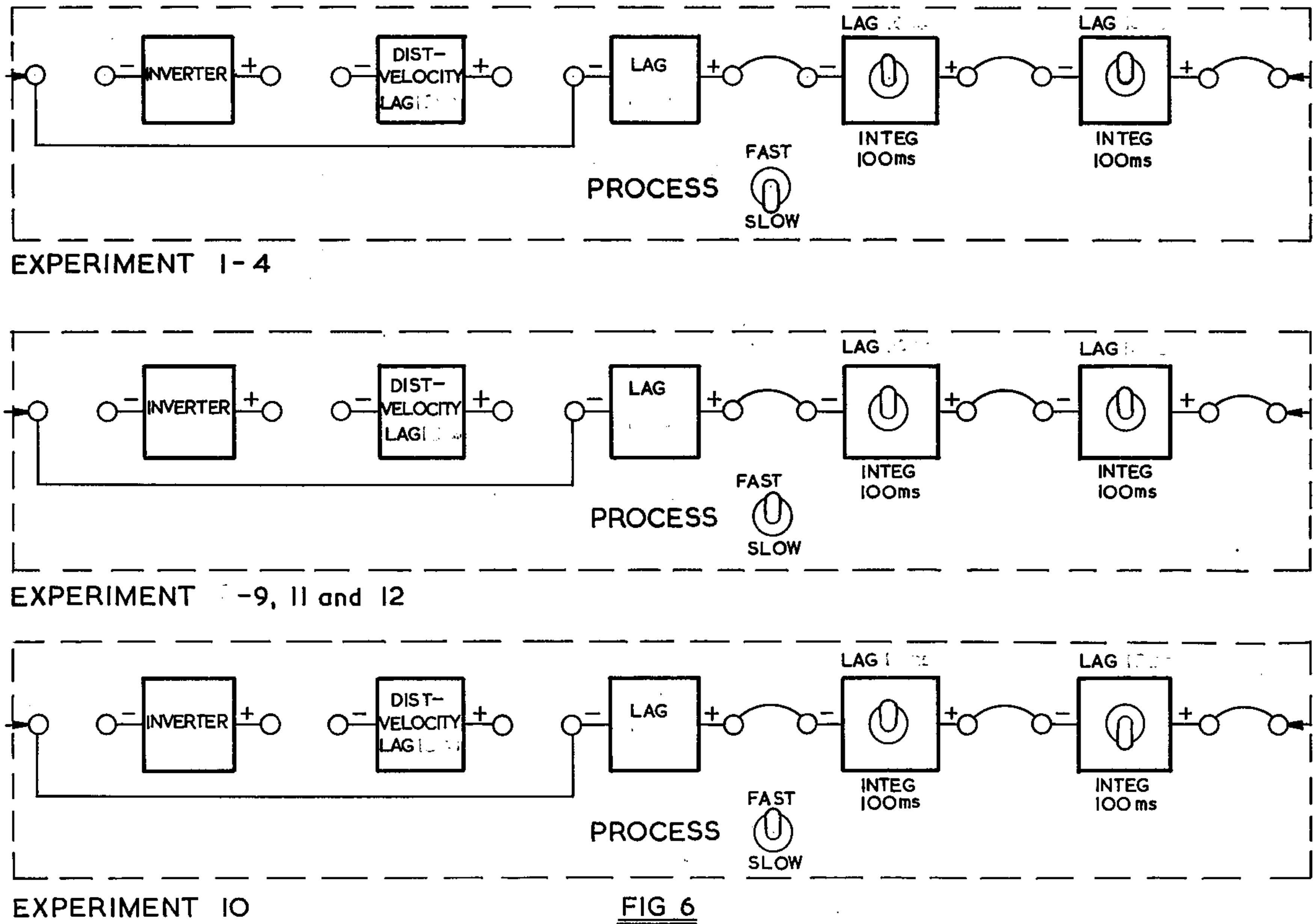

INVERTER
DIST-VELOCITY LAG
LAG
LAG
INTEG 100ms
FAST
SLOW
PROCESS
EXPERIMENT 1-4
EXPERIMENT -9, 11 and 12
EXPERIMENT 10

FIG 6

5.1 Scope

The patch connections for the processes used in the experiments are shown in fig 6 and it is assumed these will be patched up and the overlay fitted prior to the student starting the experiment.

Test signal voltages and frequencies specified in the text are intended as a guide only and can be varied to suit individual needs.

The experiments in this section provide a general coverage for such courses as City and Guilds Instrument Maintenance 309 and Industrial Measurement and Control 310.

As an introduction to more advanced work, APPENDIX 1 contains some experiments on frequency response measurements and methods of setting up controllers.

For demonstration purposes both process and controller can be patched up and the overlays fitted leaving only the relevant controls in view.

5.2 Introduction

A process and its associated control equipment can range from the very simple such as a domestic hot water system, to the highly complex such as an automatic oil refining plant.

The complex system will consist of a number of individual systems which link together to form the whole.

However complex the overall system may be it can be broken into individual simple systems and these can be further reduced into basic component parts which are common for all systems.

A process may be chemical, thermal, electrical, mechanical, etc. or any combinations of these.

Supplies such as steam, water, electricity or mechanical power are fed in and together with some combination of controlling devices produces a desired condition of an end-product, commonly called the 'LOAD' of the system.

Any process control consists of the process plant and the control equipment, each of which have certain characteristics. To understand how the whole system operates a study of each individual part must be made.

The problem of process control is that of matching the characteristics of the controller with that of the plant to obtain the required overall behaviour.

5.3 A simple process and its control

There are four component sections of any process control as shown in fig 7.

The process itself, some device to detect the condition at the output of the process, a controller to act upon infomation from the detecting element, and some device to apply corrective action to the process.

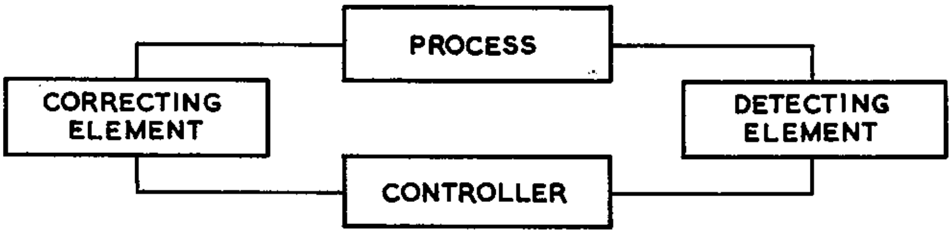


FIG 7

The controller could be a human operator but it is better to have some form of automatic controller.

Let us examine a simple process control such as a domestic hot water system.

The process is that of heating water to a desired temperature, the detecting element the thermometer which forms part of the thermostat, the controller is the switch of the thermostat, and the correcting element the heater.

Operation of the system is such that the water temperature is maintained at a value preset in the thermostat.

327H-18

There are certain definitions used in process control and these can be applied to our simple system.

The CONTROLLED CONDITION is the temperature of the water. A DESIRED VALUE the temperature we specify for the CONTROLLED CONDITION.

SET VALUE is that value set on the thermostat to obtain the DESIRED VALUE.

It should be noted here that due to characteristics of certain forms of controller SET VALUE and DESIRED VALUE are not always the same.

MEASURED VALUE is the value of the controlled condition at any instant in time.

In the system we are considering that the correcting element, i.e the heater, heats the water so bringing the measured value of the controlled condition up towards the set value. Power will be supplied until such time as the difference between the measured value and the set value, i.e DEVIATION, is zero, and the controller switches OFF as the desired value has been reached.

This example of a system has been used to illustrate the meaning of a few definitions and will be examined in greater detail at a later stage.

5.4 Manual ON-OFF open-loop control

An example of a simple process could be an electric furnace for melting metals.

The metal constitutes the load and the desired condition is that the metal be at melting point. The supply is the power to the heating elements and the control the switch controlling the power to the elements.

If a thermometer is fitted to the furnace, a human operator can monitor the temperature and switch the power ON and OFF as necessary to keep the metal at the required temperature.

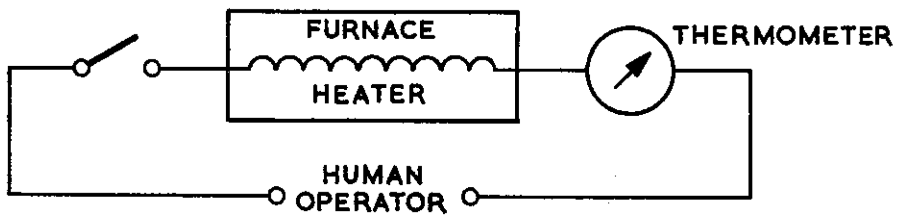


FIG 8

An arrangement such as in fig 8 is an 'open loop' system, as the link between the furnace temperature and the power control is formed by something external to the actual system, i.e the human operator.

Such systems have certain disadvantages which can be examined in the following experiment.

EXPERIMENT 1 SIMPLE OPEN-LOOP TWO-STEP CONTROL

Patch the front panel of the PC S327 is in fig 9.

Set the controls and switches as indicated.

Adjust the Set Value control until the Measured Value meter reads approx. 10.

Using the shorting link A in fig 9 as an ON-OFF switch try to make the MEASURED VALUE meter indicate five.

SUMMARY

In this experiment the simulator was used to represent the furnace, and the shorting link the ON-OFF switch, with the human operator performing the control.

The DESIRED VALUE, i.e the required temperature of the furnace, was zero, and the MEASURED VALUE was the actual temperature at any time.

Power to the furnace was either fully ON or OFF. By continual switching ON and OFF the temperature could be kept somewhere near the DESIRED VALUE, but this was a difficult process.

Such a system would be inefficient and probably unacceptable.

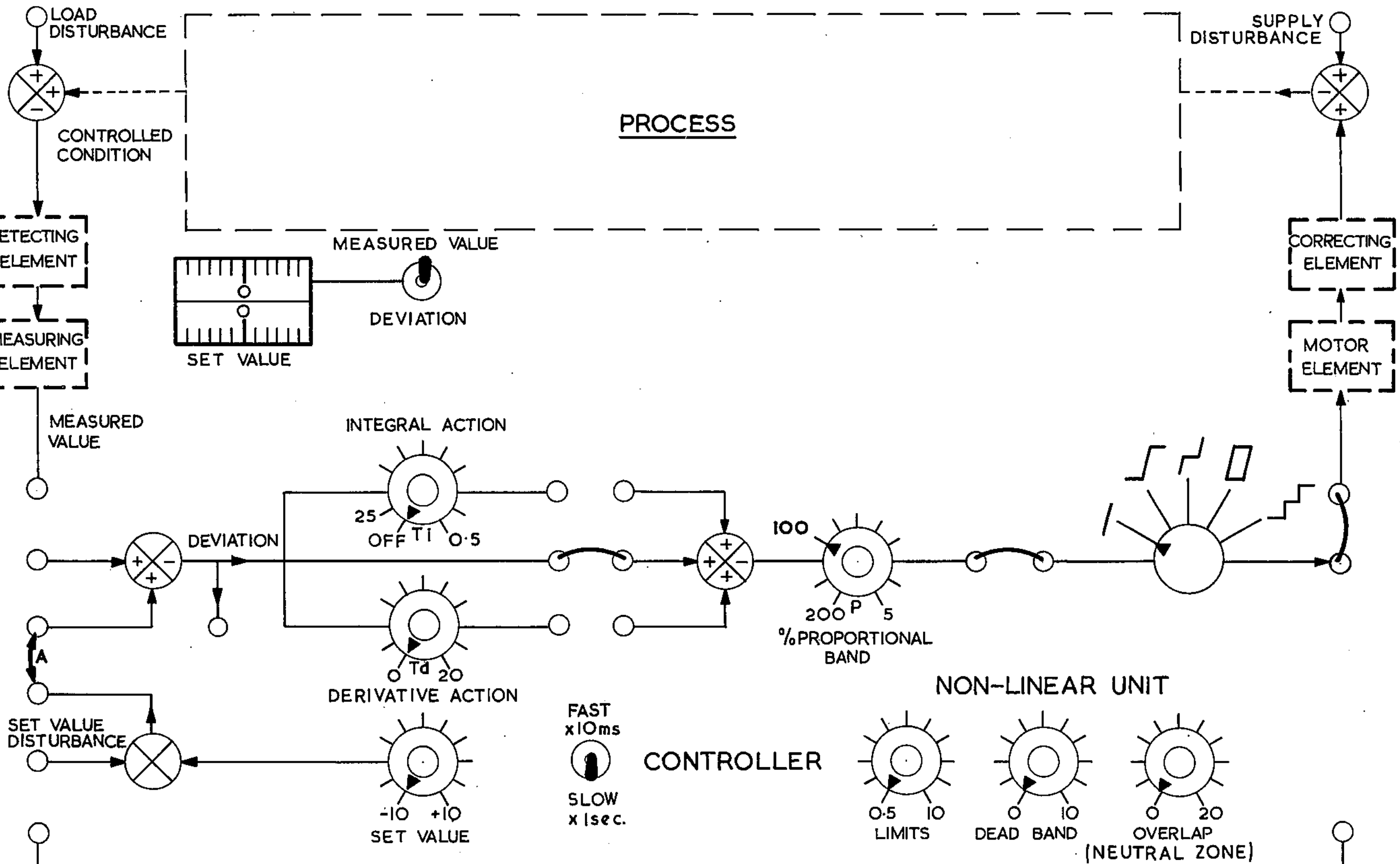

LOAD DISTURBANCE
CONTROLLED CONDITION
PROCESS
SUPPLY DISTURBANCE
DETECTING ELEMENT
MEASURING ELEMENT
MEASURED VALUE
SET VALUE
MEASURED VALUE
DEVIATION
CORRECTING ELEMENT
MOTOR ELEMENT
DEVIATION
INTEGRAL ACTION
25
OFF
Ti
0·5
DERIVATIVE ACTION
0
Td
20
A
SET VALUE DISTURBANCE
-10
+10
SET VALUE
FAST x10ms
SLOW x1sec.
CONTROLLER
100
200
P
5
%PROPORTIONAL BAND
NON-LINEAR UNIT
0·5
10
LIMITS
0
10
DEAD BAND
0
20
OVERLAP (NEUTRAL ZONE)

FIG 9