PROCESS TRAINER
PT 326

FEEDBACK INSTRUMENTS LIMITED. CROWBOROUGH. SUSSEX. ENGLAND.
Telephone: Crowborough (089 26) 3322. Cables: Feedback Crowbr Telex. Telex: 95255.

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The Health and Safety at Work Act 1974

We are required under the Health and Safety at Work Act 1974, to make available to users of this equipment certain information regarding its safe use.

The equipment, when used in normal or prescribed applications within the parameters set for its mechanical and electrical performance, should not cause any danger or hazard to health and safety if normal engineering practices are observed and they are used in accordance with the instructions supplied.

If, in specific cases, circumstances exist in which a potential hazard may be brought about by careless or improper use, these will be pointed out and the necessary precautions emphasized.

While we attempt to give the fullest possible user information in our handbooks, if there is any doubt whatsoever about any aspect relating to the proper use of this equipment the user should contact the Product Safety Officer at Feedback Instruments Limited, Crowborough.

Component replacement

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

We endeavour to improve our equipment continually by incorporating the latest developments and components, even up to the time of despatch. If it is practicable we include such new or revised information in the manual.

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.

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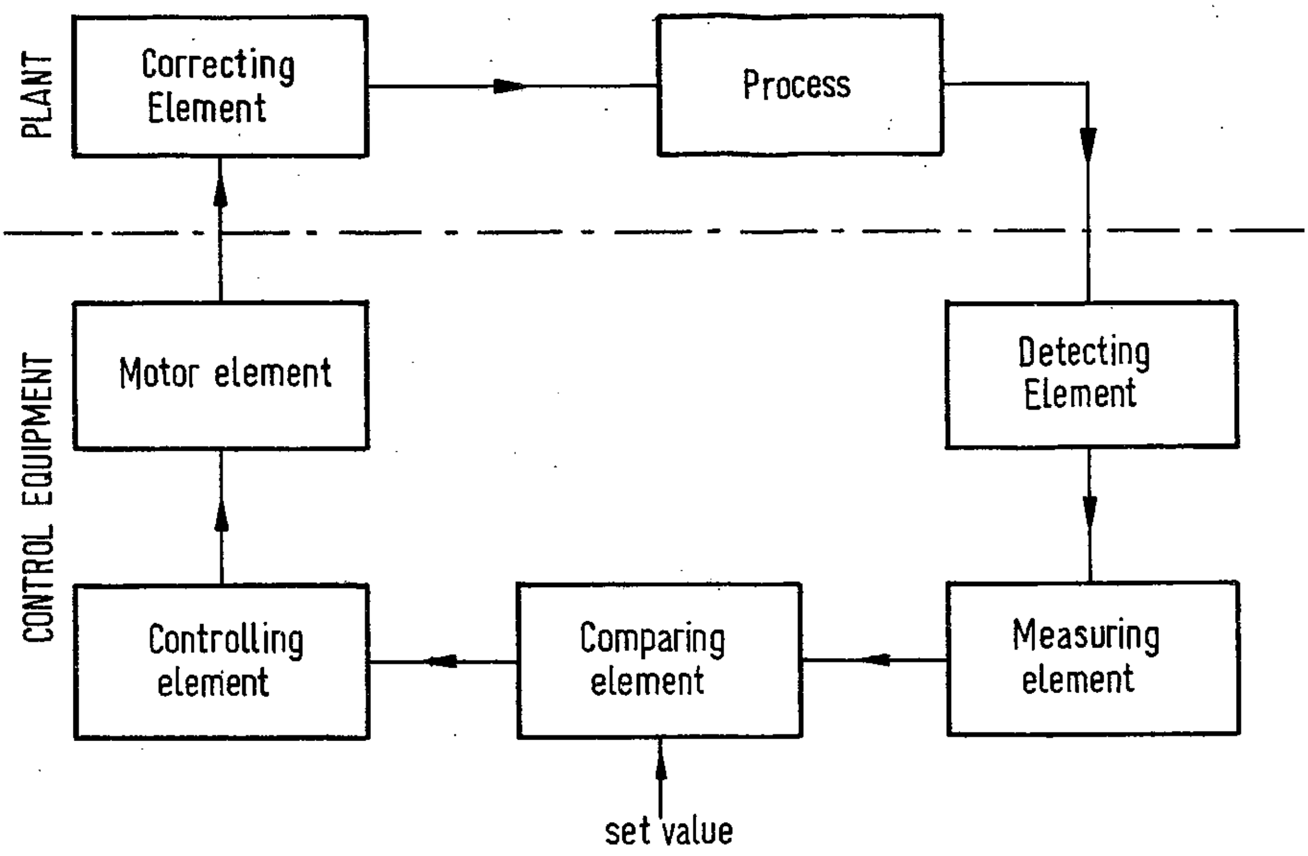
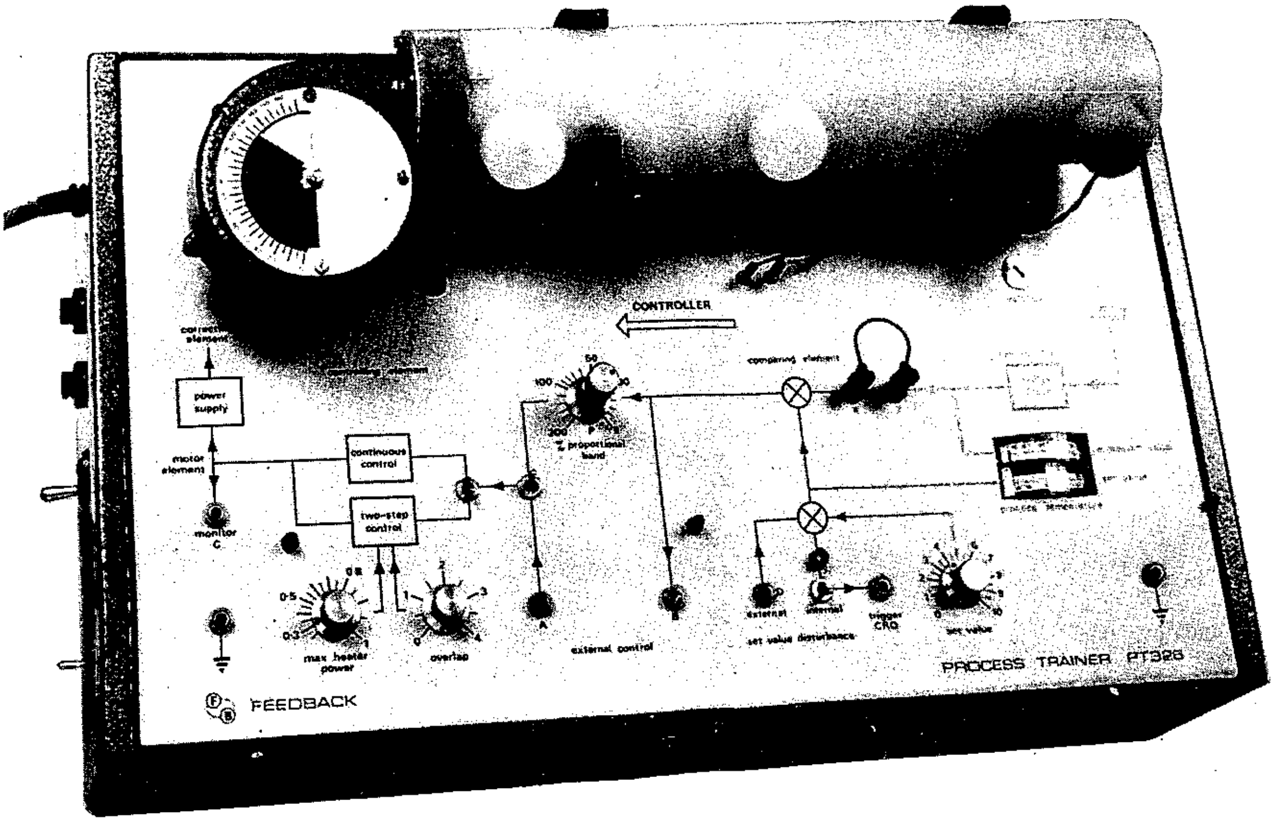


BASIC ELEMENTS OF CLOSED LOOP PROCESS CONTROL SYSTEM FIG 1



LAYOUT OF FRONT PANEL FIG. 2

INTRODUCTION

SECTION 1

The PT326 Process Trainer is a self-contained process and control equipment. It has the basic characteristics of a large plant, enabling distance/velocity lag, transfer lag, system response, proportional and two-step control etc. to be demonstrated. Due to its relatively fast response, changes in set value and measured value can be displayed on an oscilloscope.

In this equipment, air drawn from atmosphere by a centrifugal blower is driven past a heater grid and through a length of tubing to atmosphere again. The process consists of heating the air flowing in the tube to the desired temperature level, and the purpose of the control equipment is to measure the air temperature, compare it with a value set by the operator and generate a control signal which determines the amount of electrical power supplied to a correcting element, in this case a heater mounted adjacent to the blower. The elements which form the system are shown in fig 1 and the layout of the front panel in fig 2.

The instrument contains integrated circuit operational amplifiers and has self-contained power supplies. It can be coupled to the Feedback Process Control Simulator PCS327 for the application of three-term control to the process.

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

UK - British Standard BS1523 : 1960 Section 2.
USA - 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'
'Controlled signal' or 'Correcting condition'	'Manipulated variable'
'Overlap'	'Neutral zone'

PT326 PROCESS TRAINER - GENERAL DESCRIPTION SECTION 2

Supplies

The equipment operates from an a.c mains supply of either 220-250V, or 100-120V selected by a change-over switch mounted beneath the front panel. The mains on-off switch, neon indicator lamp, 2A and 100mA fuses are mounted on the left-hand side of the instrument.

Front Panel

The elements which make up the system are shown in block diagram form on this panel. An overlay is provided, which can be fitted over the controlling element, leaving only the proportional band adjustment visible.

Process

This general term is used to describe a physical or chemical change or the conversion of energy, and includes change of pressure, temperature or speed of a fluid, the rate at which a chemical reaction proceeds, the level of liquid in a tank, etc. In this case the temperature of air flowing in the process tube is raised to a desired value within the range of ambient temperature to 60°C.

Detecting Element

A bead thermistor fitted to the end of a probe can be inserted into the air stream at any one of three points along the tube, spaced 1.1in (28mm), 5.5in(140mm) and 11in (279mm) from the heater.

Measuring Element

The thermistor probe forms one arm of a d.c bridge which is in balance at 40°C. The bridge output voltage is applied to a d.c amplifier and produces a voltage varying from 0 to +10 volts for an air temperature change of 30°C to 60°C. The output from the measuring element can be monitored at Socket Y on the front panel.

Measured Value θ_o

This is the output signal from the measuring element corresponding to the value of the controlled condition.

Set Value θ_i

This is the value of the controlled condition to which the automatic controller is set. The internal set value control can be used to raise the process air temperature to 60°C. Set value may be adjusted externally by applying a voltage between 0 and -10V to socket D on the front panel, a negative going change in voltage producing a rise in process temperature.

Deviation θ

The difference between the measured value of the controlled condition and the set value.

$$\theta = \theta_o - \theta_i$$

Set Value Disturbance

By operating the switch marked INTERNAL SET VALUE DISTURBANCE a step change in set value is applied internally.

Comparing Element

A summing amplifier is used to compare the measured value from the bridge amplifier with the set value. In this equipment the signals are arranged to be of opposite sign, so that the output from the summing amplifier represents deviation. This can be monitored at socket B on the front panel.

Controlling Element

A signal proportional to deviation is applied to the controlling element, which then generates a control signal for transmission to the correcting unit.

In this equipment the controlling element can be switched to give either continuous or two-step control. The control output signal can be monitored at socket C on the front panel.

Continuous Control

1. Internal This gives proportional action only, with means of adjustment of 'proportional band', i.e the range of values of deviation which will cause the controller output to vary over its full working range, expressed as a percentage of the range of the measuring element.

2. External The proportional band adjustment can be switche out of circuit and in its place a PCS327 Process Control Simulator can be connected. This permits proportional +integral, proportional +derivative, proportional +integral +derivative action to be used.

Two-step Control

When the controlling element is switched to two-step or on-off action the proportional band adjustment is by-passed and adjustment of maximum heater power and overlap introduced into the system. These terms are defined below.

Maximum Heater Power This adjustment enables the power applied to the heater during 'on' periods to be set between 15 and 80 watts.

Overlap With zero overlap the controller output signal causes the power applied to the heater to alternate between maximum and minimum levels as the controlled condition falls below or rises above the desired value.

With a given overlap the controller output signal causes the power applied to the heater to alternate between maximum and minimum levels as the controlled condition falls below a lower limit or rises above an upper limit.

Motor Element

In any process this element produces an output which may take the form of electrical power, mechanical displacement etc, where the level of the output signal is adjusted in response to a signal from the controlling element. In this equipment the motor element is a variable power supply which gives an electrical output of between 15 and 80 watts as determined by the controller signal.

Correcting Element

Directly affects the controlled condition. In this equipment the correcting element is an electrically heated wire grid, to which the output from the motor element is applied. Heat is transferred from the grid to the moving air, the rate of heat transfer being dependent on the heater temperature and the air flow velocity etc.

Automatic Controller

Comprises the Measuring, Comparing and Controlling elements.

Correcting Unit

Comprises the Motor and Correcting elements.

SPECIFICATION

SECTION 3

General

Input signal voltage range	0 to -10V
Output signal voltage range	0 to +10V
Minimum resistive load on any output	5kΩ
Set value and measured value meter scales	0 to 80°C

Process

Air flow range	1 to 10 ft/sec
Heater power range	15 to 80 watts
Controlled air temperature range	30° to 60°C
With throttle opening of 40° and detector at 11" position:-	
Distance/velocity lag	0.18 sec

Controller

Continuous control	
Proportional band	200% to 5% corresponding to gain of 0.5 to 20
Set value adjustment scale	0 to 10
Set value range	30°C to 60°C
Measured value range	30°C to 60°C
Two-step Control	
Max heater power scale	0.25 to 1
Overlap scale	0 to 4

Power supply and internal voltage levels

AC supply input	220 to 250V, 50/60Hz or 110 to 120V, 50/60Hz
Internal d.c lines	±15V
Internal a.c heater line	115V, 50/60Hz

Dimensions

Width	Depth	Height	Weight
20.5in 520mm	11.5in 292mm	8.5in 216mm	21lb 9.5kg

Initial operation

Confirm that the screw-in fuses mounted on the left-hand panel of the instrument are as labelled. Switch on and set the switch on the side of the Trainer to HEATER; check that the main indicator lamp glows and that the blower operates. Make the connections and settings shown in fig 3 and leave the instrument to run for a warm-up period of approximately half an hour.

Check that an increase in the SET VALUE adjustment causes both the set value and measured value meter readings to increase. Switch on the internal SET VALUE DISTURBANCE and check that the adjacent indicator lamp glows and that there is an increase in the set and measured value meter readings.

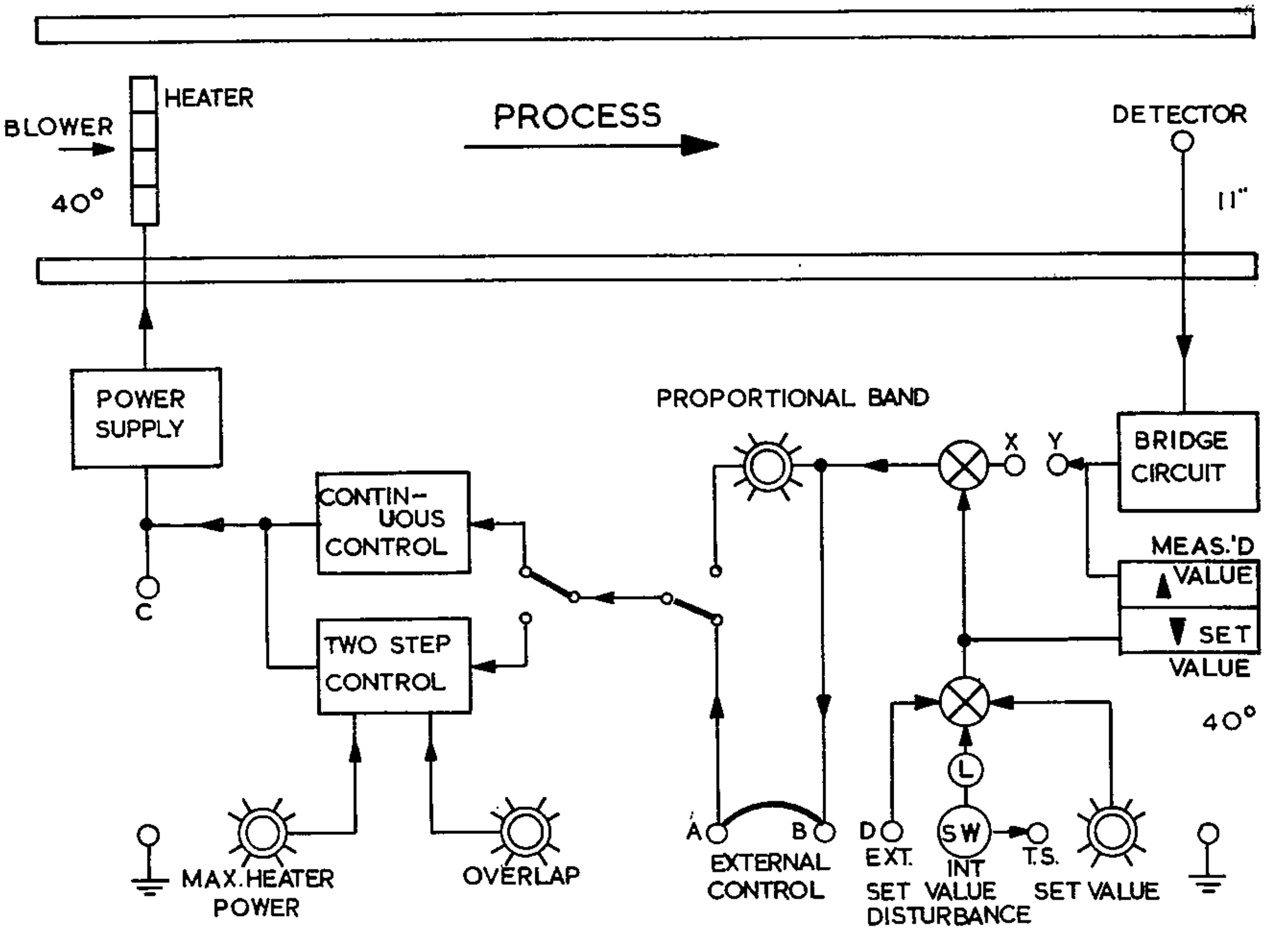


FIG 3

Ancillary equipment

The PT326 requires a source of sinusiodal, trapesoidal and square wave input signals for frequency response and step function testing.

Suitable signal sources are Feedback TWG500 (with variable phase output) or FG600, TWG501 (without variable phase).

An oscilloscope is required to display set and measured values, deviation or controller output signals. It should preferably be one with a long persistance trace, capable of either X - Y or time-base operation.

Open-loop operation

With the connections shown in fig 3 the process temperature may be controlled manually by adjustment of SET VALUE. With this connection the PROPORTIONAL BAND adjustment is by-passed, leaving the controller set to unity gain (100% proportional band).

The response to a step change or ramp input signal enables distance/velocity and transfer lags to be measured and the effect of changing the air flow rate can be observed. With sinusoidal input signal the frequency response characteristics can be determined.

Closed-loop operation

By linking X to Y the feedback loop is closed and the process is then under either continuous control with variable proportional band adjustment or two-step control with variable heater power and overlap adjustments.

The effect of percentage proportional band on deviation and stability, of overlap on frequency of operation, can be demonstrated.

Use of Process Control Simulator PCS327

The controller of the PCS327 can be used to provide three-term control of the Process Trainer PT326. When the two are interconnected the addition of Integral and/or Derivative control action enables deviation to be reduced to zero and response time decreased.

Overlay Panel

An overlay panel can be fitted over part of the controller to simplify the feedback loop diagram when connected for proportional control. Is is secured to the front panel by two quick-release spring fasteners.

SECTION 5

BASIC THEORY AND EXPERIMENTS

1. DISTANCE/VELOCITY LAG
2. TRANSFER LAG
3. CALIBRATION
4. TWO-STEP CONTROL
5. PROPORTIONAL CONTROL
6. DISTURBANCE AND SYSTEM RESPONSE
7. FREQUENCY RESPONSE
8. COMPOUND CONTROLLER ACTION

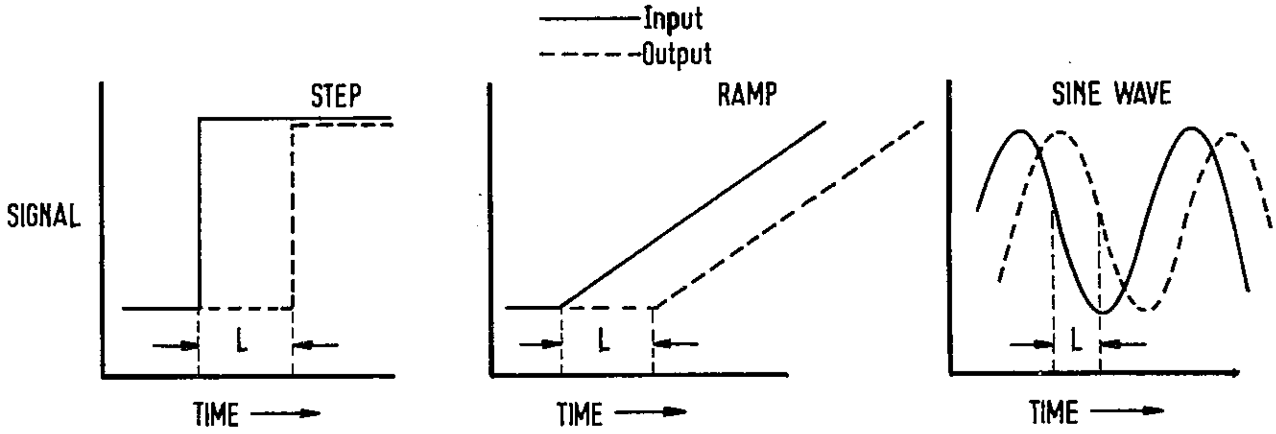
EXPERIMENT 1 DISTANCE/VELOCITY LAG

An alteration to the condition of a process affects the detecting element after a time interval which is dependent on the velocity of the process and the distance between the point of change and the detector. This time interval L is the distance/velocity or transport lag, as given by the equation

$$L = \frac{\text{distance}}{\text{velocity}}$$

It represents a pure lag, there being no change in the magnitude or form of the signal.

The effect of distance/velocity lag on different forms of input signal is shown in fig 4.



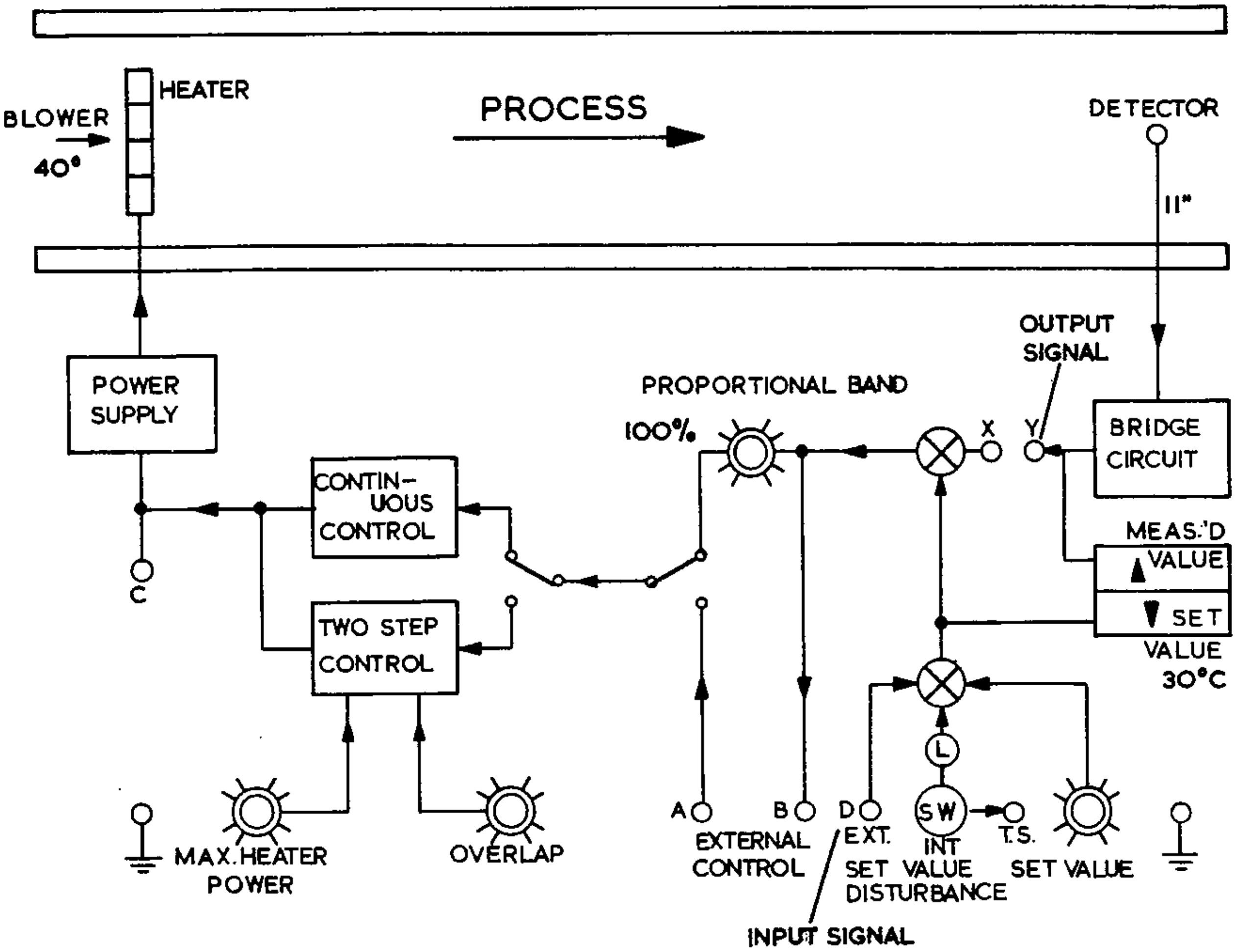
DISTANCE / VELOCITY LAG

FIG. 4

OPERATING NOTES

This process is carried out with the control loop open and the controller set to 100% proportional band (PB). After switching to CONTINUOUS CONTROL the overlay may be fitted over part of the controller, leaving the proportional band adjustment visible.

With the process temperature at a low level a step change in set value is introduced either from an external source or by operation of the switch on the Process Trainer. An increase in set value increases the power applied to the heater element leading to a rise in process temperature, its final value measured on open loop being determined by the inherent regulation of the system.



CONNECTION DIAGRAM

FIG 5

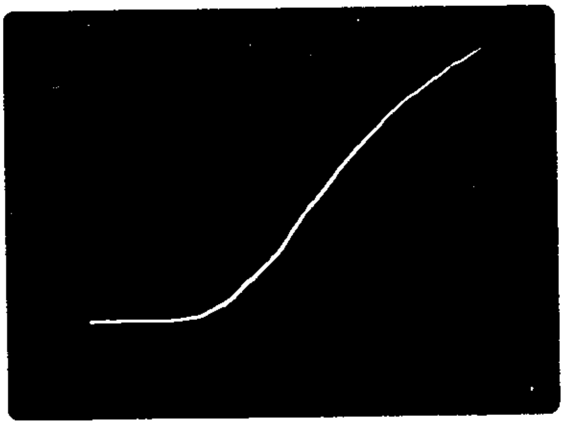


Fig 6a

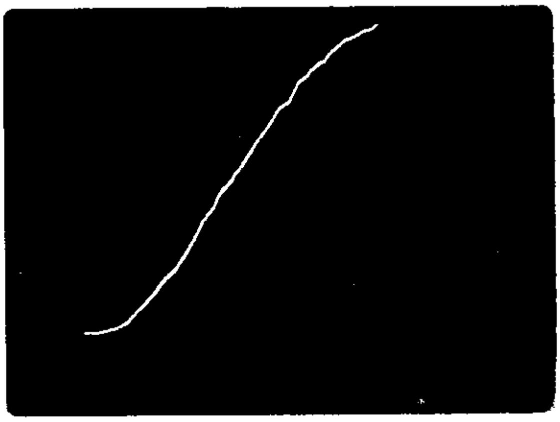


Fig 6b

Process Trainer

Make the connection and switch settings given in fig 5.

Adjust SET VALUE to 30°C

Adjust BLOWER INLET to 40°

Place DETECTOR PROBE in 11" position

Then set switch on side of Trainer to HEATER

Set Value Disturbance

If a waveform generator is available set it to give a 2-volt, 0.1Hz, square wave and connect to SOCKET D on Process Trainer.

Connect the trigger output to the external trigger socket of the oscilloscope.

If a waveform generator is not available the SET VALUE DISTURBANCE switch on the Process Trainer may be used to provide a 2.5-volt step change in set value. In this case the oscilloscope is triggered from the TRIGGER CRO socket.

Oscilloscope (Preferably with long persistance tube)

Set Y1 to 1 volt/div and connect to SOCKET Y on the Process Trainer.

Set the time-base to 0.1 sec/div, external trigger.

OPERATION

Switch on the Process Trainer and ancillary instruments and adjust the oscilloscope so that it is triggered by the waveform generator or by a step change of set value.

The measured value as displayed on the oscilloscope will take the form shown in fig 6a. The change in measured value due to the step change of input commences after a delay of approximately 0.18sec. This is the distance/velocity (d/v) lag corresponding to the chosen air flow rate and heater/detector spacing.

Repeat the test with detector probe moved to the 1.1" position. This will give a much reduced d/v lag, as shown in fig 6b.

With the detector in the 11" position, increase air flow rate by increasing the blower throttle angle from 40° to 60° and observe that the d/v lag has decreased.

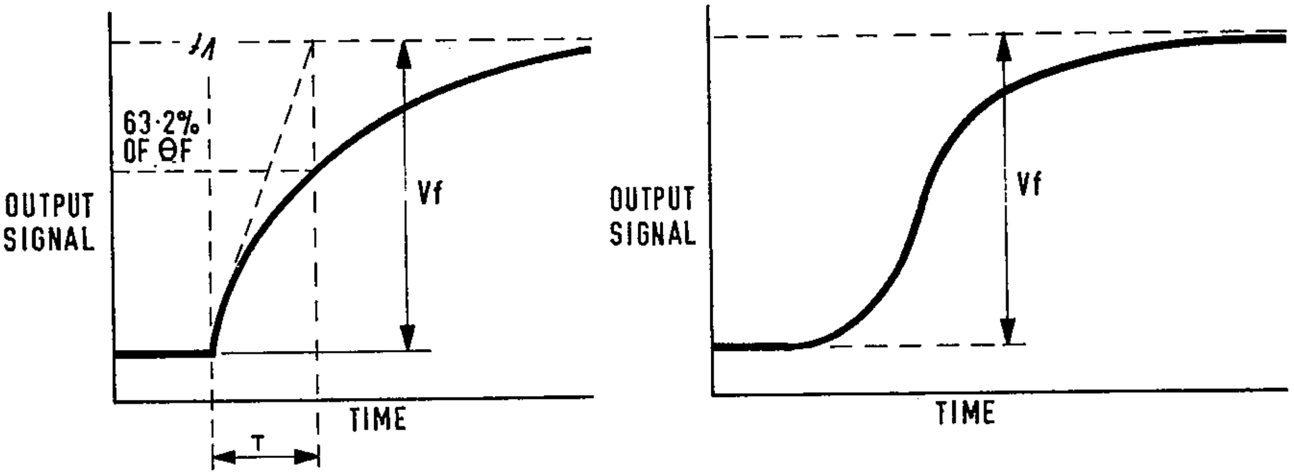
In all these tests it will be seen that in addition to d/v lag there is a further time delay due to the asymptotic rise of process temperature to its final value. This is known as transfer lag and will be discussed in the next experiment.

EXPERIMENT 2 TRANSFER LAG

The response of the detector to a step change in heater power is affected by two time lags - distance/velocity lag, which has no effect on the form of the input signal, and transfer lag, which does affect the form of the signal.

In any stage of a thermal process where heat is transferred through thermal resistance to or away from a thermal capacity, the temperature rise following a step change of input, is exponential as shown in fig 7a. It reaches 63.2% of its final value Vf after time T, which is the exponential lag of that stage.

In a complete process several exponential lags are normally present, leading to a response curve of the form shown in fig 7b, and producing a time lag which is referred to as the transfer lag of the process.



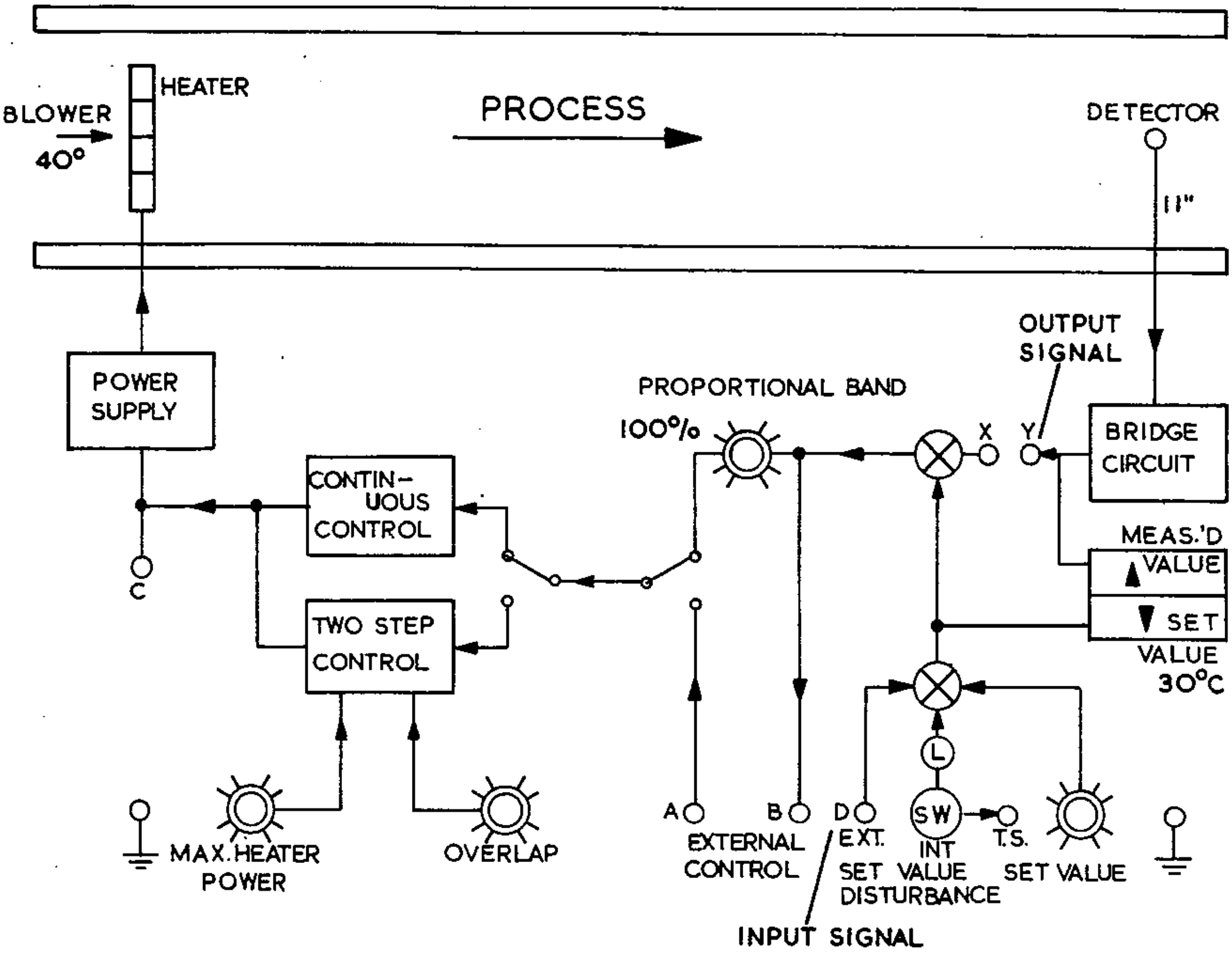
a. WITH SINGLE EXPONENTIAL LAG b. WITH MORE THAN ONE EXPONENTIAL LAG

RESPONSE OF SYSTEM TO STEP CHANGE OF INPUT SIGNAL FIG 7

OPERATING NOTES

In this experiment the control loop is open and the controller set to 100% PB. With the process temperature at a low level a step change in set value is introduced either from an external source or by operation of the switch on the process trainer. The amplified response of the detecting element is displayed on an oscilloscope, showing distance/velocity and transfer lag.

With the system switched to continuous control the overlay may be fitted over part of the controller leaving the proportional band adjustment visible.



CONNECTION DIAGRAM

FIG 8

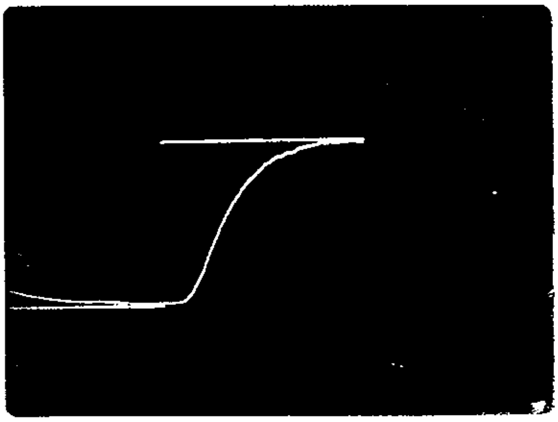


Fig 9a

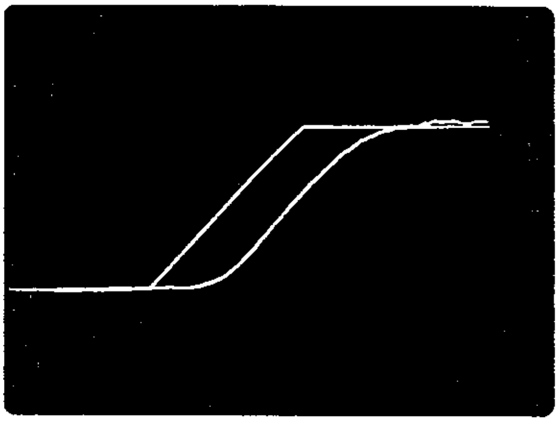


Fig 9b

Process Trainer

Make the connections and switch settings given in fig 8.

Adjust SET VALUE to 30°C

Adjust BLOWER INLET THROTTLE to 40°

Place DETECTOR PROBE in 11" position

Then set switch on side of Trainer to HEATER

Set Value Disturbance

If a waveform generator is available, set it to give a 2-volt, 0.1Hz, square wave. Connect the square-wave output to socket D on the Process Trainer.

Connect the trigger output to the external trigger socket of the oscilloscope.

If a waveform generator is not available the SET VALUE DISTURBANCE switch on the Process Trainer may be used to provide a step change in set value. In this case the oscilloscope is triggered from the TRIGGER oscilloscope socket.

Oscilloscope (Preferably with a long persistence tube)

Set Y1 to 1v/div and connect to SOCKET Y on Process Trainer.

Set time base to 0.5 sec/div, external trigger.

OPERATION

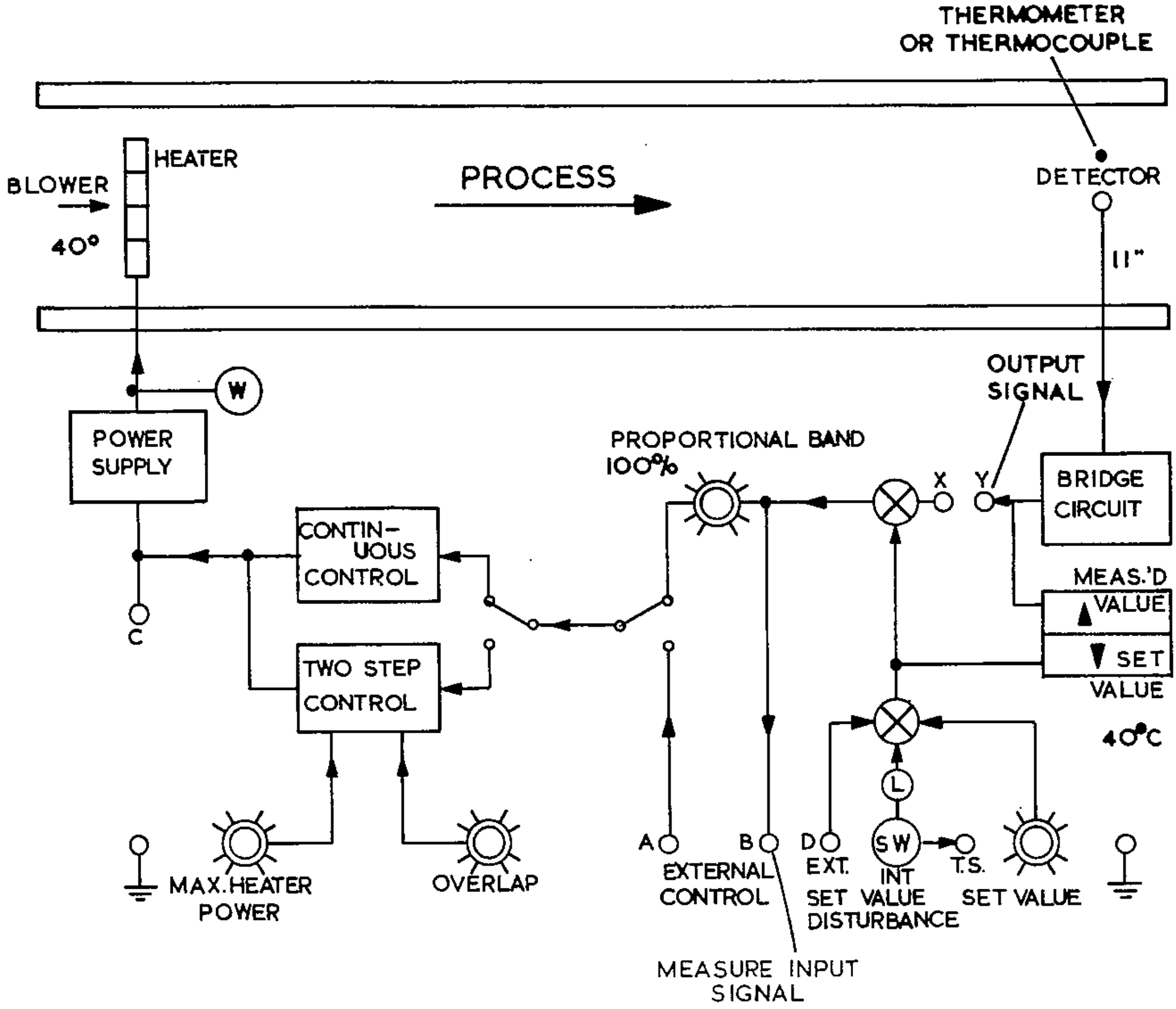
Switch on the Process Trainer and ancillary instruments.

Adjust the oscilloscope so that it is triggered by the waveform generator or a step change of set value.

The measured value, as displayed on the oscilloscope will take the form shown in fig 9a.

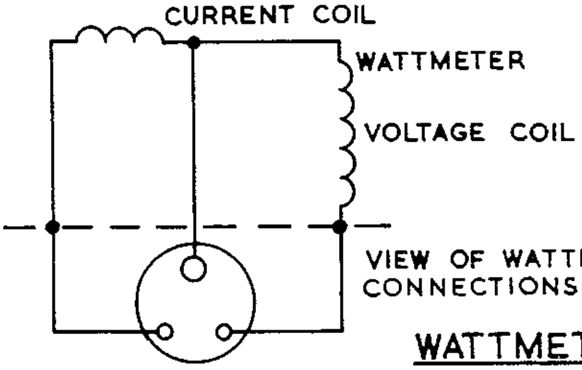
Repeat with a trapesoidal signal from the waveform generator to show a ramp change in set value. This will give a measured value response similar to that shown in fig 9b.

Repeat with the blower inlet throttle set to 60° and observe the resulting decrease in transfer lag.



CONNECTION DIAGRAM

FIG 10



VIEW OF WATTMETER PLUG
CONNECTIONS WITH COVER REMOVED

WATTMETER CONNECTIONS

EXPERIMENT 3

CALIBRATION

Steady state signal levels at different parts of the system can be measured and the results used to obtain the relationship between set value, heater power level, air temperature etc.

These tests are carried out on open-loop with a d.c input signal. In a later experiment the response of the system to a sine wave output is considered.

After switching to CONTINUOUS CONTROL the overlay may be fitted over part of the controller leaving the proportional band adjustment visible.

OPERATING NOTES

Process Trainer

Make the connections and switch settings shown in fig 10.

Adjust BLOWER INLET to 40°

Place DETECTOR PROBE in 11" position

Set PROPORTIONAL BAND to 100%

Wattmeter - To cover range 10 - 100 watts.

Set switch on side of Trainer to WATTMETER

Max. voltage: 120V AC

Max. current: 1.0A AC

Connect wattmeter plug as shown in fig 10.

Voltmeters

Two 0 - 15V DC. Connect one voltmeter between socket Y and earth and the other between socket B and earth.

Air Temperature

Thermometer or Thermocouple placed in air stream near detector probe.

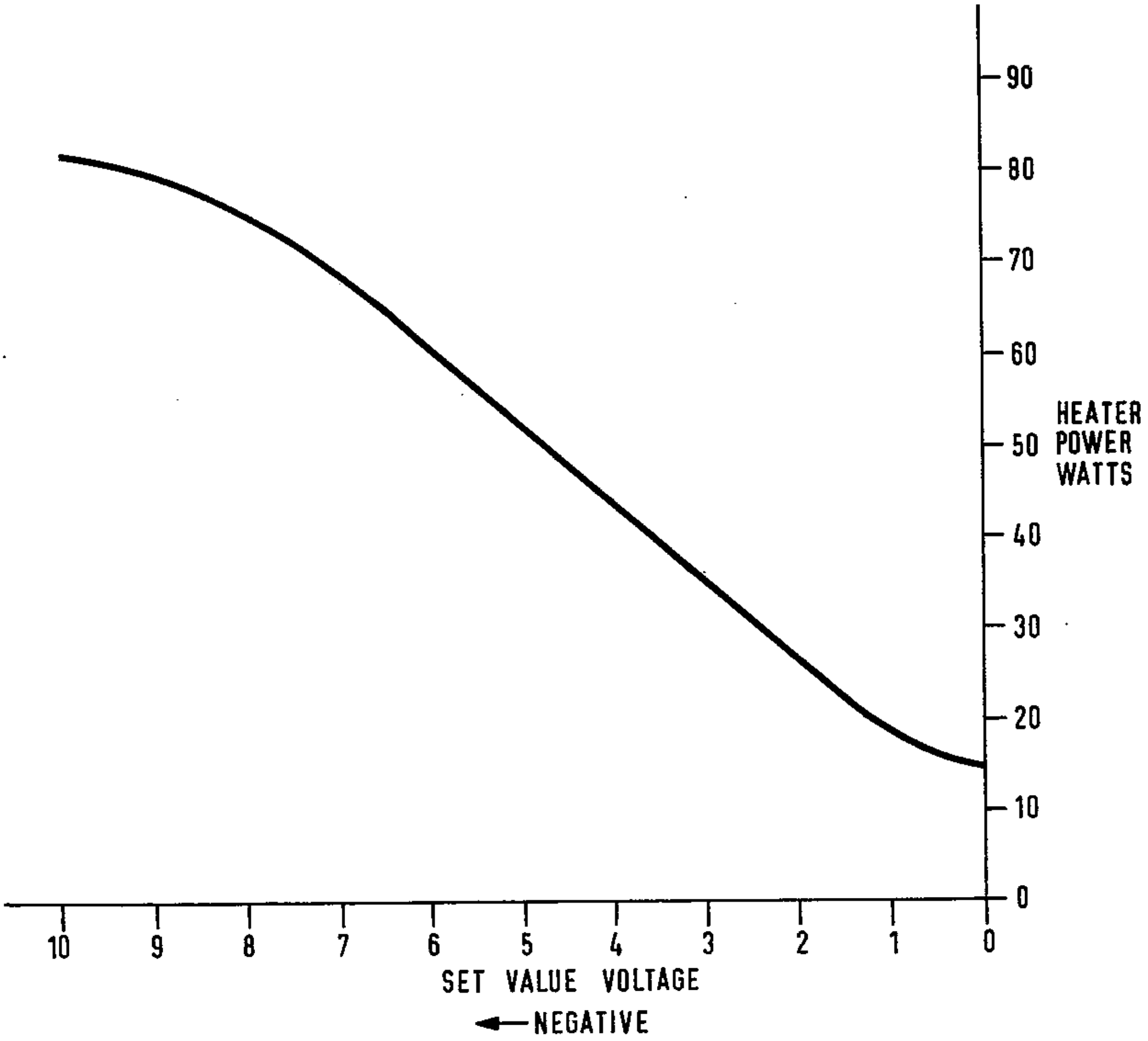
Temperature range: 0 to 80°C.

OPERATION

Switch on the Process Trainer.

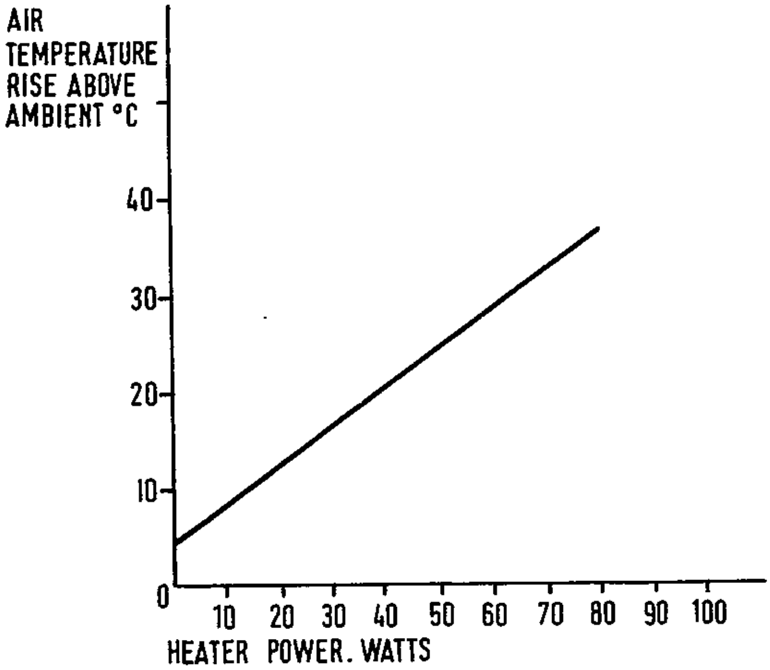
Adjust SET VALUE voltage, measured at socket B from 0 to -10V in steps, taking readings of set value voltage, heater power, process air temperature and measured value voltage at each step.

Figs 11 and 12 show typical graphs of heater power/set value and air temperature rise/heater power.



HEATER POWER / SET VALUE

FIG 11



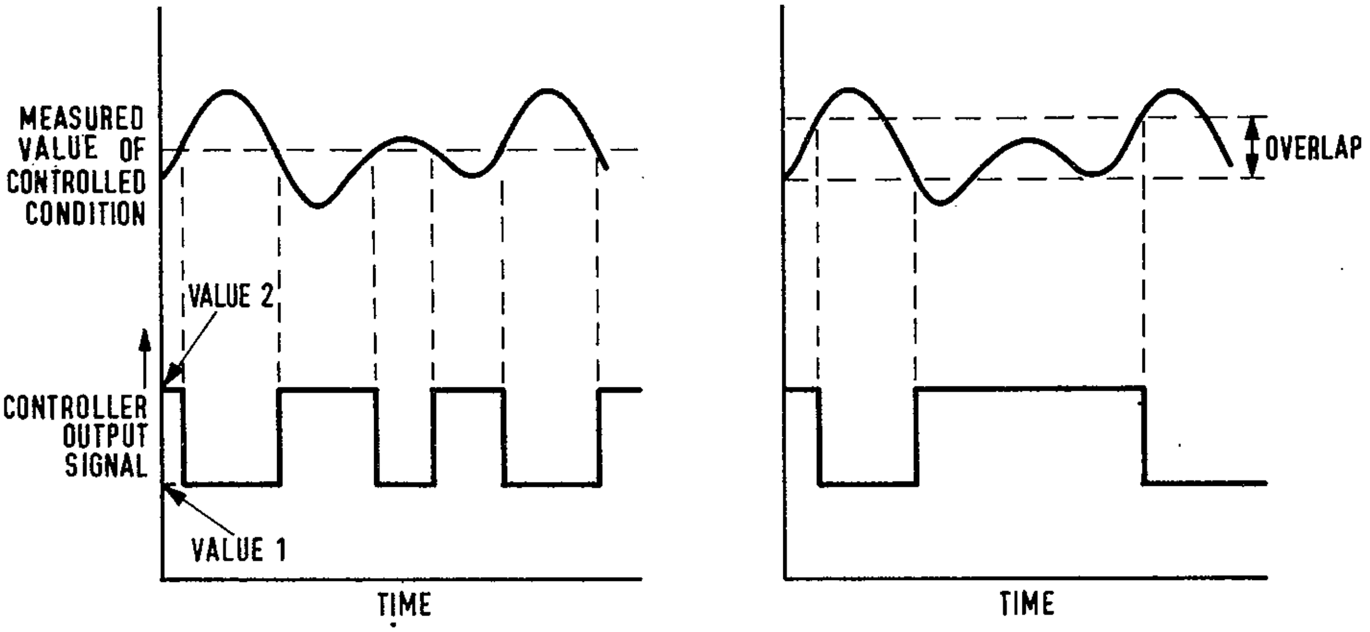
AIR TEMPERATURE RISE/HEATER POWER

FIG 12

EXPERIMENT 4 TWO-STEP CONTROL

In a two-step controller the output signal changes from one pre-determined value to another when the deviation changes sign. This leads to a system in which the controlled condition alternates above and below a mean value at a frequency determined by the energy level at which the correcting element operates, and by the distance/velocity and transfer lags, fig 13a.

With overlap applied, the controller changes to its higher value when the controlled condition falls below a lower limit, and to its lower value when the controlled condition exceeds an upper limit, as in fig 13b.



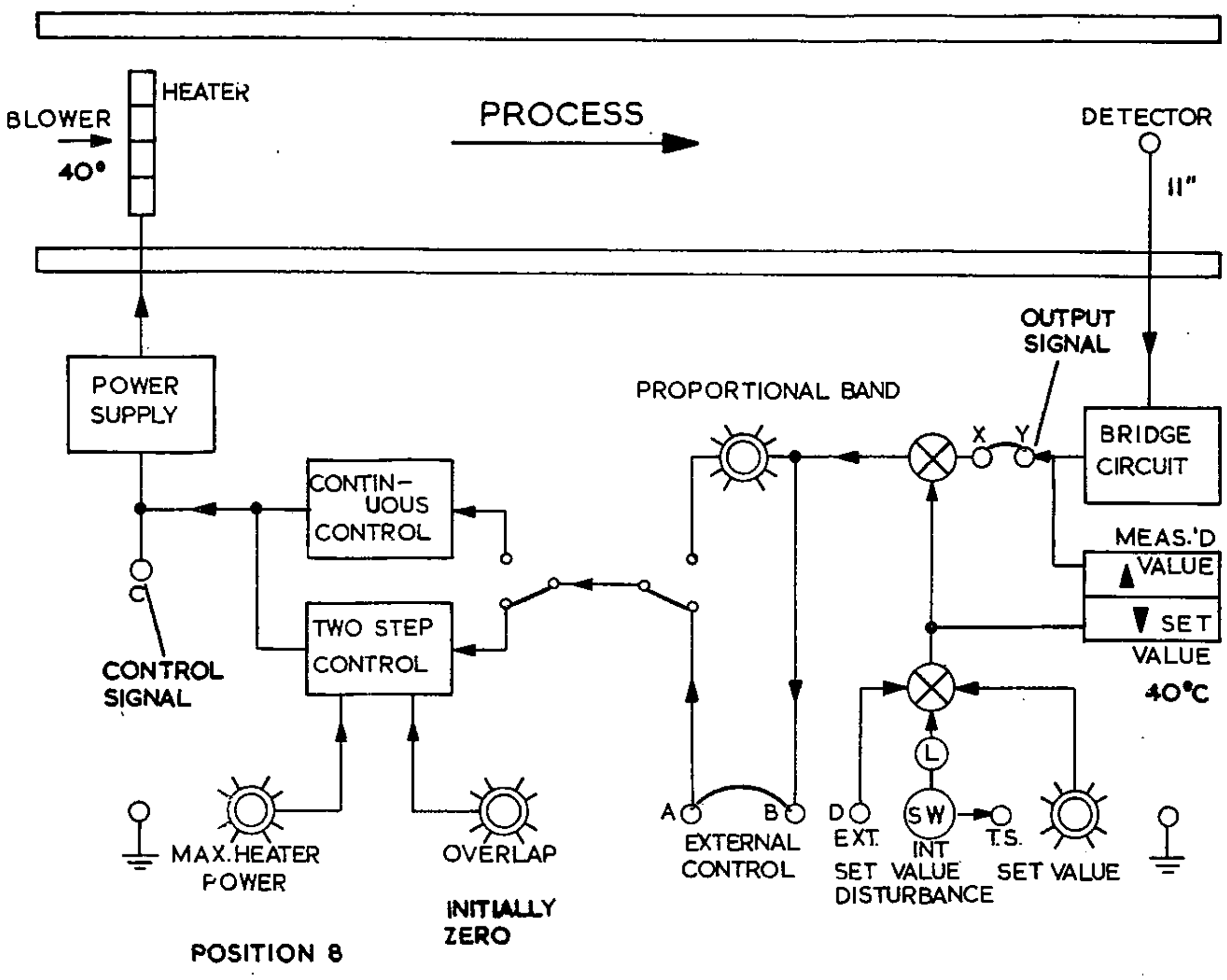
WITHOUT OVERLAP a. WITH OVERLAP b.

TWO STEP CONTROLLER ACTION FIG 13

OPERATING NOTES

The controller is switched to give two-step control with no overlap initially. Although the change in output level of the correcting element occurs as soon as the deviation changes sign, the temperature of the process does not immediately change, due to the effect of transfer lag. This leads to an increase in the amplitude of the controlled condition variation but a useful decrease in the frequency at which the correcting unit is required to operate.

With the introduction of overlap the correcting unit is made to operate only when the measured value passes beyond pre-set limits. This gives a further reduction in the frequency at which the system oscillates.



CONNECTION DIAGRAM FIG 14

Process Trainer

Make the connections and switch settings given in fig 14.

Adjust SET VALUE to 40°C

Set OVERLAP to 0

Set MAX POWER to 1.0

Adjust BLOWER INLET THROTTLE to 40°

Place DETECTOR PROBE in 11" position

Set switch on side of Trainer to HEATER

Oscilloscope (Preferably with a long persistence tube)

Set Y1 to 5V/div and connect to SOCKET Y on Process Trainer.

Set Y2 to 5V/div and connect to SOCKET C on Process Trainer.

Set Time Base to 0.5 sec/div, internal trigger.

OPERATION

Switch on the Process Trainer and Oscilloscope. The system will oscillate at a frequency of approximately 1Hz as shown in fig 15a. Observe the effect of alterations in set value and maximum heater power on the frequency of oscillation.

Repeat the experiment with the overlap adjustment at position 3 and observe the decrease in frequency and increase in amplitude of the measured value when overlap is introduced, fig 15b.

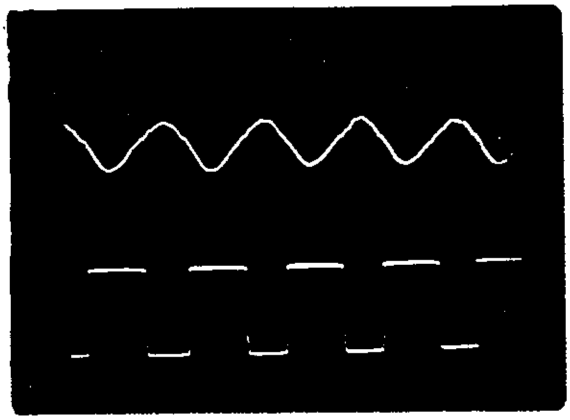


Fig 15a

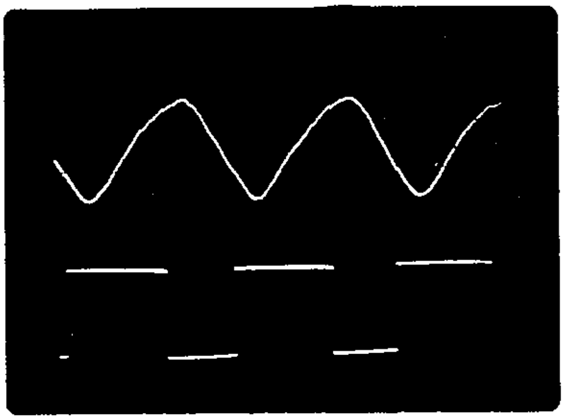


Fig 15b

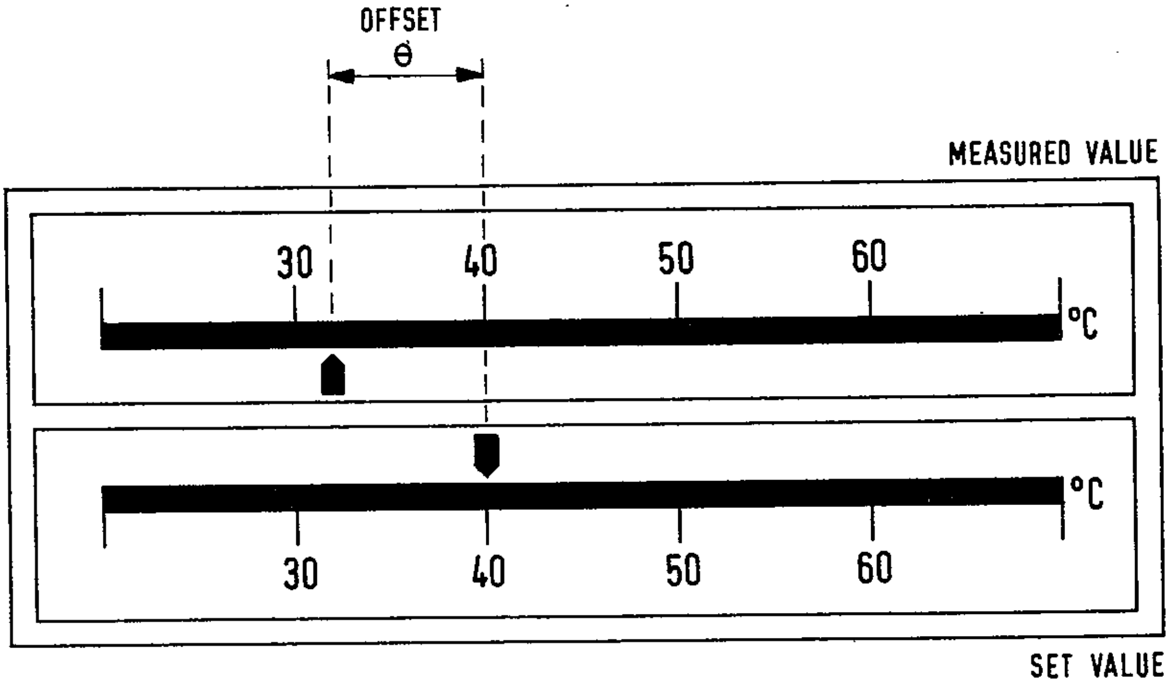
Deviation θ, is the difference between the measured value of the controlled condition and the set value. Sustained deviation is termed Offset.

$\theta = \theta_o - \theta_i$, as shown in fig 16.

In a controller with proportional action the output signal is directly proportional to deviation, causing the correcting element to supply more or less power to the process.

The relationship between deviation and controller output is expressed as 'proportional band'. This is the value of deviation which will cause the controller to operate over its full output range, and is expressed as a percentage of the range of values which the measuring unit is designed to read.

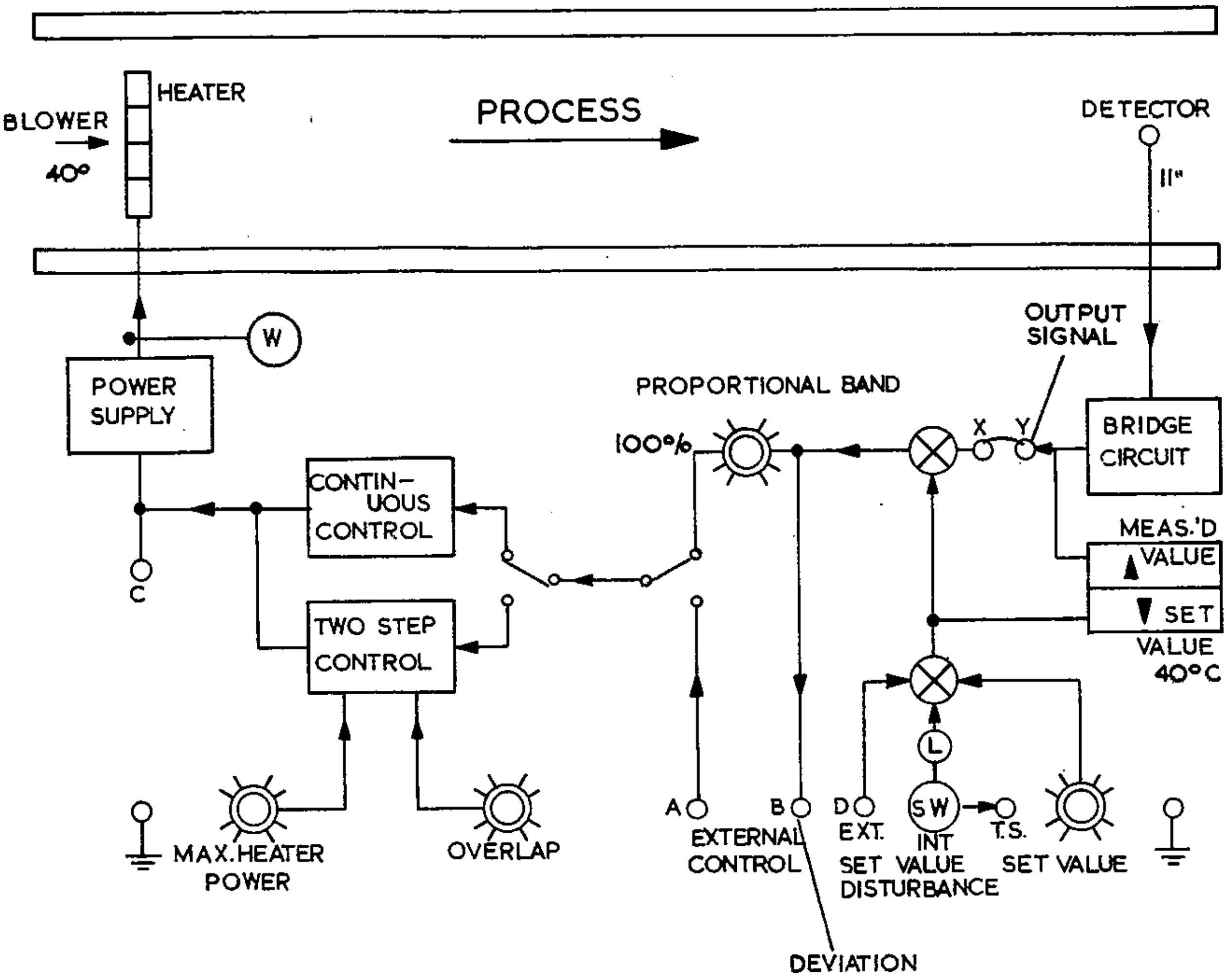
Offset, the sustained deviation always present in proportional control, is dependent on the proportional band-width. As proportional band is decreased, deviation is reduced until a point is reached at which the system becomes unstable.



REDUCTION IN OFFSET BY DECREASE IN PROPORTIONAL BAND FIG 16

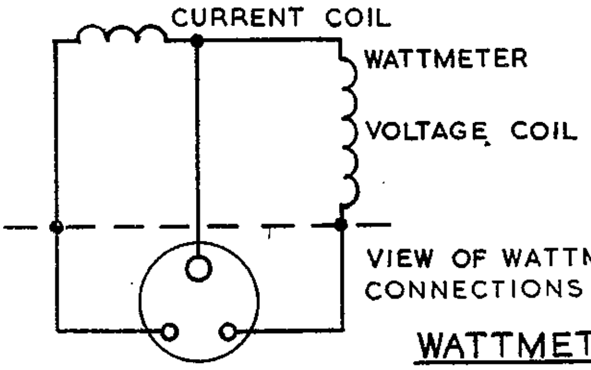
OPERATING NOTES

The controller is switched to continuous control with the process temperature set to an intermediate level. The overlay may be fitted over part of the controller in this experiment, leaving the proportional band adjustment visible.



CONNECTION DIAGRAM

FIG 17



WATTMETER CONNECTIONS

The effect on deviation and measured value of changes in proportional band and set value is measured by a comparison of the two meter readings or by an oscilloscope connected to the monitor sockets. The power supplied to the correcting element for different values of deviation may be measured by a wattmeter connected in the heater circuit.

Process Trainer

Make the connections and switch settings given in fig 17.

Adjust SET VALUE to 40°C

Set PROPORTIONAL BAND to 100%

Adjust BLOWER INLET to 40°

Place DETECTOR PROBE in 11" position

Oscilloscope (Preferably with long persistence tube)

Set Y1 to 2V/div and connect to SOCKET B on Process Trainer.

Set Y2 to 2V/div and connect to SOCKET Y on Process Trainer.

Set Time-base to 0.5 sec/div, externally triggered, and connect to TRIGGER CRO socket on Process Trainer.

Voltmeter

A 0 - 15V DC voltmeter may be used in place of the oscilloscope to read measured value and deviation.

Wattmeter

Set switch on side of Trainer to WATTMETER

Connect to wattmeter plug as shown in fig 17.

Max. voltage: 120V AC

Max. current: 1.0A AC

OPERATION

Switch on the Process Trainer and Oscilloscope.

Switch on the INTERNAL SET VALUE DISTURBANCE and observe changes in set value, measured value, deviation and heater power.

Set the CRO to internal trigger and with the settings as in the previous test, adjust % PB from 200% to 40% in steps, taking readings of deviation and heater power at each step. Plot the results to obtain curves similar to those of fig 18.

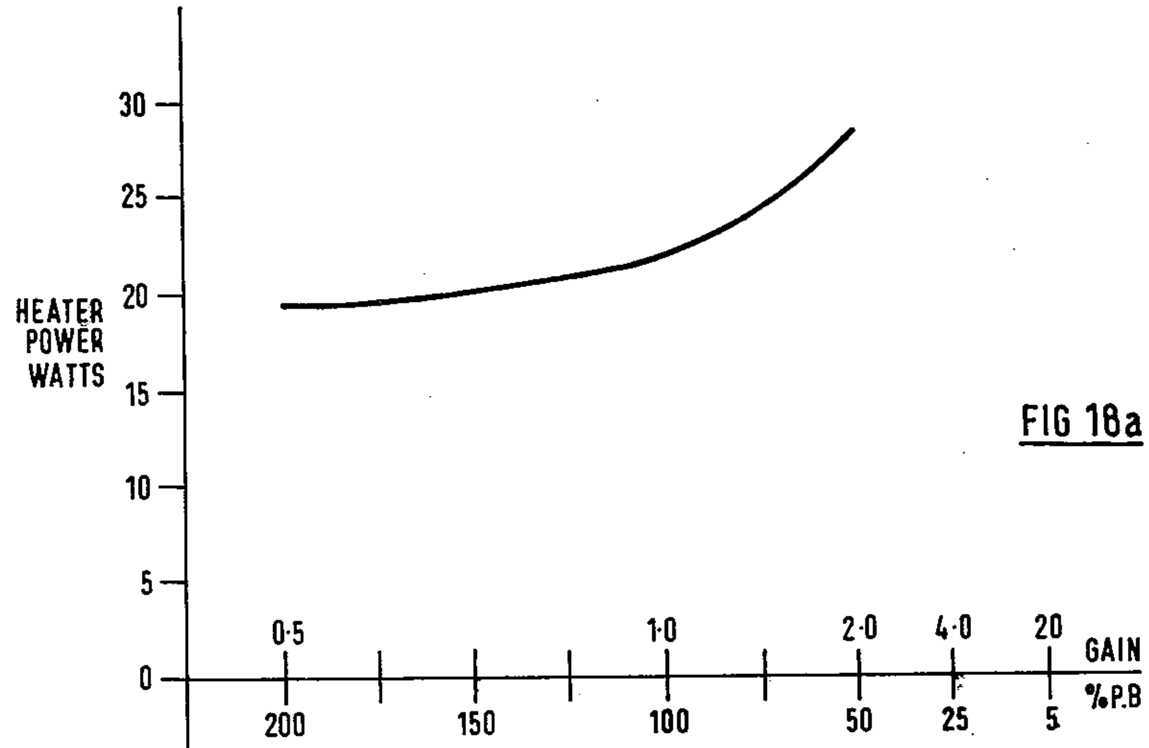


FIG 18a

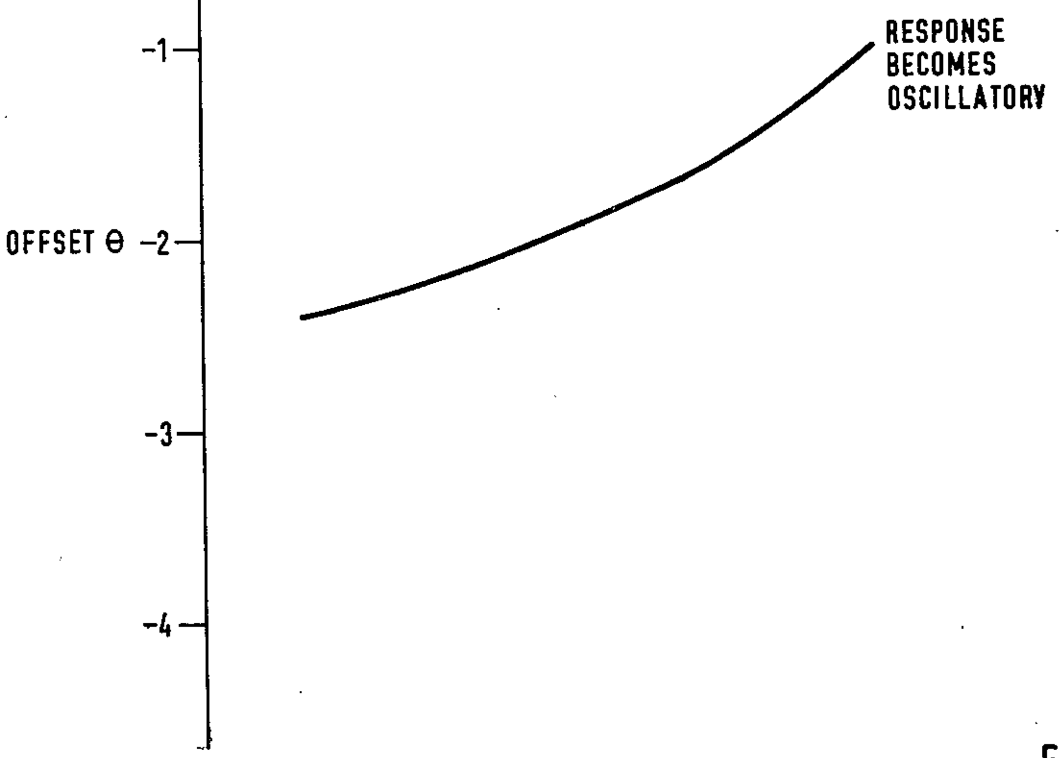


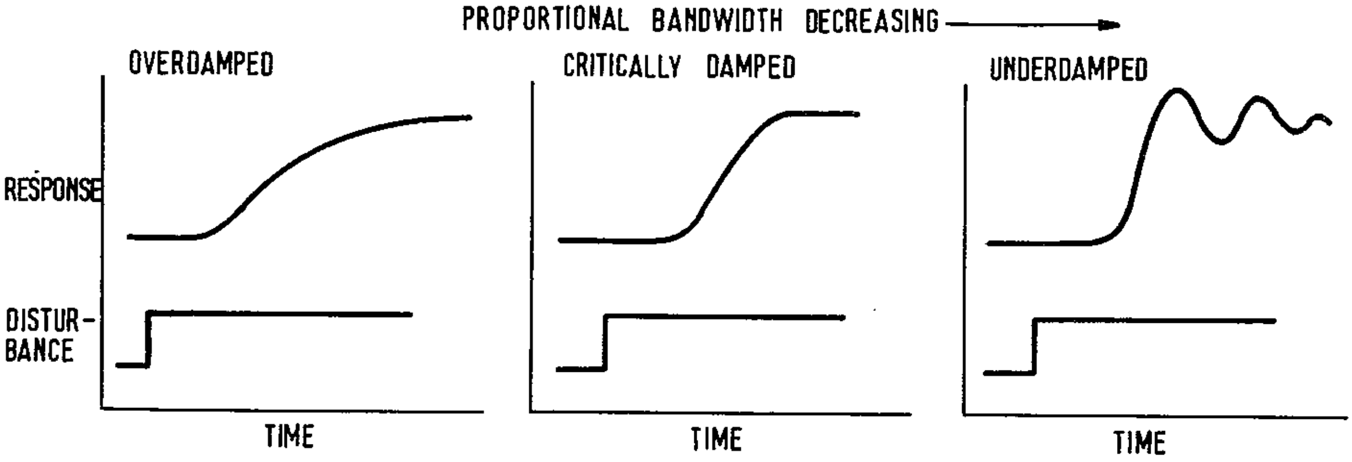
FIG 18b

OFFSET & HEATER POWER / PROPORTIONAL BAND

EXPERIMENT 6 DISTURBANCE AND SYSTEM RESPONSE

Disturbance of the process, causing a change in the controlled condition, may occur on the supply side or the demand side of the system.

In this process, supply-side disturbances can be caused by changes of inlet air flow, ambient air temperature or supply voltage to the heater. The response of the system to a disturbance is dependent on proportional band-width as shown in fig 19.

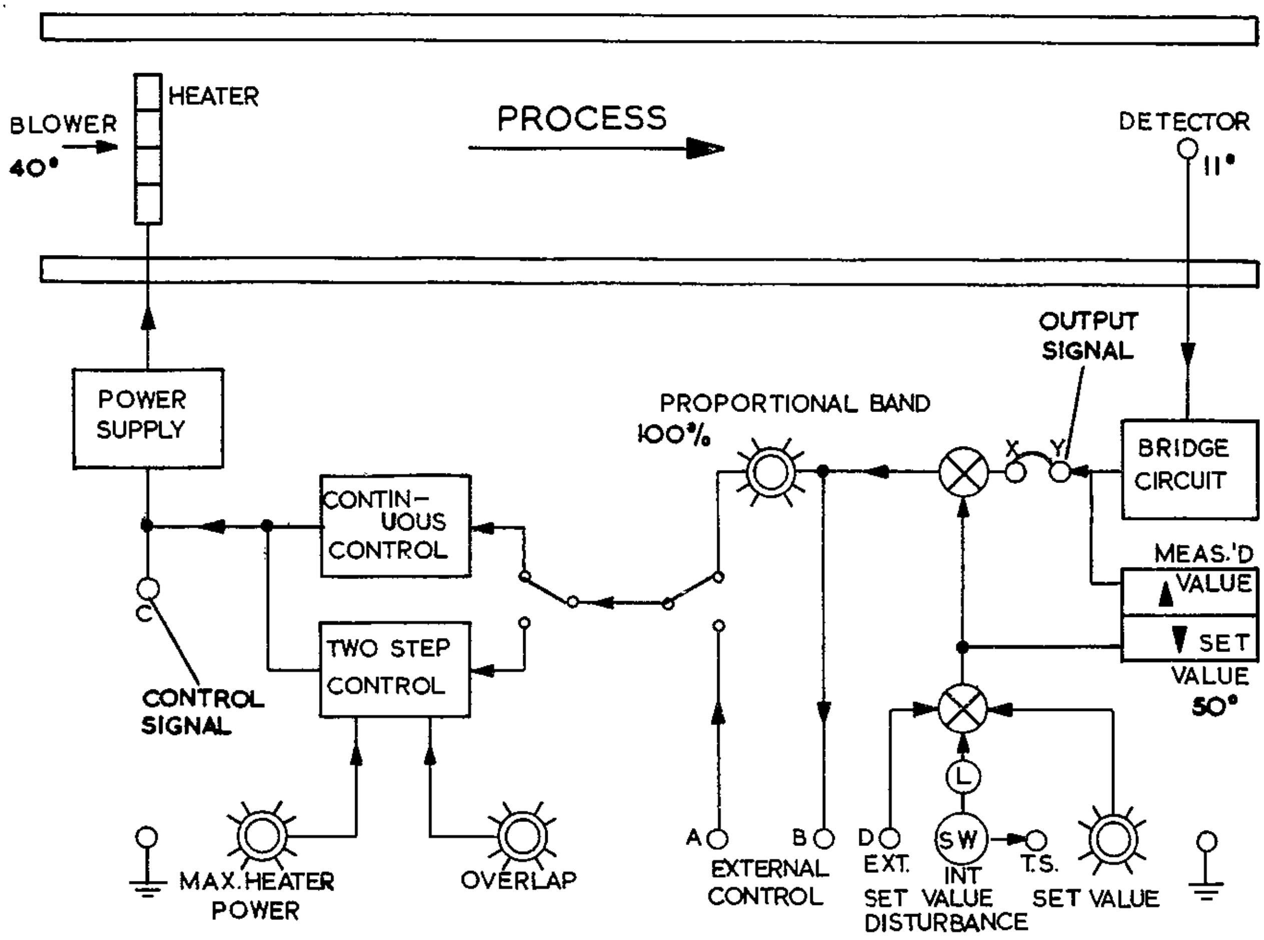


RESPONSE TO STEP CHANGE DISTURBANCE FIG 19

OPERATING NOTES

For this experiment, after switching the controller to continuous control, the overlay can be fitted, leaving the proportional band adjustment visible. With set value adjusted to an intermediate level and % PB set to 100% a rapid increase in the blower throttle opening will cause a change in measured value and deviation. The response to the disturbance and subsequent recovery is dependent on proportional band-width. As this is decreased, deviation is also decreased, but the response to a disturbance becomes more oscillatory until finally instability occurs.

A change in set value provides a convenient means of assessing the response of the system to different forms of disturbance. In this case a step, ramp or sine-wave disturbance derived from a waveform generator can be applied to the SET VALUE DISTURBANCE socket on the Process Trainer and the response measured by an oscilloscope connected to the MEASURED VALUE socket. Alternatively, operation of the INTERNAL SET VALUE DISTURBANCE switch will produce the required step change.



CONNECTION DIAGRAM

FIG 20

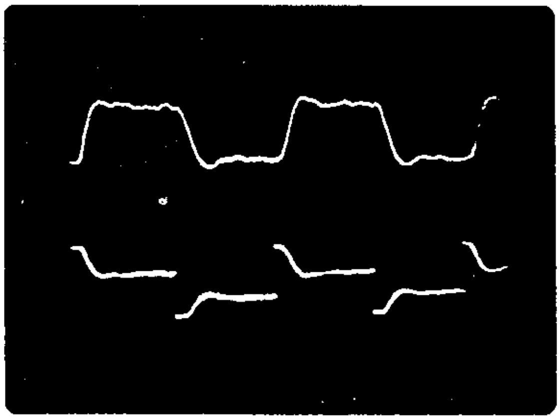


Fig 22a

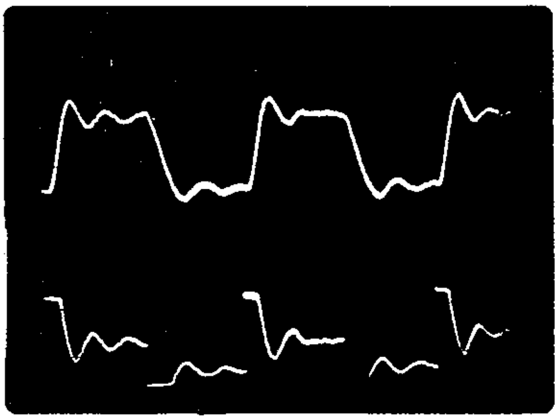


Fig 22b

Process Trainer

Make the connections and switch settings given in fig 20.

Adjust SET VALUE to 50°C

Set PROPORTIONAL BAND to 100%

Adjust BLOWER INLET to 40°

Place DETECTOR PROBE in 11" position

Set switch on side of Trainer to HEATER

Oscilloscope (Preferably with long persistence tube)

Set Y1 to 1V/div and connect to socket Y on Process Trainer.

Set Y2 to 1V/div and connect to socket C on Process Trainer.

Set Time-base to 0.5 sec/div, internally triggered.

Voltmeter

A 0 - 15V DC voltmeter may be used in place of the oscilloscope to read measured value and controller output voltage.

OPERATION

Supply Side Disturbance

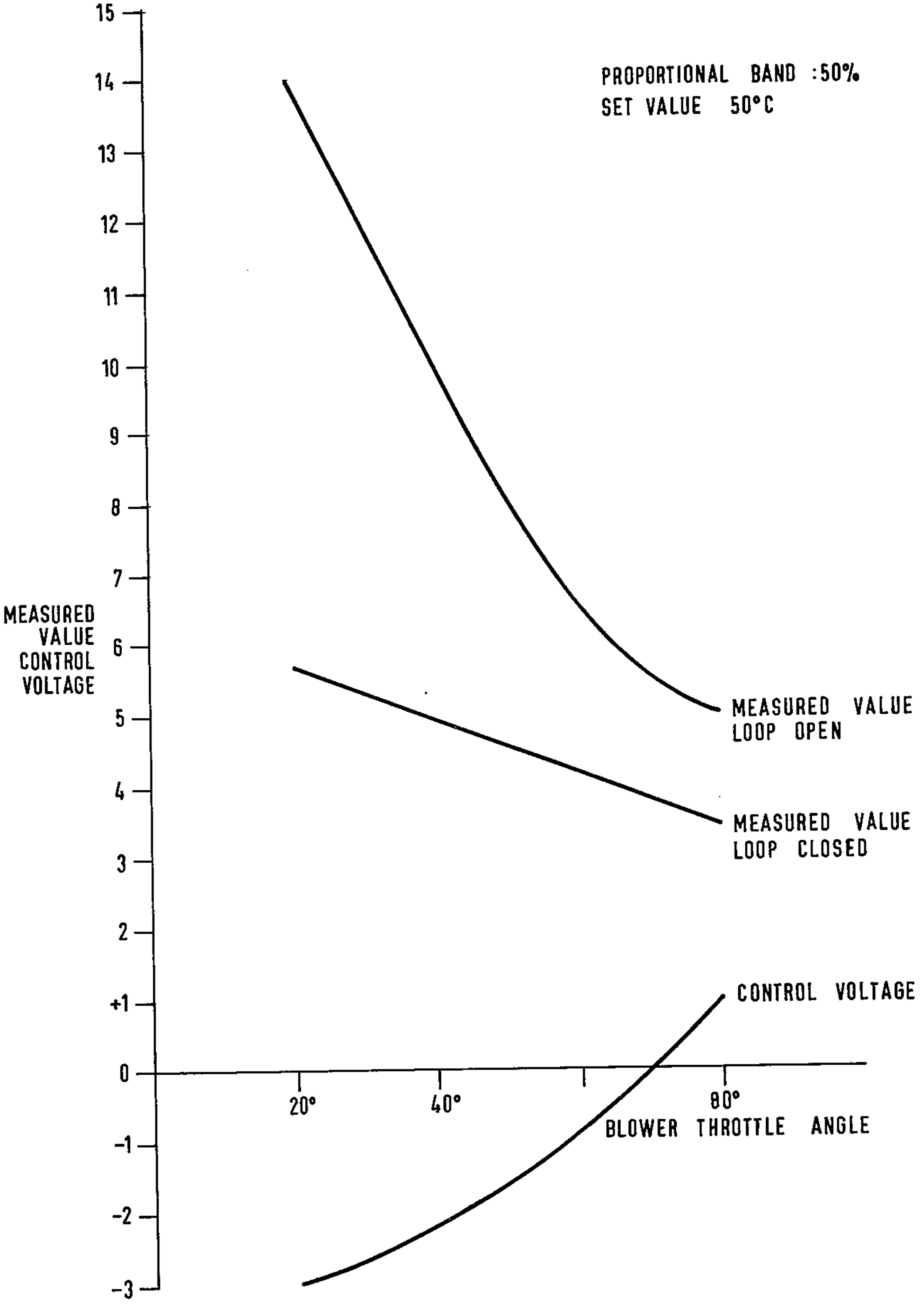
Switch on the Process Trainer and Oscilloscope and with the settings given above rapidly change the blower throttle opening from 40° to 60°. Note that there is a decrease in measured value but that the control signal increases to compensate for the effect of the disturbance. Repeat with PB set at 200% and at 30%.

Set % PB to 50% and vary the blower throttle angle from 20° to 80° in steps, taking readings of measured value and controller output voltage at each step. Repeat with loop open and plot the results as in the graph of fig 21.

Set Value Disturbance

The set value disturbance may be provided by a waveform generator or by operation of the switch on the Process Trainer. If a waveform generator is used it is set initially to give a square wave output of 2 volts amplitude at 1.5Hz.

Note that a step change in set value disturbance produces an immediate change in control output and a delayed response in measured value due to the distance/velocity and transfer lags. At 100% PB the response is sufficiently damped to give little overshoot or oscillation as shown in fig 22a. With proportional band decreased to 50% the response is damped oscillatory with some overshoot as in fig 22b.



MEASURED VALUE & CONTROLLER OUTPUT VOLTAGE AGAINST BLOWER THROTTLE ANGLE FIG 21

FREQUENCY RESPONSE

A Process may be considered to be a series of transfer stages - each with its own time lag, plus a distance/velocity lag. If the control loop is opened as in fig 23 and a sine-wave signal is applied to the input, measurements of the amplitude and phase of the output signal provide useful information which can be used to assess the closed-loop stability of the system.

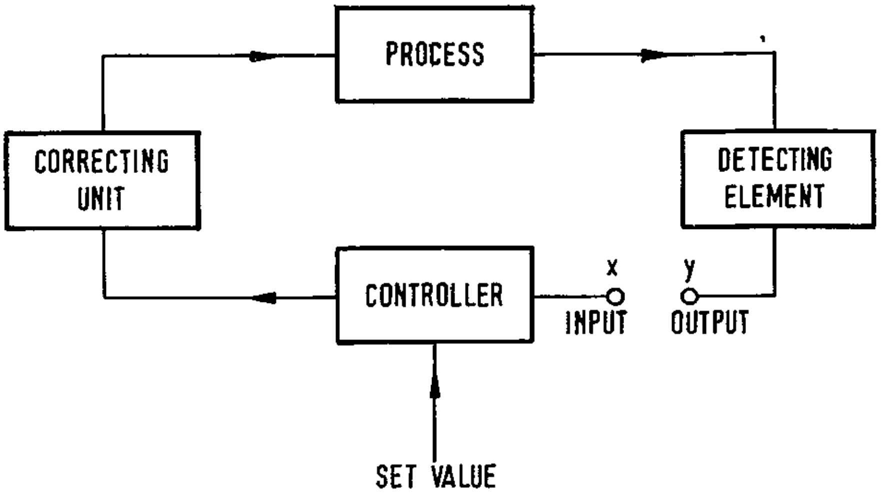


FIG 23

The results may be plotted on a Nyquist diagram or Bode diagram. In each case the principal object is to find the frequency at which the phase lag is 180° and to measure the gain at this frequency.

In these diagrams gain is defined as

$$G = \frac{\text{change of output signal}}{\text{change of input signal}}$$

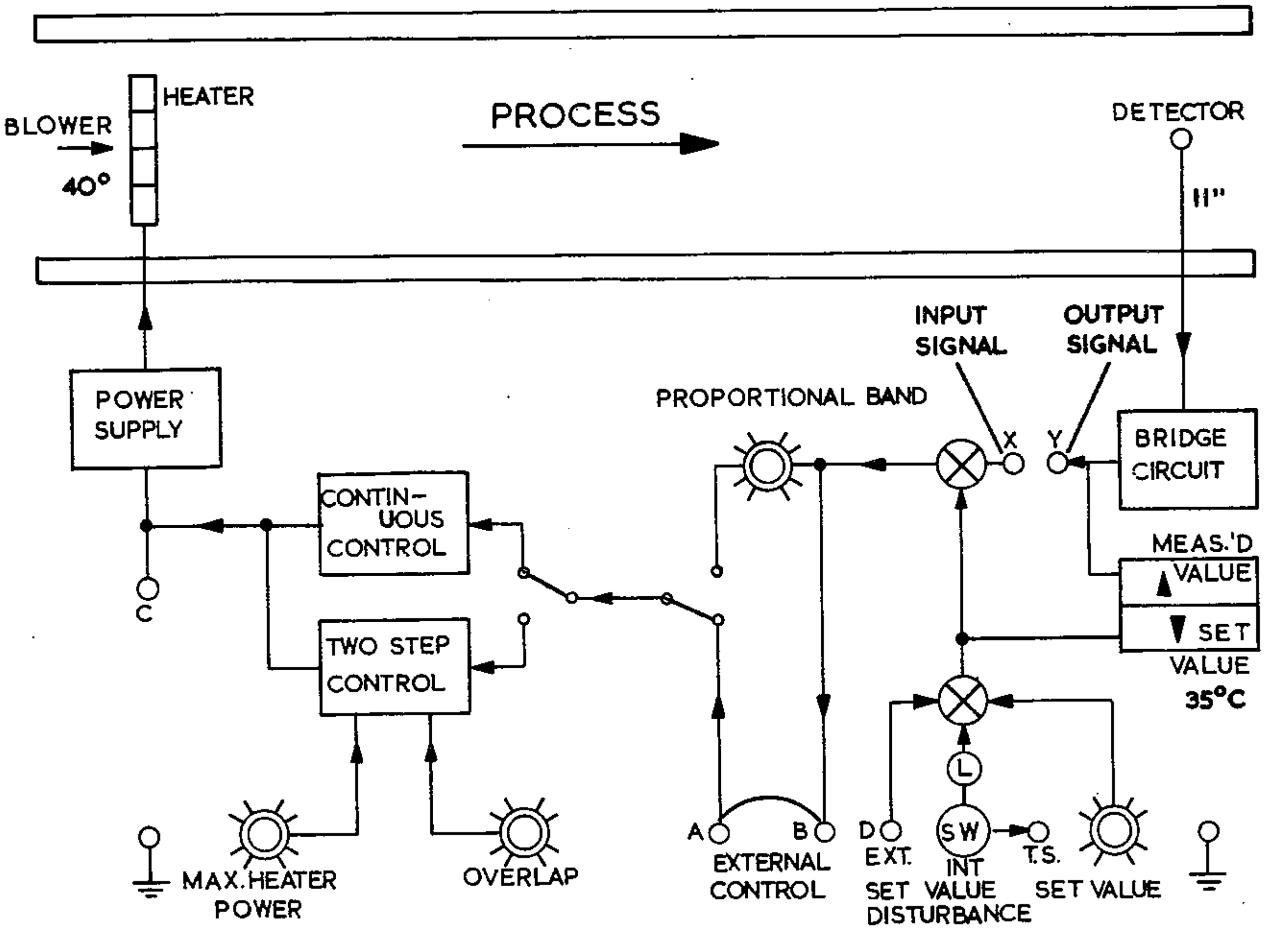
where both input and output signals are in the same units: voltage, power level, pressure, etc and their ratio is non-dimensional.

In some controllers the input and output signals may be in different units, e.g a change in temperature producing a change in pressure, and to avoid conversion factors the output/input relationship may be expressed as 'proportional band'. This is the range of input signals which will cause the controller to operate over its full working range, and is expressed as a percentage of the range of controlled condition which the measuring unit is designed to measure. The relationship between gain and percentage proportional band is

$$G = \frac{100}{\%PB}$$

Phase lag is the angle in degrees by which the output signal lags the input signal

$$\phi = \frac{\text{time lag, input to output signal, secs} \times 360}{\text{period of signal, secs}}$$



CONNECTION DIAGRAM

FIG 24

A controller with proportional action produces an output signal proportional to deviation, but in phase opposition to it. A phase shift of 180° in the process represents a further phase reversal, so that when the loop is closed there is one frequency at which a disturbing signal and the response to it are in phase. If at this frequency the product of controller gain and the gain of the rest of the system is equal to or greater than unit, the system will oscillate.

OPERATING NOTES

This experiment is carried out on open loop, with set value at an intermediate level and the proportional band control by-passed. A sine-wave signal is superimposed on the set value, causing the measured value to vary cyclically about a mean level. Measurements of the gain and phase lag of the system are made over a frequency range 0.1Hz to 3Hz and the results plotted as a Nyquist diagram or Bode diagram, figs 26 and 27.

From these results the frequency at which the phase lag is 180° is measured together with the open loop gain of the system at that frequency. The loop is now closed and the proportional band set to a value such that

$$\text{Open-loop gain} \times \text{Controller gain} = 1$$

or

$$\text{Open-loop gain} \times \frac{100}{\%\text{PB}} = 1$$

and

$$\%\text{PB} = \text{Open-loop} \times 100$$

At this setting the system should be found to just sustain oscillation. For stability %PB should be set at twice the above value.

1. FREQUENCY RESPONSE

Process Trainer

Make the connections and switch settings given in fig 24.

Adjust SET VALUE to 35°C

Adjust BLOWER INLET to 40°

Place DETECTOR PROBE in 11" position

Set switch on side of Trainer to HEATER

Oscilloscope (Preferably with long persistence tube).

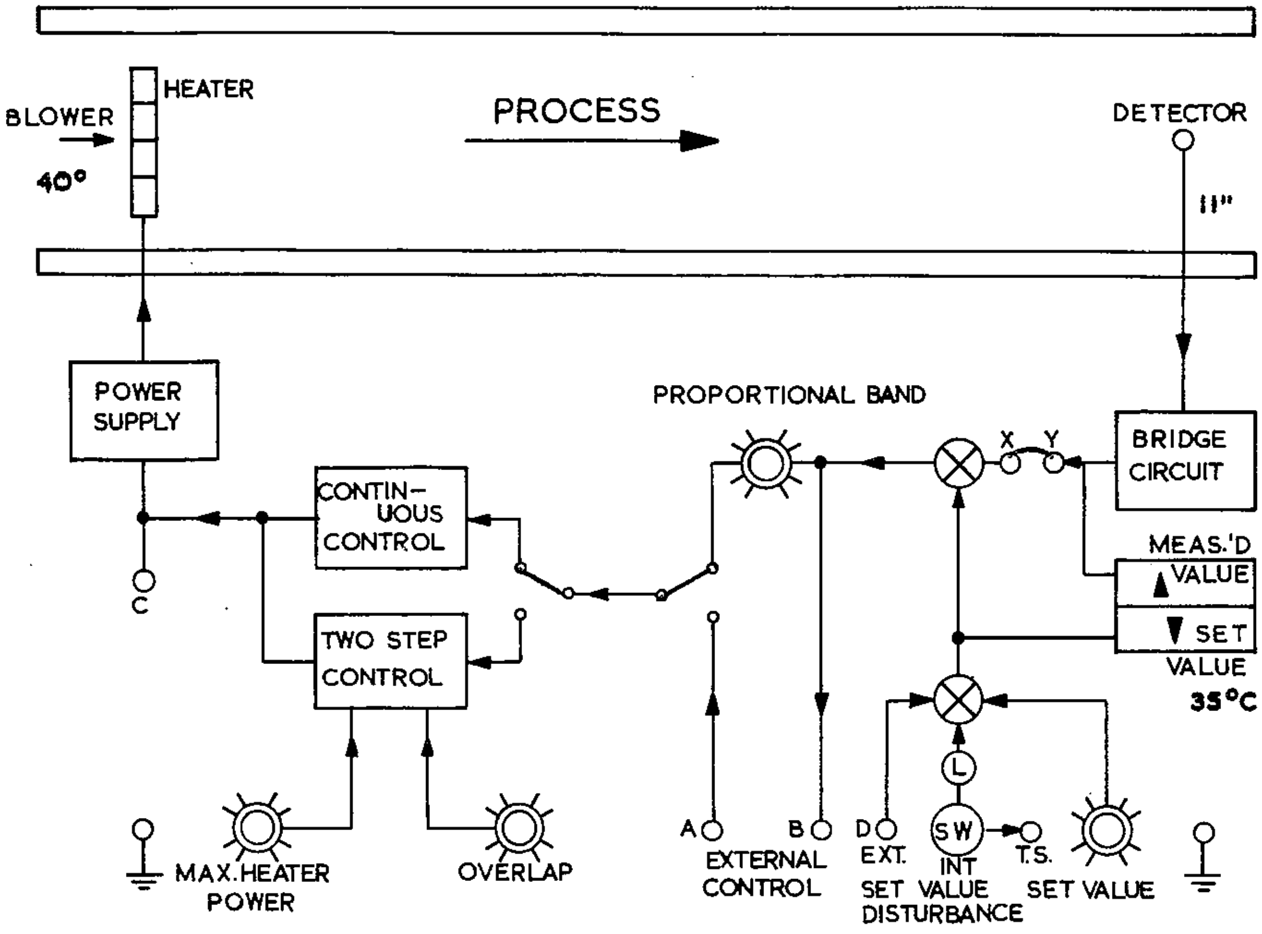
Set Y1 to 2V/div and connect to socket X on Process Trainer.

Set Y2 to 2V/div and connect to socket Y on Process Trainer.

Set Time-base to 1.0 sec/div, internal trigger.

Waveform generator

Set to sine-wave output, 2V amplitude, 0.1Hz, and connect to socket X on the Process Trainer.



CONNECTION DIAGRAM

FIG 25

OPERATION

Switch on the Process Trainer and ancillary equipment.

At input frequency of 0.1Hz measure amplitude and phase relationship of input signal and output signal.

Repeat over a range of frequencies up to 3Hz.

Plot results as in fig 26 or fig 27.

2. CONTROLLER SETTINGS

Process Trainer

Make the connections and switch settings shown in fig 25.

Adjust SET VALUE to 35°

Adjust BLOWER INLET to 40°

Place DETECTOR PROBE in 11" position

Set switch on side of Trainer to HEATER

Oscilloscope

Set Y1 to 2V/div and connect to socket Y on Process Trainer.

Set Time-base to 1 sec/div, triggered by Waveform Generator.

Waveform generator

Set to square wave output, 2V amplitude, 0.2Hz, and connect to socket D.

OPERATION

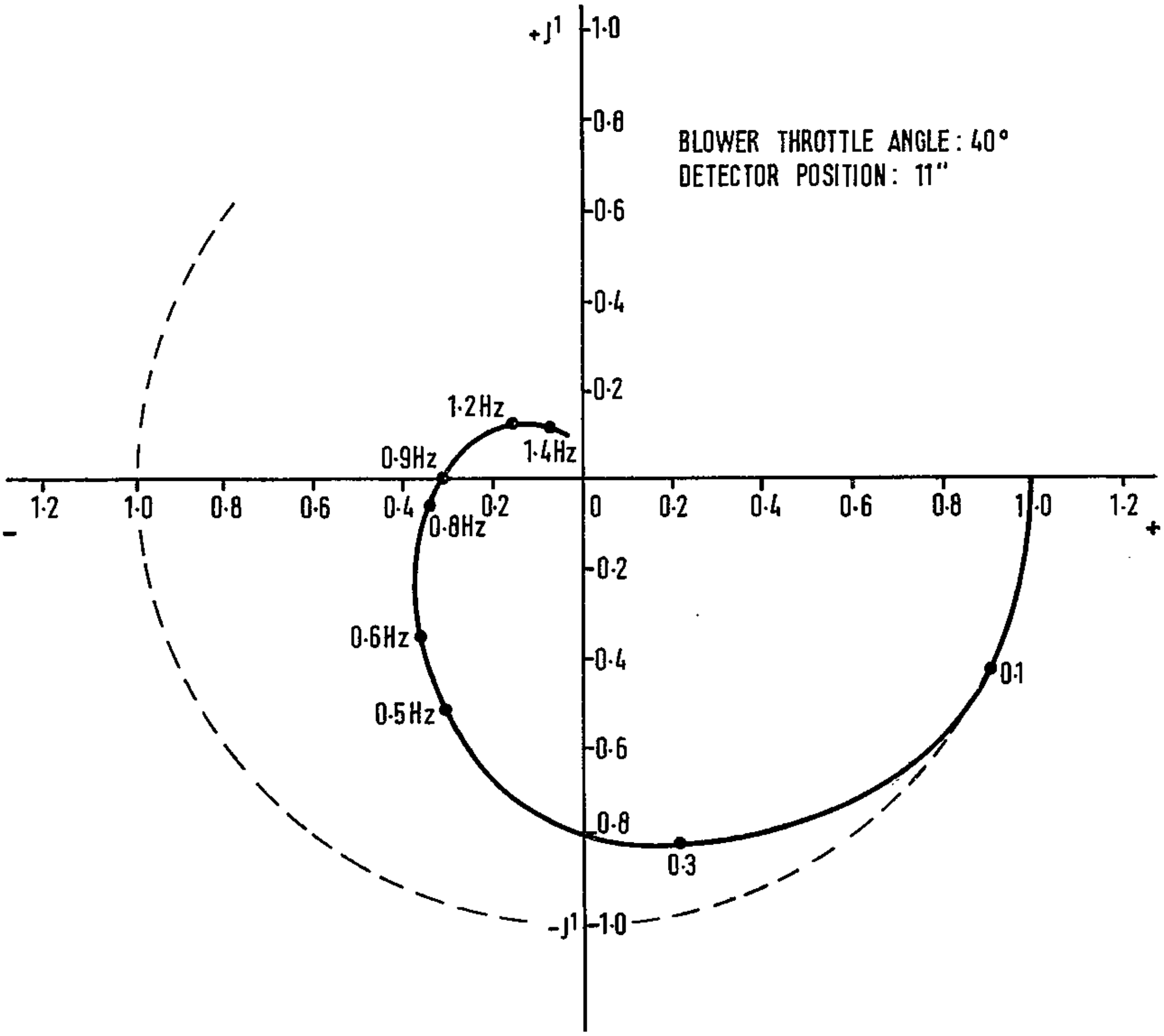
Switch on the Process Trainer and ancillary equipment.

Adjust % PB to the value derived from the frequency response test, using the equation

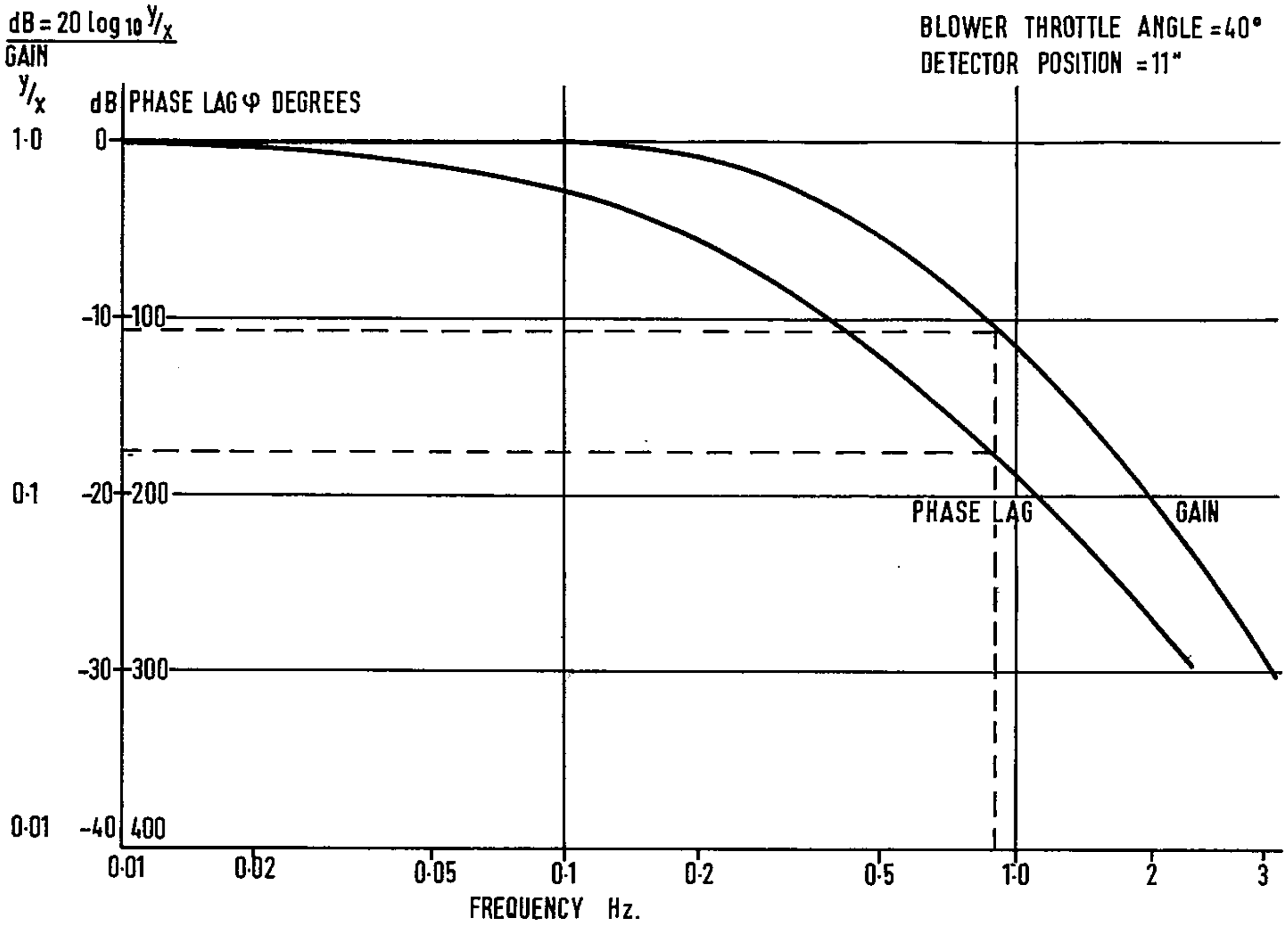
$$\%PB = (\text{open-loop gain when phase lag is } 180^{\circ}) \times 100\%$$

Check that this value of proportional band is just sufficient to cause the system to oscillate.

Double the given value of %PB and check that the system is stable.



NYQUIST DIAGRAM FIG 26



WHEN PHASE LAG = 180 GAIN = -10·5 dB (y/x = 0·3)
AND FREQUENCY = 0·9Hz
FOR SUSTAINED OSCILLATIONS $\frac{100}{PB} \times 0{\cdot}3 = 1$
∴ PB = 30%

LOOP GAIN & PHASE LAG AGAINST FREQUENCY FIG 27

EXPERIMENT 8

COMPOUND CONTROLLER ACTION

In a process which is controlled by proportional action alone the controller output is proportional to deviation, and there must be always a sustained deviation or offset present to maintain the process at the desired value.

If the controller has an output proportional to the time integral of deviation it will produce a correcting signal so long as any offset is present. By combining integral with proportional action, offset may be reduced to zero though the response time will be greater than with proportional action alone.

If the controller has an output proportional to rate of change of deviation the effect of time lags in the process can be reduced. As a correcting signal is only produced when there is a change in deviation, derivative action cannot be used on its own, but in combination with proportional or proportional + integral action it will decrease the response time.

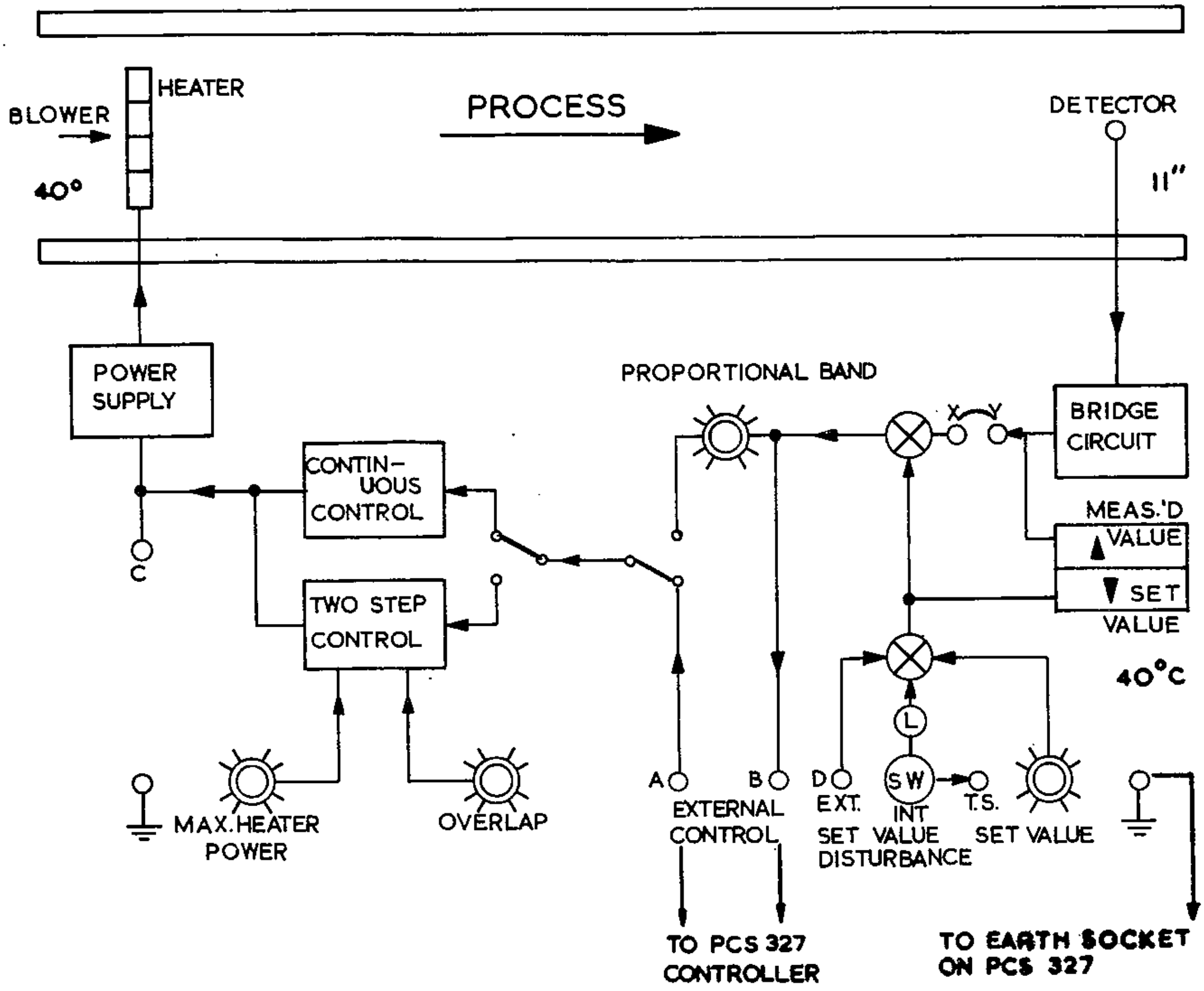
The table below summarizes the characteristics of proportional and compound controller actions. In the equations quoted:

V = controller output

θ = deviation

K_1, K_2, K_3 are respectively the proportional, integral and derivative action factors.

CONTROLLER ACTION	EQUATION	CHARACTERISTICS
Proportional	$V = -K_1\,\theta$	Offset always present
Proportional + Integral	$V = -(K_1\theta + K_2\,\theta dt)$	Zero offset, but response time increased
Proportional + Derivative	$V = -(K_1\theta + K_3\frac{d\theta}{dt})$	Reduced overshoot and response time
Proportional + Integral + Derivative (Three term controller)	$V = -(K_1\theta + K_2\,\theta dt + K_3\frac{d\theta}{dt})$	



CONNECTION DIAGRAM

FIG 28

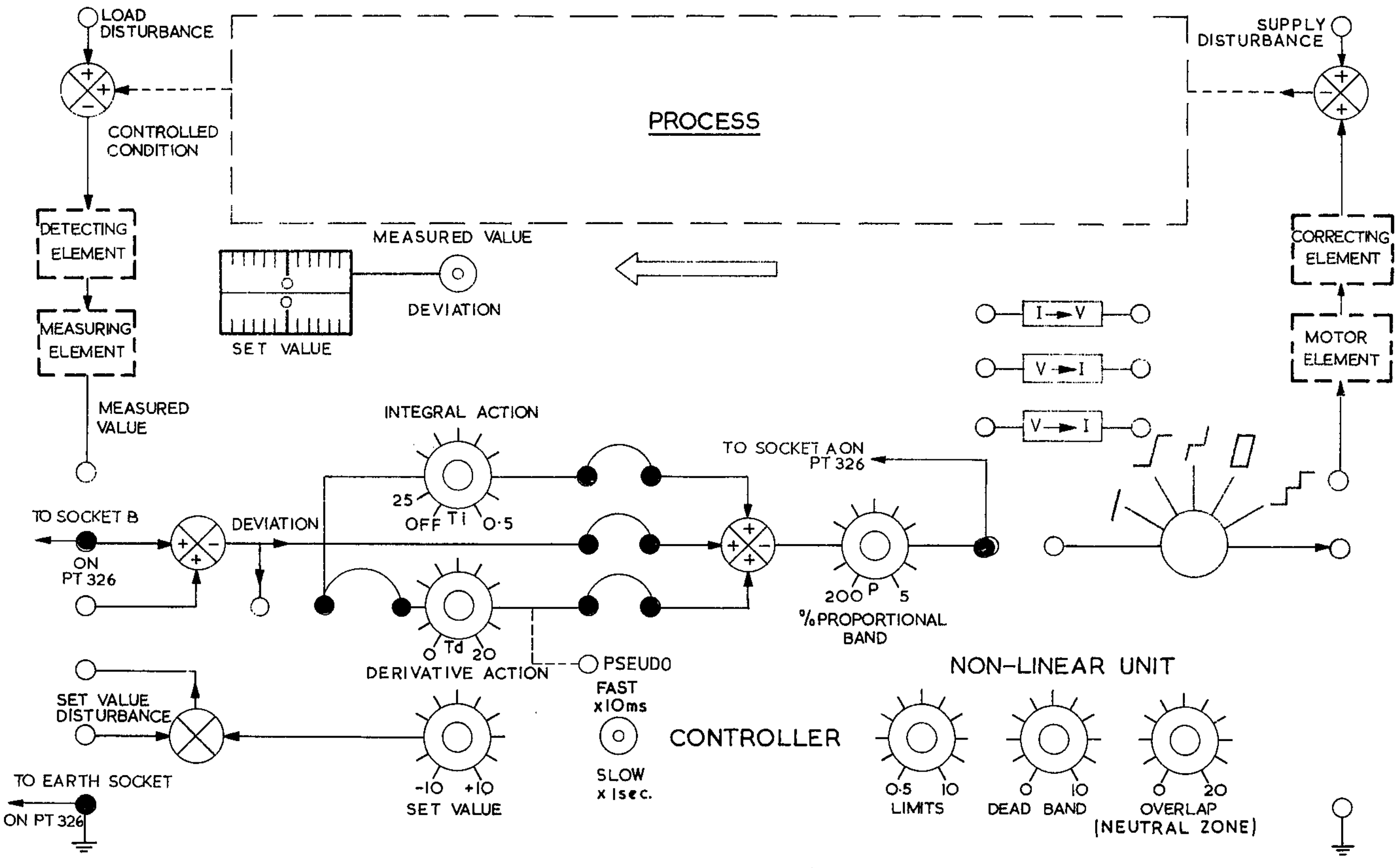


FIG.29 PROCESS CONTROL SIMULATOR PCS 327

OPERATING NOTES

The Process Trainer PT326 is here used with the Process Simulator PCS327, which provides proportional, integral and derivative controller actions. The offset which occurs with proportional action alone is reduced to zero by the introduction of integral action, and overshoot is reduced by the addition of derivative action. The results of the frequency response experiment can be used to calculate settings of the proportional, integral and derivative controls which will give rapid response with zero offset.

Process Trainer

Make the connection and switch settings given in fig 28.

Adjust SET VALUE to 40°C

Adjust BLOWER INLET to 40°

Place DETECTOR PROBE in 11" position

Set switch on side of Trainer to HEATER

PCS327

Connect as in fig 29 and make the required interconnections with the Process Trainer.

The settings given below will provide a starting point from which further adjustment can be made to provide the required controller operation:-

P, I and D settings

From the Frequency response test, taking P_o as the percentage proportional band setting at which the system just oscillates and T_o the period of oscillation. Make the following settings:-

$$\%PB = 2 \times P_o$$

$$\text{Integral time, } T_i = T_o$$

$$\text{Derivative time, } T_d = \frac{T_o}{5}$$

Set value disturbance

If a waveform generator is available set to 2 volts amplitude, 0.1Hz, square-wave, and connect to SOCKET D on Process Trainer.

Alternatively, manual operation of the SET VALUE DISTURBANCE switch on the Process Trainer will produce a step change in Set Value.

Oscilloscope (Preferably with long persistence tube)

Set Y1 to 1V/div and connect to Socket Y on the Process Trainer

Set Y2 to 1V/div and connect to Socket B on the Process Trainer

Set Time-base to 1 sec/div, internal trigger.

OPERATION

Switch on and note the system response to a step change of set value. With the settings given there should be zero deviation and little overshoot.

Observe the effect on response and deviation of alterations to the proportional, integral and derivative adjustments. To find the controller settings experimentally, without data from a frequency response plot, the following procedure may be used:-

1. Switch INTEGRAL ACTION TIME to maximum (OFF) position, and DERIVATIVE ACTION TIME to zero.
2. Reduce PROPORTIONAL BAND until oscillation occurs, note %PB setting P_o, and period of oscillation to T_o.
3. Increase PROPORTIONAL BAND to twice P_o.
4. Reduce INTEGRAL ACTION until offset of zero.
5. Observe response of system to a step change disturbance. Increase DERIVATIVE ACTION TIME until overshoot is approximately 20%.

Typical settings for rapid response with no offset are:-

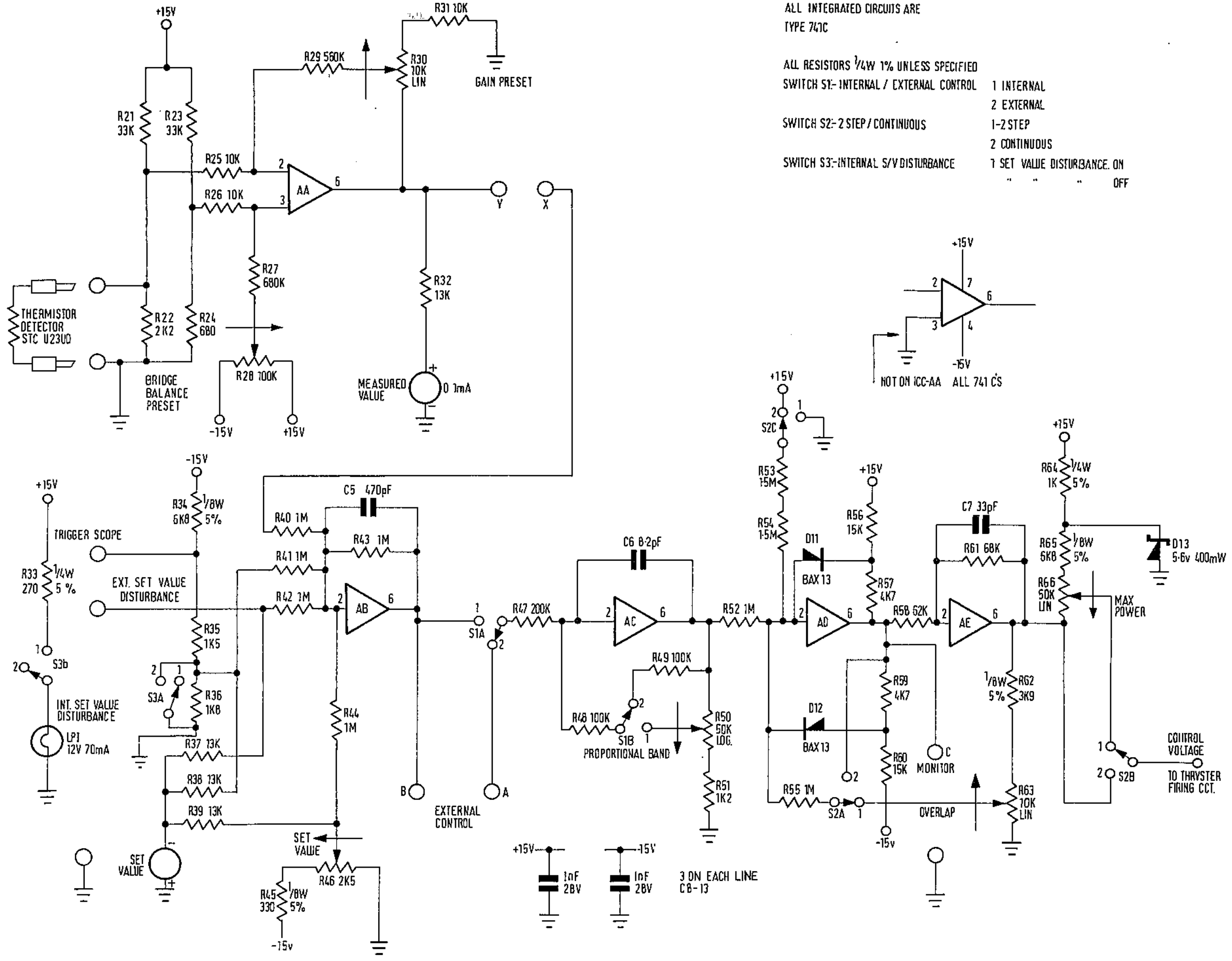
%PB = 50%

T_i = 1.0 sec

T_d = 0.1 sec

ALL INTEGRATED CIRCUITS ARE
TYPE 741C

ALL RESISTORS 1/4W 1% UNLESS SPECIFIED
SWITCH S1:- INTERNAL / EXTERNAL CONTROL — 1 INTERNAL
2 EXTERNAL
SWITCH S2:- 2 STEP / CONTINUOUS — 1-2 STEP
2 CONTINUOUS
SWITCH S3:- INTERNAL S/V DISTURBANCE — 1 SET VALUE DISTURBANCE. ON
" " " OFF



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326 BRIDGE AMPLIFIER AND CONTROLLER - CIRCUIT DIAGRAM

3-326-5077-ISS 5

SECTION 6

CIRCUIT DESCRIPTION

Refer to Drawing 326 - 5077

Detecting and Measuring elements

Amplifier AA. A bead thermistor exposed to the process air, is connected in parallel with R22 to form one arm of a bridge. The bridge is in balance at 40°C and the error voltage varies from -0.11 to +0.11 volts for a process temperature change of 20°C to 80°C; -0.08 to +0.08 volts for change of 30°C to 60°C. The bridge error voltage is applied to amplifier AA whose output varies from 0 to +10V for a process temperature change of 30°C to 60°C. Bridge balance and amplifier gain can be adjusted by the preset potentiometers, R28 and R30 respectively.

The output voltage is connected to socket Y on the front panel, and is also applied to the 0-1mA MEASURED VALUE meter, scaled 0°C to 80°C; a link between sockets X and Y connects the measured value signal to the input of the comparing element.

Comparing element

Amplifier AB. A summing amplifier operating at unity gain adds the bridge amplifier output to the set value signal which is negative going for an increase in process temperature. As these signals are of opposite sign the amplifier output is effectively equal to deviation.

There are three possible set value signals.

1. SET VALUE adjustment on front panel, R46

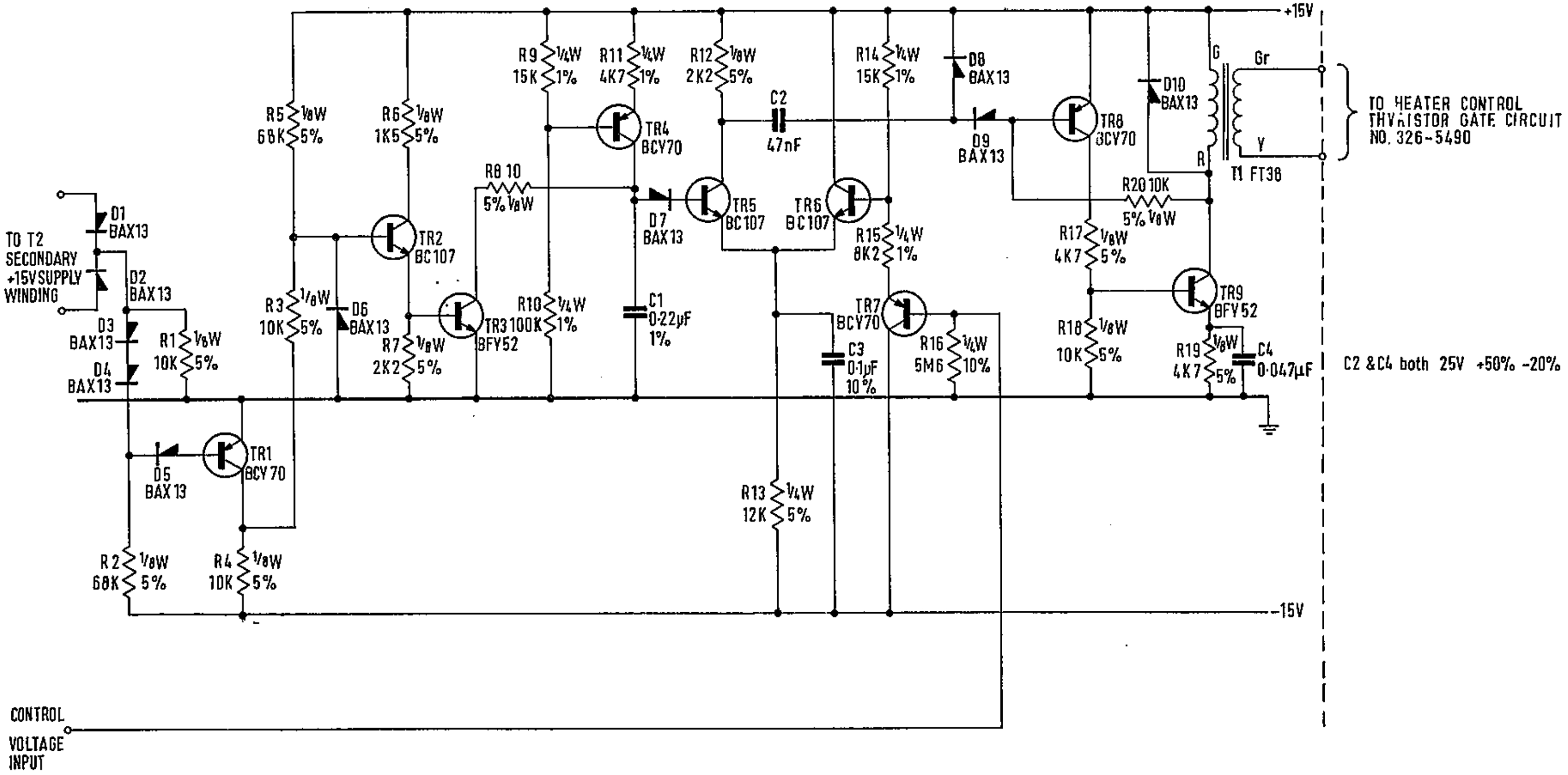
2. SET VALUE EXTERNAL DISTURBANCE, socket D

3. SET VALUE INTERNAL DISTURBANCE. Operation of switch S3 applies a -2.5-volt step, corresponding to an increase in temperature of approximately 7.5°C. The 0-1mA SET VALUE meter, scaled 0 to 80°C reads the sum of the set value signals applied.

Controlling element

Amplifiers AC, AD, AE. The output of the summing amplifier is connected by switch S1 either directly to AC, position 1, or through an external controller, position 2.

Switch S2 selects either linear or two-step controller action. The controller signal is monitored at socket C.



C2 & C4 both 25V +50% -20%

FEEDBACK LTD.

326 THYRISTOR FIRING CONTROL-CIRCUIT DIAGRAM

3-326-5078 ISS. 3

Linear control

S2 on position 1. Potentiometer R50 gives proportional band adjustment from 200% to 5% - a gain of 0.5 to 20. Amplifier AD operates at unity gain with a maximum output swing of 10V, and AE provides the ±5.6-volt signal required to operate the thyristor firing circuit over its full range.

Two-step control

S2 on position 2. AD and AE form a Schmitt trigger circuit which produces an output of +5.6 or -5.6 volts with an input overlap adjustable by potentiometer R63 from 0 to ±4 volts.

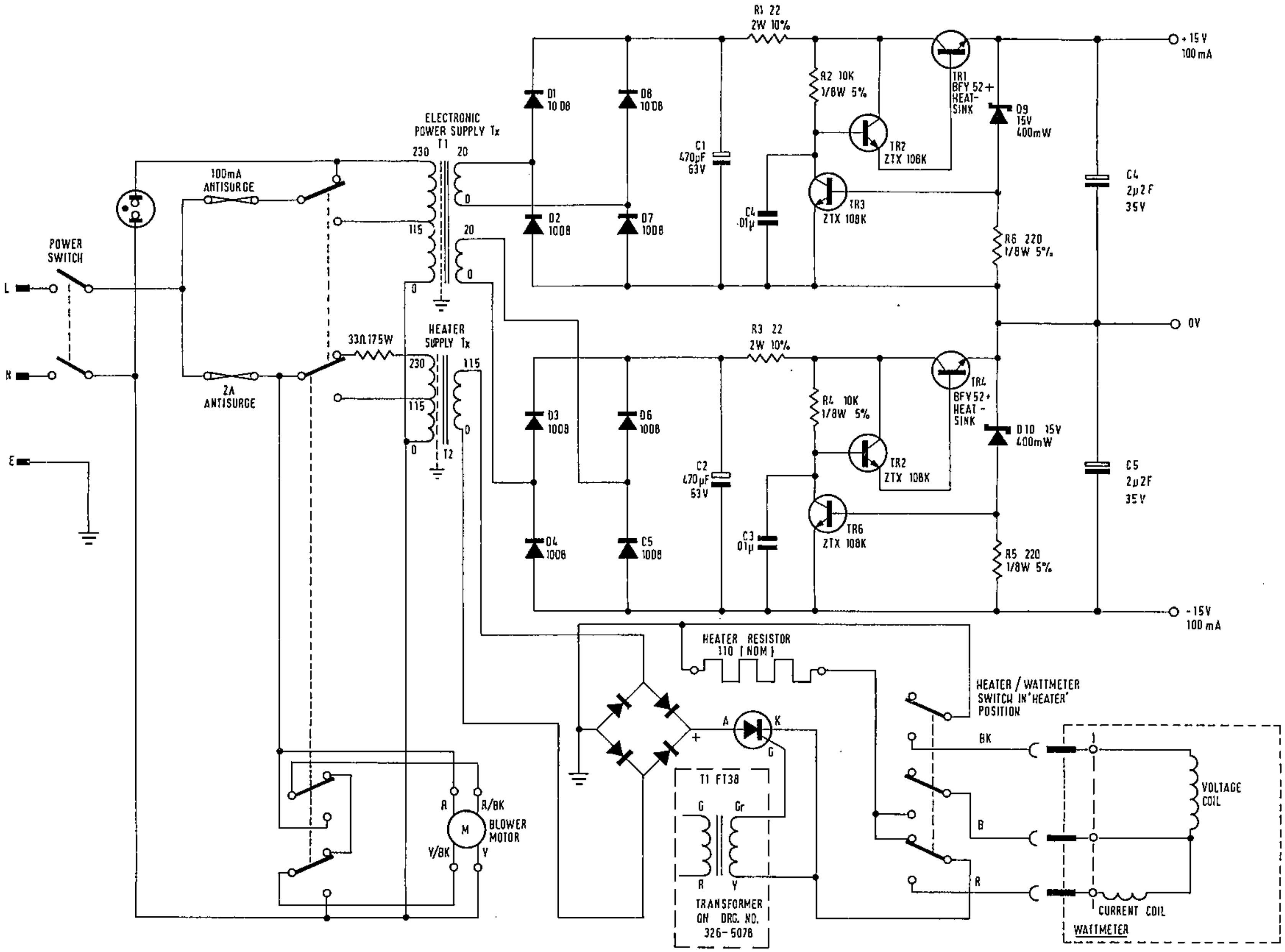
With two-step control the low power output level is fixed at 10 watts and the upper level adjustable from 25 to 85 watts by the MAX HEATER POWER potentiometer, R66.

Refer to Drawing 326 - 5078

Motor element and Correcting element

The early stages of the thyristor firing circuit which include D1, D2, TR1, TR2, TR3 cause C1 to be discharged at the beginning of each half cycle of the supply. C1 is then charged linearly from a constant current source via TR4 and the ramp output voltage is compared with the control voltage level. When they are equal TR5 is switched on, triggering TR8 and TR9, so producing a short pulse which fires the thyristor.

The output from a bridge rectifier connected to a 110V AC supply is applied to the thyristor and the 120-ohm heater grid. The control voltage swing is limited to ±0.6V, corresponding to a firing angle of 136° to 40° and a change in power output level of 15 watts to 85 watts.



FEEDBACK INSTRUMENTS LTD

PT326 POWER SUPPLY - CIRCUIT DIAGRAM

3 326 5490 ISS 7

MAINTENANCE

Supply voltage

220 - 250V AC

100 - 120V AC

The voltage selector switch, labelled 115/230 is mounted on the case beneath the front panel, and access to it is obtained by removing the six fixing screws and partly withdrawing the front panel from the case.

Fuse links

2A, Anti-surge - protects blower and heater supply.

100mA, Anti-surge - protects electronic circuits.

The screw-in fuseholders are mounted on the left-hand panel of the instrument.

Pre-set adjustments

Although the pre-set potentiometers seldom require adjustment any change in bridge amplifier output range or balance can be checked and corrected by the following procedures:-

Set the system to unity gain on open-loop and connect a 0 - 15V d.c voltmeter between socket Y and the earth socket. Check that full rotation of the SET VALUE control knob causes the voltmeter reading to vary between 0 and +10V.

If this voltage swing is not obtained the bridge amplifier pre-set adjustment should be checked and adjusted as necessary. Remove the six fixing screws holding the front panel to the case and withdraw the front panel within the limits of the interconnecting leads. To increase or decrease the range of measured voltage, adjust the preset gain control, R31. If the voltage range is correct but it has shifted beyond the above limits, adjust the pre-set balance control R28.

Replacements

The following spares can be supplied by Feedback Instruments Limited or, if more convenient, directly from the manufacturer.

✓ Thermistor Detector Type U32Ud. STC Ltd, Semiconductor Division, Foots Cray, Sidcup, Kent.

Mains Indicator Lamp Type S1268/C, Amber, 240V. Arco Electric Switches Ltd, Central Avenue, West Molesey, Surrey.

Set Value Disturbance Indicator Lamp Type LS 7GW, Amber, 12V. Guest International Ltd, Nicholas House, Brigstock Road, Thornton Heath, Surrey.

Fuse Links 2A. TDC11. Beswick Ltd, Alert Works, Frome, Somerset.

AMERICAN TECHNICAL ENTERPRISES
ΑΠΟΚΛΕΙΣΤΙΚΟΙ ΑΝΤΙΠΡΟΣΩΠΟΙ
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ΤΑΧ. ΔΙΝΣΙΣ: ΤΑΧ. [illegible] 156 ΑΘΗΝΑΙ Κ
ΤΗΛ. 819.470

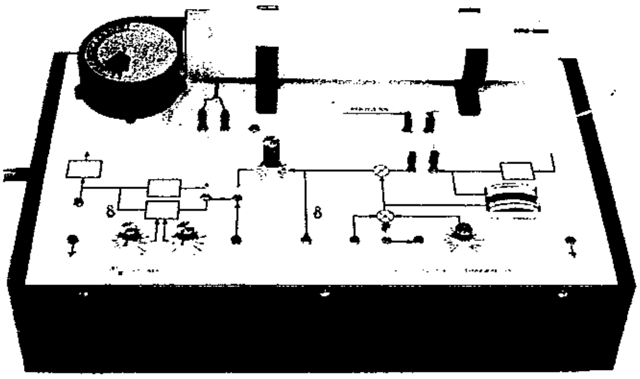
Provisional Leaflet No. D326
Catalogue Section
PROCESS TRAINING
EQUIPMENT

FEEDBACK

PROCESS TRAINER

PT 326

- For teaching the basic ideas of Process Control to technicians, process operators and control engineers.
- Is a practical process in miniature which involves the temperature control of a heated airstream so simulating the conditions found in furnaces, boilers, air conditioning systems etc.
- Designed for the instruction of students of all standards.
- Demonstrates closed and open-loop continuous control as well as two-step control.
- Response times enable dynamic behaviour to be seen on oscilloscope or chart recorder.
- The system exhibits thermal time constants and time transport lag. Airstream temperature is sensed by thermistor comprising one arm of a sensitive bridge.
- Meters with side-by-side pointers indicate set and measured values.
- Gain can be increased to show oscillatory response and instability.
- Compatible with the Feedback Process Control Simulator PCS327 to apply 3-term control



Description

A heating element controlled by a thyristor circuit feeds heat into the airstream circulated by a centrifugal fan along a polypropylene tube. A thermistor detector, which may be placed at one of three points along the tube length, senses the temperature at that point.

The volume of air flow is manually controlled by a shutter on the fan inlet. A change in setting represents a supply side disturbance and the effects are easily demonstrated.

The detector output is amplified to provide both an indication of the measured temperature and a feedback signal for comparison with a set value derived from a separate control. A comparison of these signals generates a deviation signal which is applied to the heater control circuit such that the controlled condition is maintained at the desired value.

The variation of dynamic behaviour with loop gain can be studied with the aid of a gain control (proportional band); by increasing the loop gain, oscillatory responses and finally instability are caused. Provision is made for the introduction of set value disturbances in the form of electrical inputs from a suitable waveform generator (e.g Feedback TWG501 and TWG500) and responses are fast enough to be observed on a long-persistence oscilloscope, or they may be recorded on a suitable chart recorder for permanent record.

Many simple temperature control systems use two step (ON/OFF) controls which operate when the temperature is outside the controlled limits.

A simple switch converts the PCS327 to this mode of operation so that control accuracy and stability can be demonstrated.

An extended range of practical experimental work can be tackled by combining the Process Trainer PT326 with the 3-term controller section of the Process Control Simulator PT327.

As a simple demonstration this shows the powerful action of the Controller in reducing the deviation and improving the response time.

The PT326 is compatible with the Feedback Process Control Simulator PCS327 to apply 3-term control, and disturbances can be introduced by Function Generators TWG500 or TWG501.

Oscilloscope (Preferably with long persistance tube)

Set Y1 to 1V/div and connect to Socket Y on the Process Trainer

Set Y2 to 1V/div and connect to Socket B on the Process Trainer

Set Time-base to 1 sec/div, internal trigger.

OPERATION

Switch on and note the system response to a step change of set value. With the settings given there should be zero deviation and little overshoot.

Observe the effect on response and deviation of alterations to the proportional, integral and derivative adjustments. To find the controller settings experimentally, without data from a frequency response plot, the following procedure may be used:-

1. Switch INTEGRAL ACTION TIME to maximum (OFF) position, and DERIVATIVE ACTION TIME to zero.
2. Reduce PROPORTIONAL BAND until oscillation occurs, note %PB setting P_o, and period of oscillation to T_o.
3. Increase PROPORTIONAL BAND to twice P_o.
4. Reduce INTEGRAL ACTION until offset of zero.
5. Observe response of system to a step change disturbance. Increase DERIVATIVE ACTION TIME until overshoot is approximately 20%.

Typical settings for rapid response with no offset are:-

%PB = 50%

T_i = 1.0 sec

T_d = 0.1 sec

SECTION 6

CIRCUIT DESCRIPTION

Refer to Drawing 326 - 5077

Detecting and Measuring elements

Amplifier IC1. A bead thermistor exposed to the process air, is connected in parallel with R21 to form one arm of a bridge. The bridge is in balance at 40°C and the error voltage varies from -0.11 to +0.11 volts for a process temperature change of 20°C to 80°C; -0.08 to +0.08 volts for change of 30°C to 60°C. The bridge error voltage is applied to amplifier IC1 whose output varies from 0 to +10V for a process temperature change of 30°C to 60°C. Bridge balance and amplifier gain can be adjusted by the preset potentiometers, R28 and R31 respectively.

The output voltage is connected to socket Y on the front panel, and is also applied to the 0-1mA MEASURED VALUE meter, scaled 0°C to 80°C; a link between sockets X and Y connects the measured value signal to the input of the comparing element.

Comparing element

Amplifier IC2. A summing amplifier operating at unity gain adds the bridge amplifier output to the set value signal which is negative going for an increase in process temperature. As these signals are of opposite sign the amplifier output is effectively equal to deviation.

There are three possible set value signals.

1. SET VALUE adjustment on front panel, R48

2. SET VALUE EXTERNAL DISTURBANCE, socket D

3. SET VALUE INTERNAL DISTURBANCE. Operation of switch S3 applies a -2.5-volt step, corresponding to an increase in temperature of approximately 7.5°C. The 0-1mA SET VALUE meter, scaled 0 to 80°C reads the sum of the set value signals applied.

Controlling element

Amplifiers IC3, IC4, IC5. The output of the summing amplifier is connect by switch S1 either directly to IC3, position 1, or through an external controller, position 2.

Switch S2 selects either linear or two-step controller action. The controller signal is monitored at socket C.

Linear control

S2 on position 1. Potentiometer R55 gives proportional band adjustment from 200% to 5% - a gain of 0.5 to 20. Amplifier IC4 operates at unity gain with a maximum output swing of 10V, and IC5 provides the ±5.6-volt signal required to operate the thyristor firing circuit over its full range.

Two-step control

S2 on position 2. IC4 and IC5 form a Schmitt trigger circuit which produces an output of +5.6 or -5.6 volts with an input overlap adjustable by potentiometer R67 from 0 to ±4 volts.

With two-step control the low power output level is fixed at 10 watts and the upper level adjustable from 25 to 85 watts by the MAX HEATER POWER potentiometer, R70.

Refer to Drawing 326 - 5078

Motor element and Correcting element

The early stages of the thyristor firing circuit which include D1, D2, TR1, TR2, TR3 cause C1 to be discharged at the beginning of each half cycle of the supply. C1 is then charged linearly from a constant current source via TR4 and the ramp output voltage is compared with the control voltage level. When they are equal TR5 is switched on, triggering TR8 and TR9, so producing a short pulse which fires the thyristor.

The output from a bridge rectifier connected to a 110V AC supply is applied to the thyristor and the 120-ohm heater grid. The control voltage swing is limited to ±0.6V, corresponding to a firing angle of 136° to 40° and a change in power output level of 15 watts to 85 watts.