Process Control Trainer
37-100

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Process Control Trainer

37-100

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Manual: 37-100 Ed02 092007 *Printed in England by FI Ltd, Crowborough*

Feedback Part No. 1160-37100

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 or 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 provide the fullest possible user information relating to the proper use of this equipment, if there is any doubt whatsoever about any aspect, the user should contact the Product Safety Officer at Feedback Instruments Limited, Crowborough.

This equipment should not be used by inexperienced users unless they are under supervision.

We are required by European Directives to indicate on our equipment panels certain areas and warnings that require attention by the user. These have been indicated in the specified way by yellow labels with black printing, the meaning of any labels that may be fixed to the instrument are shown below:

CAUTION -
RISK OF
DANGER

Refer to accompanying documents

CAUTION -
RISK OF
ELECTRIC SHOCK

CAUTION -
ELECTROSTATIC
SENSITIVE DEVICE

PRODUCT IMPROVEMENTS

We maintain a policy of continuous product improvement by incorporating the latest developments and components into our equipment, even up to the time of dispatch.

All major changes are incorporated into up-dated editions of our manuals and this manual was believed to be correct at the time of printing. However, some product changes which do not affect the instructional capability of the equipment, may not be included until it is necessary to incorporate other significant changes.

COMPONENT REPLACEMENT

Where components are of a 'Safety Critical' nature, i.e. all components involved with the supply or carrying of voltages at supply potential or higher, these must be replaced with components of equal international safety approval in order to maintain full equipment safety.

In order to maintain compliance with international directives, all replacement components should be identical to those originally supplied.

Any component may be ordered direct from Feedback or its agents by quoting the following information:

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

Components can often be replaced by alternatives available locally, however we cannot therefore guarantee continued performance either to published specification or compliance with international standards.

CE DECLARATION CONCERNING ELECTROMAGNETIC COMPATIBILITY

Should this equipment be used outside the classroom, laboratory study area or similar such place for which it is designed and sold then Feedback Instruments Ltd hereby states that conformity with the protection requirements of the European Community Electromagnetic Compatibility Directive (89/336/EEC) may be invalidated and could lead to prosecution.

This equipment, when operated in accordance with the supplied documentation, does not cause electromagnetic disturbance outside its immediate electromagnetic environment.

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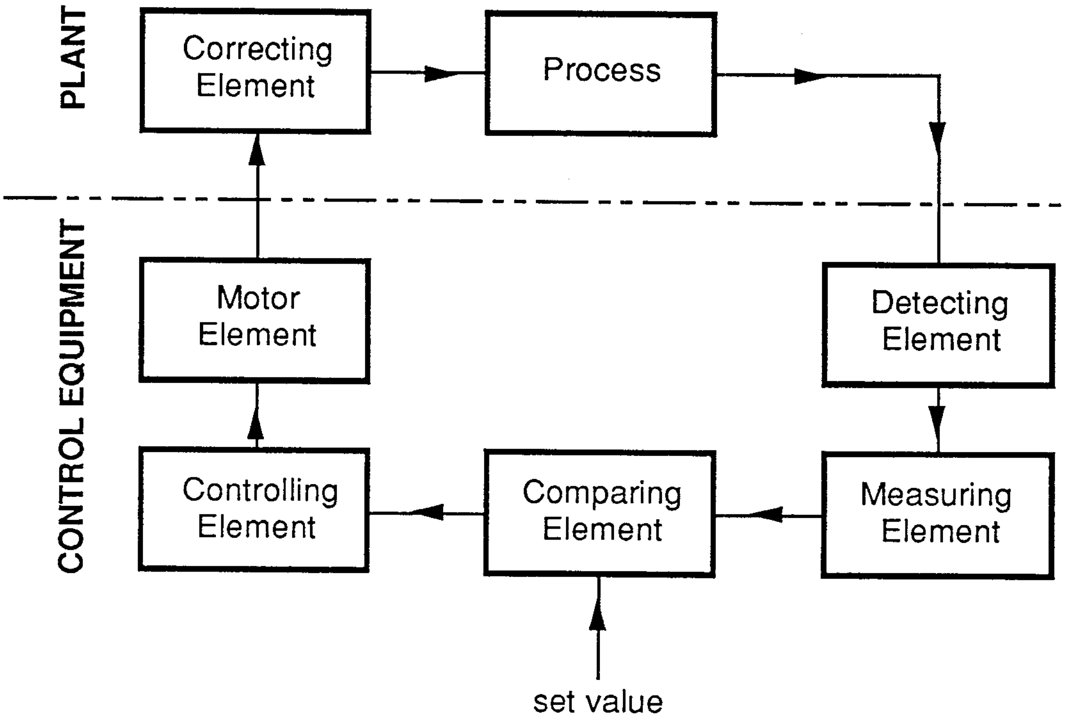


Fig 1.1 Basic Elements of Closed Loop Process Control System

INTRODUCTION

The **37-100** 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 1.1.

The instrument contains integrated circuit operational amplifiers and has self-contained power supplies. It can be coupled to the Feedback PID 150Y module for the application of three-term control to the process.
The terminology in this manual and on the instrument panel 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.

BS1532	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'

DESCRIPTION

Power 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.

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.

Ducting 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 amplfier 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

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.

External

The proportional band adjustment can be switched out of circuit and in its place a separate controller, such as the 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 control' or on-off action the proportional band adjustment is by-passed and adjustment of maximum heater power and overlap are 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

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 control at position 4 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:	20.5in (520mm)
Depth:	11.5in (292mm)
Height:	8.5in (216mm)
Weight:	21 lb (9.5 kg)

ANCILLARY EQUIPMENT

The **37-100** requires a source of sinusoidal, trapezoidal and square wave input signals for frequency response and step function testing and a means of displaying them. The following items of standard laboratory equipment are required:

Qty	Designation	Description
1	–	Function Generator, Sine, Square and Triangular outputs, 0.1 to 5Hz *(eg. Feedback FG601)*
1	–	Two–channel oscilloscope, X-Y operation, preferably with storage facility. *(A suitable type is available from Feedback Instruments)*
1	–	Wattmeter, 10-100W *(eg. Feedback EW1604*
1	–	Thermometer or thermocouple, 0-80°C
1	–	Voltmeter, 0-15V dc.

NOTES

INSPECTION

Confirm that the screw-in fuses mounted on the left-hand panel of the instrument are as labelled. Switch 'power' on and set the 'heater/wattmeter/heater' switch on the side of the Trainer to 'HEATER'; check that the 'on' indicator lamp glows and that the blower operates. Make the connections and settings shown in fig 2.1 and leave the instrument to run for a warm-up period of approximately half an hour.

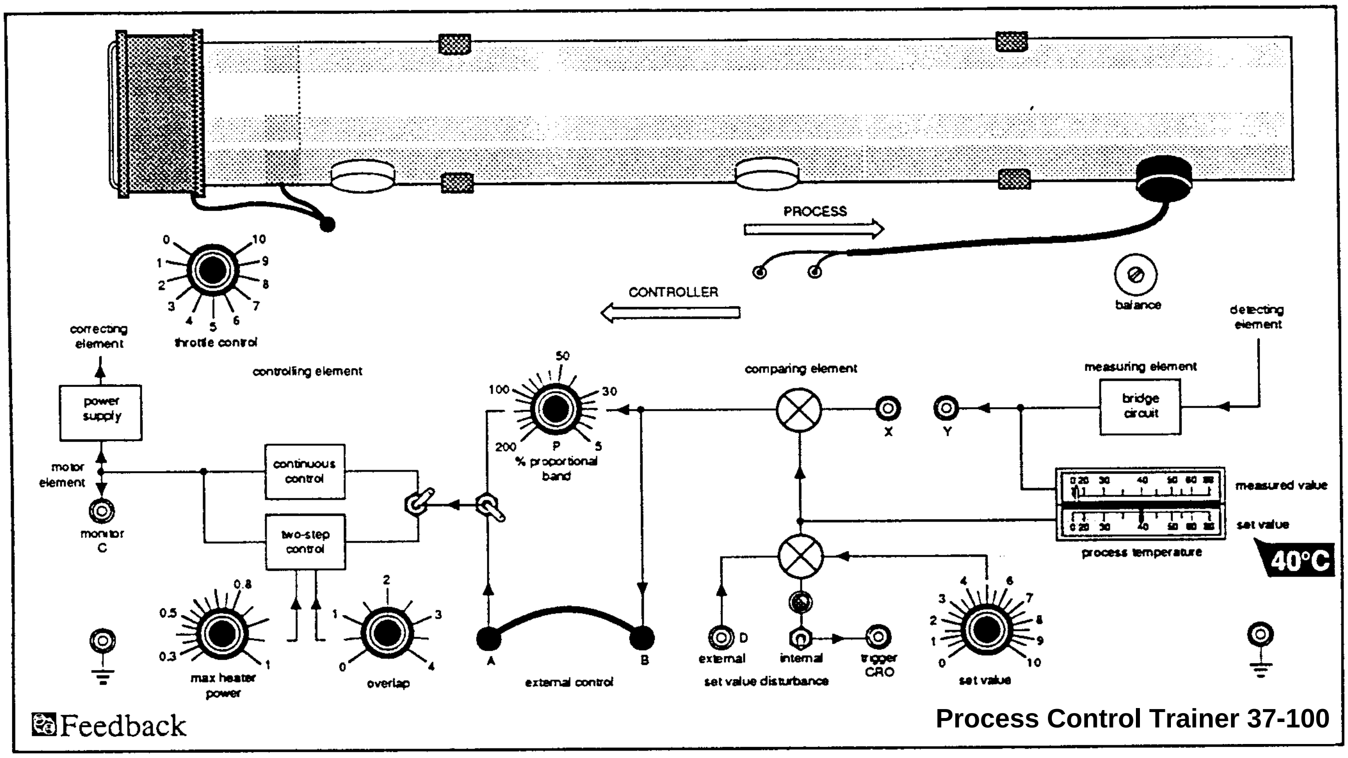


Fig 2.1

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.

Balance

The 'balanced' condition is set by the manufacturer during final testing and should not require frequent adjustment. However balance is affected by ambient temperature and the standard setting may change.

Setting up

To set up 'balanced' conditions carry out the following procedure:

Set the trainer up for unity gain by either:

Setting the % proportional band control to 100%

or Linking terminals 'A' and 'B' and setting the associated switch down for external operation.

Remove the link from sockets 'X' and 'Y'.

Connect a voltmeter, set to read up to 10V dc, between socket 'Y' and ⏚

Set the 'set value' control to zero.

Adjust the 'balance' screw immediately above the bridge circuit to produce 0°C on the measured value scale and 0V on the voltmeter.

Increase the 'set value' control to 10 and check that the voltmeter indicates 10V. Then reduce the set value to zero and check that the voltmeter again indicates 0V. If this result cannot be achieved it is necessary to remove the front panel from the case and adjust R30, see fig 5.1; and repeat the foregoing procedure.

When the required values are correctly set, disconnect the voltmeter.

Adjust the 'balance' screw to produce a reading of 25°C on the measured value scale, and leave.

If this equipment fails the foregoing check please contact your supplier.

Throttle Control

The action of the controller is dependent to some extent on ambient temperature, in addition to the settling of the throttle control. It may be necessary to vary the throttle control settings given in the various assignments in order to obtain the results described in the text.

Open-loop operation

With the connections shown in fig 2.1 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 a sinusoidal input signal the frequency response characteristics can be determined.

Closed-loop operation

By linking sockets 'X' and '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.

NOTES

The following assignments can be carried out using the equipment supplied with the **37-100** Process Trainer:

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

NOTES

DISTANCE/VELOCITY LAG — ASSIGNMENT 1

INTRODUCTION

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 4.1.1.

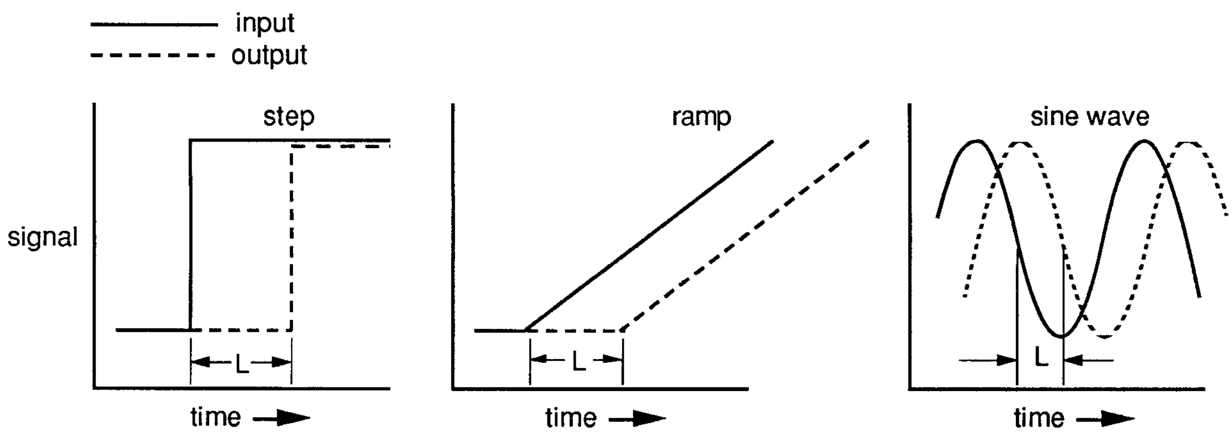


Fig 4.1.1

OPERATING NOTES

This process is carried out with the control loop open and the controller set to 100% proportional band. After switching to 'continuous control' the overlay may be fitted over part of the controller, leaving the proportional band adjustment visible if required.

With the process temperature at a low level a step change in set value (a set value disturbance) 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.

Distance/Velocity Lag — Assignment 1

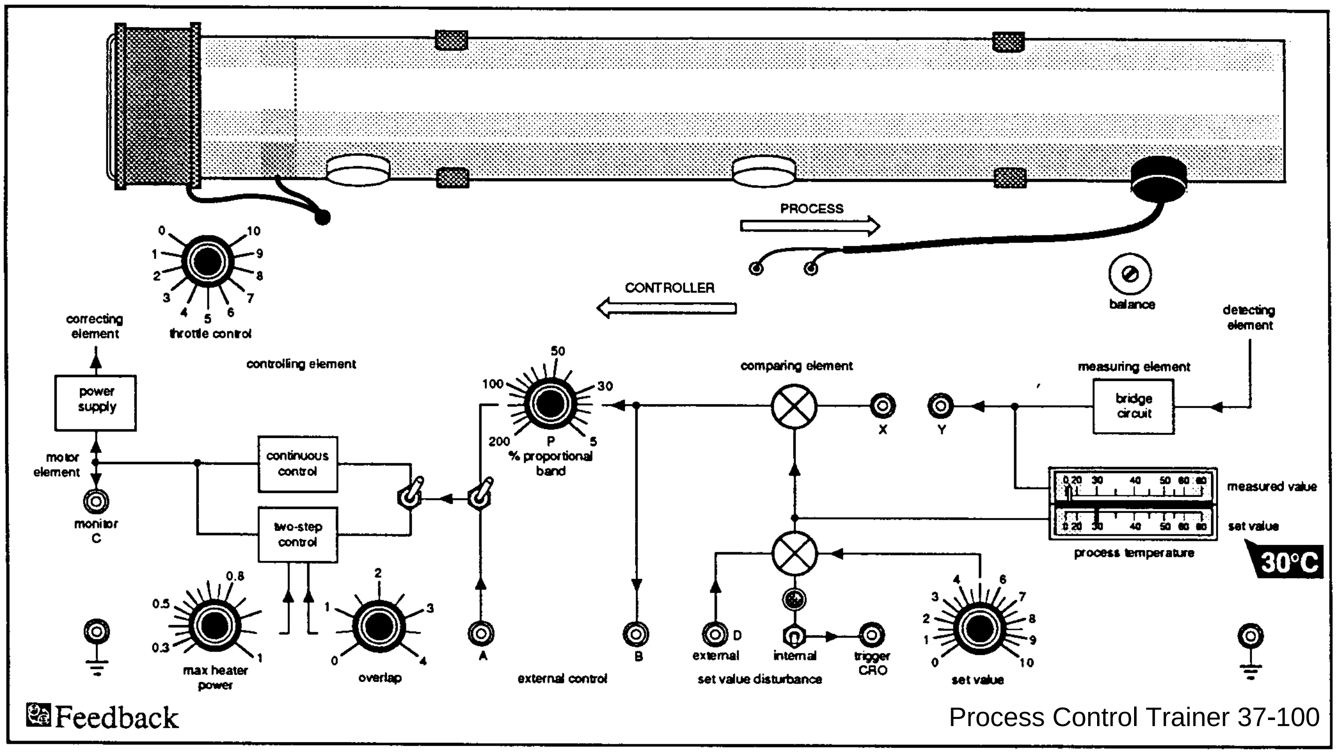


Fig 4.1.2 Connection Diagram

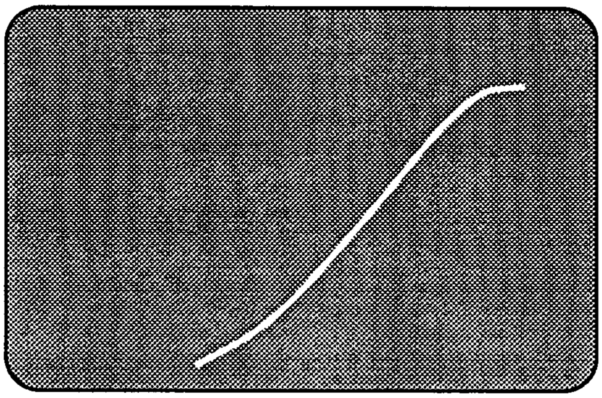


Fig 4.1.3a

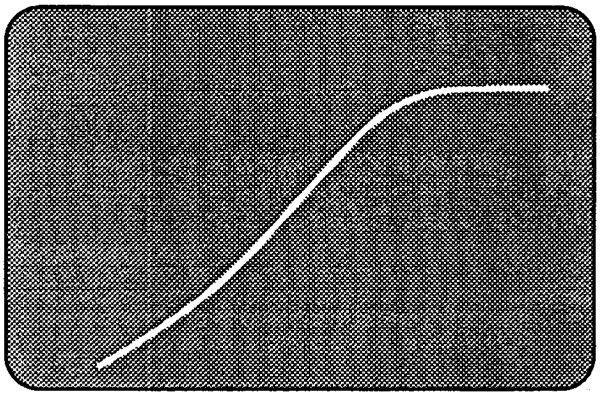


Fig 4.1.3b

Process Trainer

Make the connection and switch settings given in fig 4.1.2

Adjust 'set value' to 30°C

Adjust the throttle control to 4

Place the 'detector probe' in the 11" position

Then set the switch on side of **37-100** to 'heater'

Set Value Disturbance

If a function generator is available set it to give a 2 volt, 0.1Hz, square wave and connect its output to socket 'D' on the **37-100** .

Connect a trigger output from the function generator to the external trigger socket of the oscilloscope.

If a function generator is not available the 'set value disturbance' switch on the **37-100** 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 storage facility)

Set Y1 to 1 volt/div and connect to socket 'Y' on the **37-100** .

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

PRACTICAL

Switch on the **37-100** and ancillary instruments and adjust the oscilloscope so that it is triggered by the function generator or by an internal step change of set value.

The measured value as displayed on the oscilloscope will take the form shown in fig 4.1.3a. 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 4.1.3b.

With the detector in the 11" position, increase the air flow rate by increasing the throttle control from 4 to 6 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 exponential rise of process temperature to its final value. This is known as transfer lag and will be discussed in the next assignment.

NOTES

TRANSFER LAG

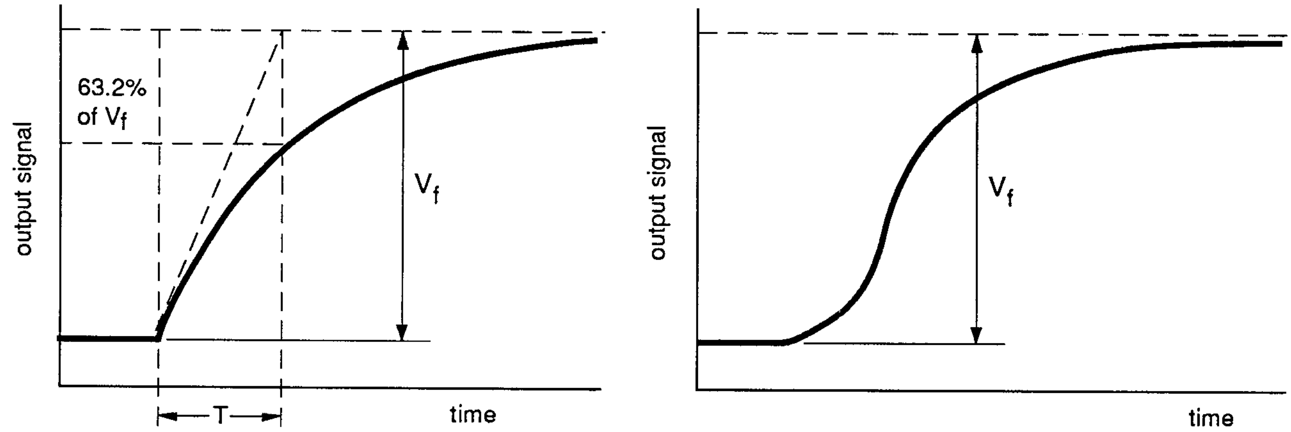
ASSIGNMENT 2

INTRODUCTION

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 4.2.1a. 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 4.2.1b, 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*

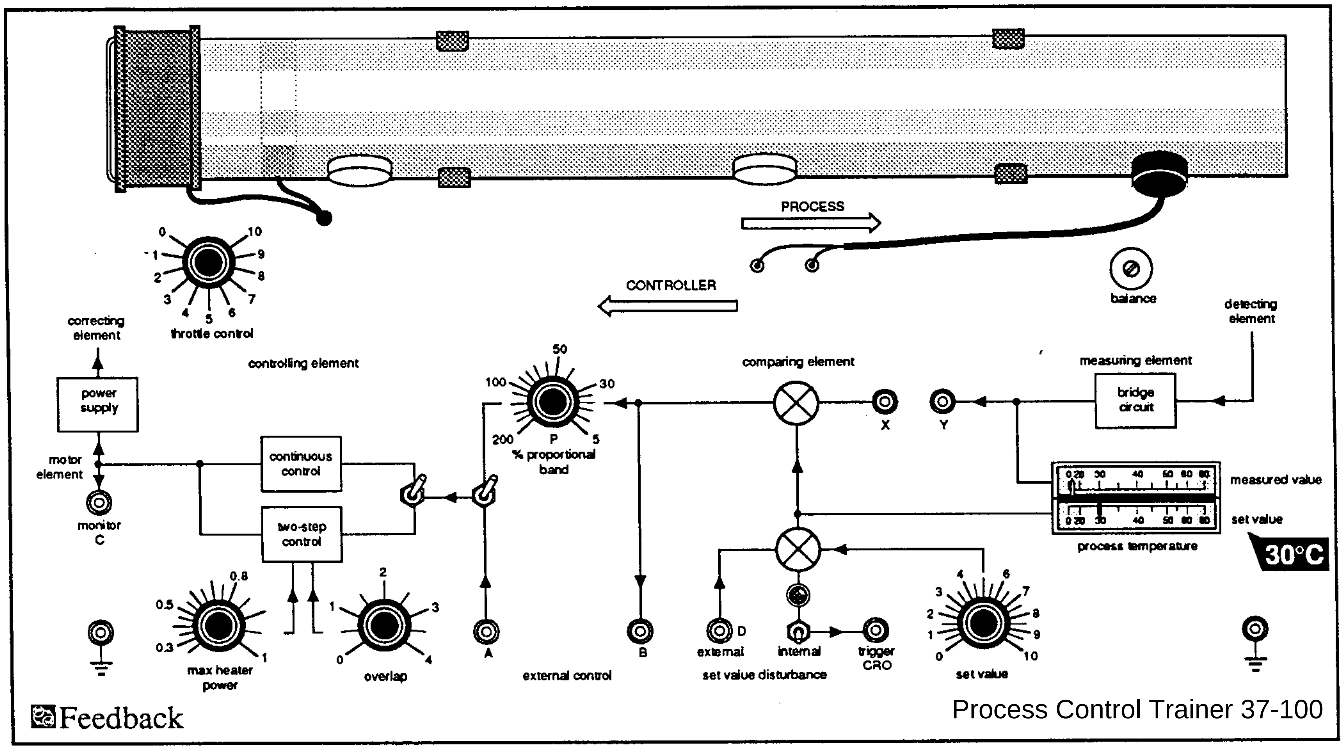
Fig 4.2.1 Response of System to a step change of Input Signal

OPERATING NOTES

In this assignment the control loop is open and the controller set to 100% proportional band. 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 if required.

Transfer Lag Assignment 2



Figs. 4.2.2 Connection Diagram

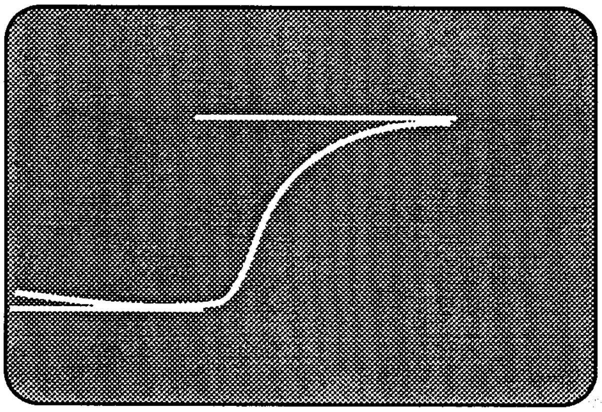


Fig 4.2.3a

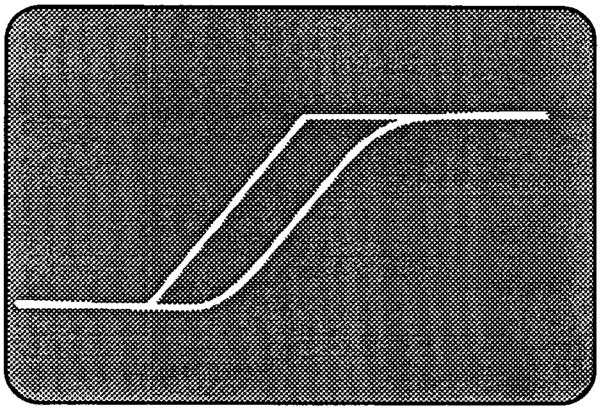


Fig 4.2.3b

Transfer Lag **Assignment 2**

Process Trainer

Make the connections and switch settings given in fig 4.2.2.

Adjust 'set value' to 30°C

Adjust the 'blower throttle control' to 4

Place the 'detector probe' in the 11" position

Then set the switch on side of the **37-100** to 'heater'.

Set Value Disturbance

If a function generator is available, set it to give a 2 volt, 0.1Hz square wave. Connect the square wave output to socket 'D' on the **37-100** .

Connect a trigger output from the function generator to the external trigger socket of the oscilloscope.

If a function generator is not available the 'set value disturbance' switch on the **37-100** may be used to provide a step change in set value. In this case the oscilloscope is triggered from the 'trigger CRO' socket.

Oscilloscope
(Preferably with storage facility)

Set Y1 to 1v/div and connect to socket 'Y' on the **37-100** .

Set the time base to 0.5 s/div, external trigger.

PRACTICAL

Switch on the **37-100** and ancillary instruments.

Adjust the oscilloscope so that it is triggered by the function generator or an internal step change of set value.

The measured value, as displayed on the oscilloscope will take the form shown in fig 4.2.3a.

Repeat with a triangular signal from the function generator to show a ramp change in set value. This will give a measured value response similar to that shown in fig 4.2.3b.

Repeat with the blower throttle control set to 6 and observe the resulting decrease in transfer lag.

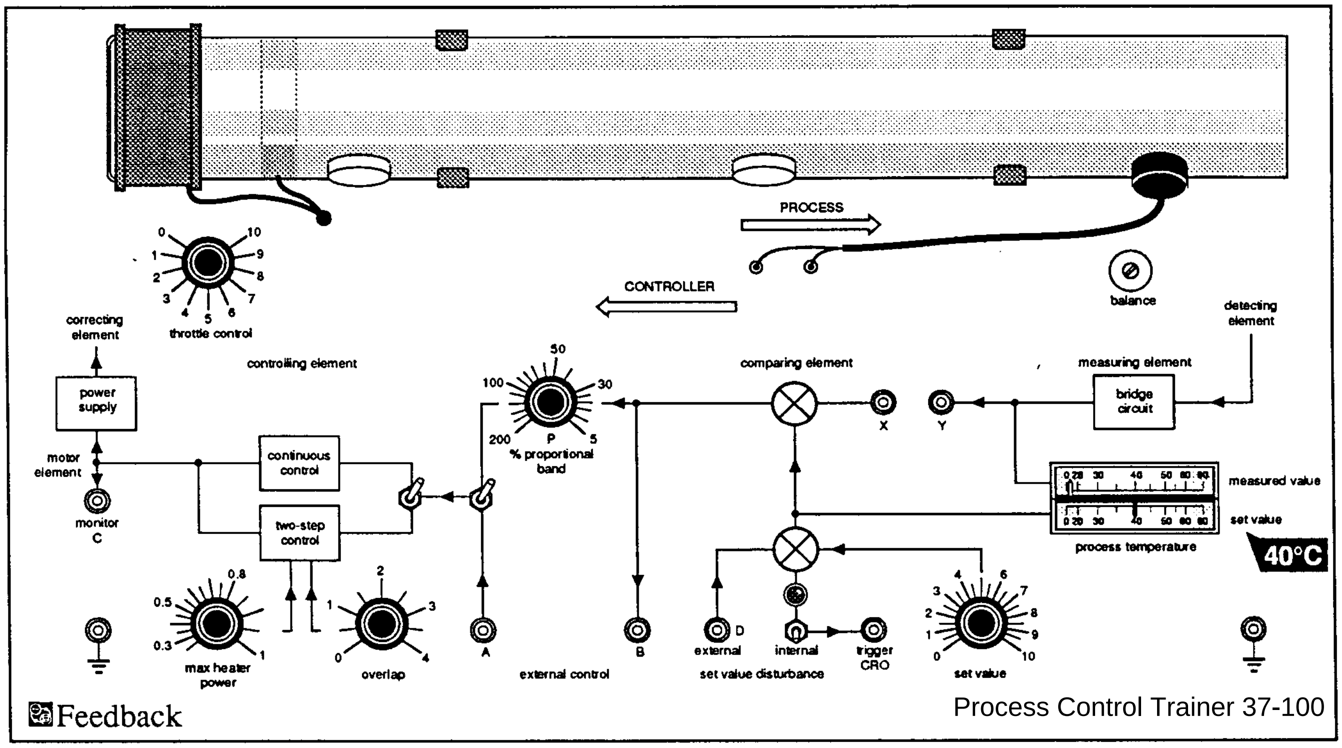


Fig 4.3.1 Connection Diagram

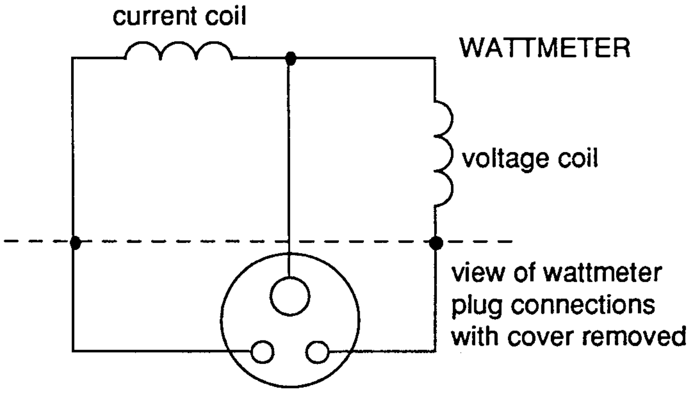


Fig 4.3.2 Wattmeter Connections

INTRODUCTION

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 d.c input signals. In a later assignment the response of the system to a sine wave is considered.

OPERATING NOTES

After switching to 'continuous control' the overlay may be fitted over part of the controller leaving the proportional band adjustment visible if required.

37-100

Make the connections and switch settings shown in fig 4.3.1.

Adjust the 'blower throttle control' to 4

Place the 'detector probe' in the 11" position

Set '% proportional band' to 100%

Wattmeter

Set up to cover the range 10-100 watts

Set the switch on side of the **37-100** to 'heater/wattmeter'

Max. voltage: 120V AC

Max. current: 1.0A AC

Connect to the wattmeter plug supplied with the **37-100** as shown in fig 4.3.2 and connect the wattmeter to the **37-100** .

Voltmeter

Using a 0-15V DC.meter, connect it between socket 'Y' and earth and between socket 'B' and earth as required.

Air Temperature Measurement

Use a thermometer or thermocouple placed in the air stream near the detector probe.

Temperature range: 0 to 80°C

PRACTICAL

Switch on the **37-100** .

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 socket 'Y' at each step.

Figs 4.3.3 and 4.3.4 show typical graphs of heater power/set value and air temperature rise/heater power.

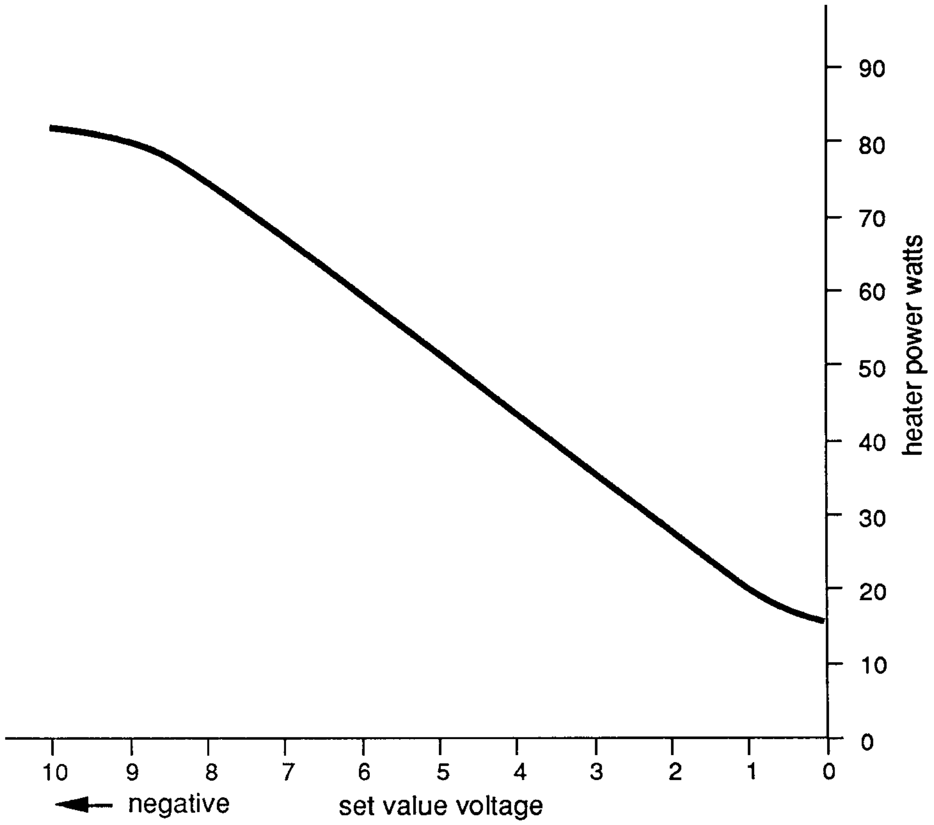


Fig 4.3.3 Heater Power/Set Value

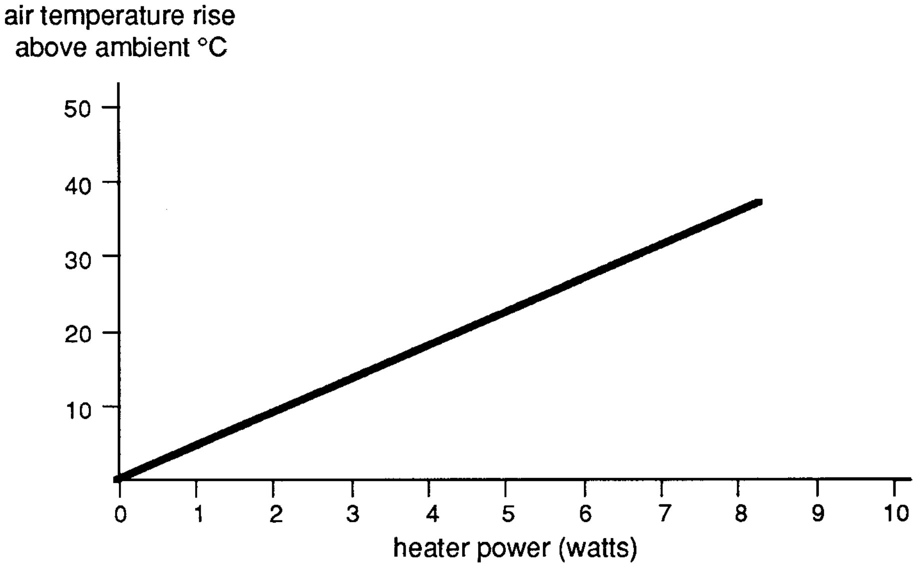


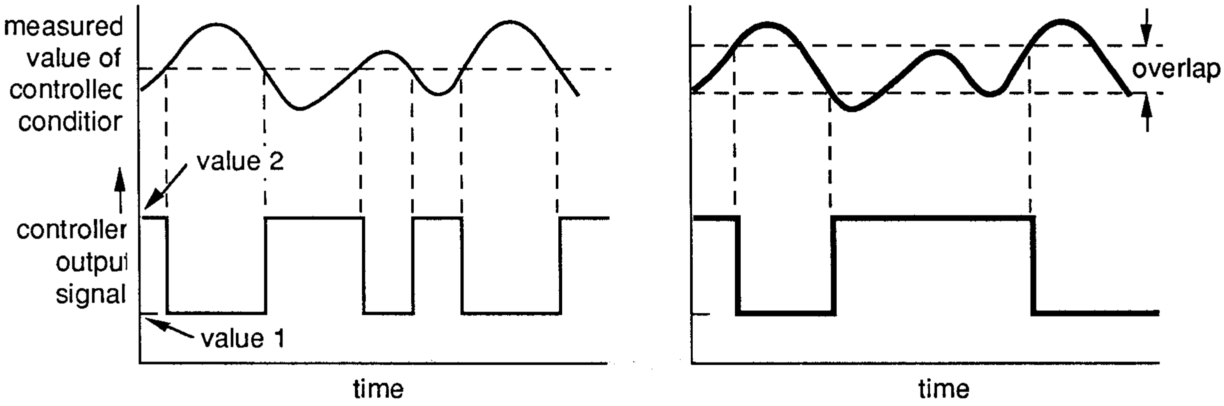
Fig 4.3.4 Air Temperature Rise/Heater Power

TWO-STEP CONTROL — ASSIGNMENT 4

INTRODUCTION

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 4.4.1a.

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 4.4.1b.



Without overlap (a) *With overlap (b)*

Fig 4.4.1 Two Step Controller Action

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.

Two-Step Control

Assignment 4

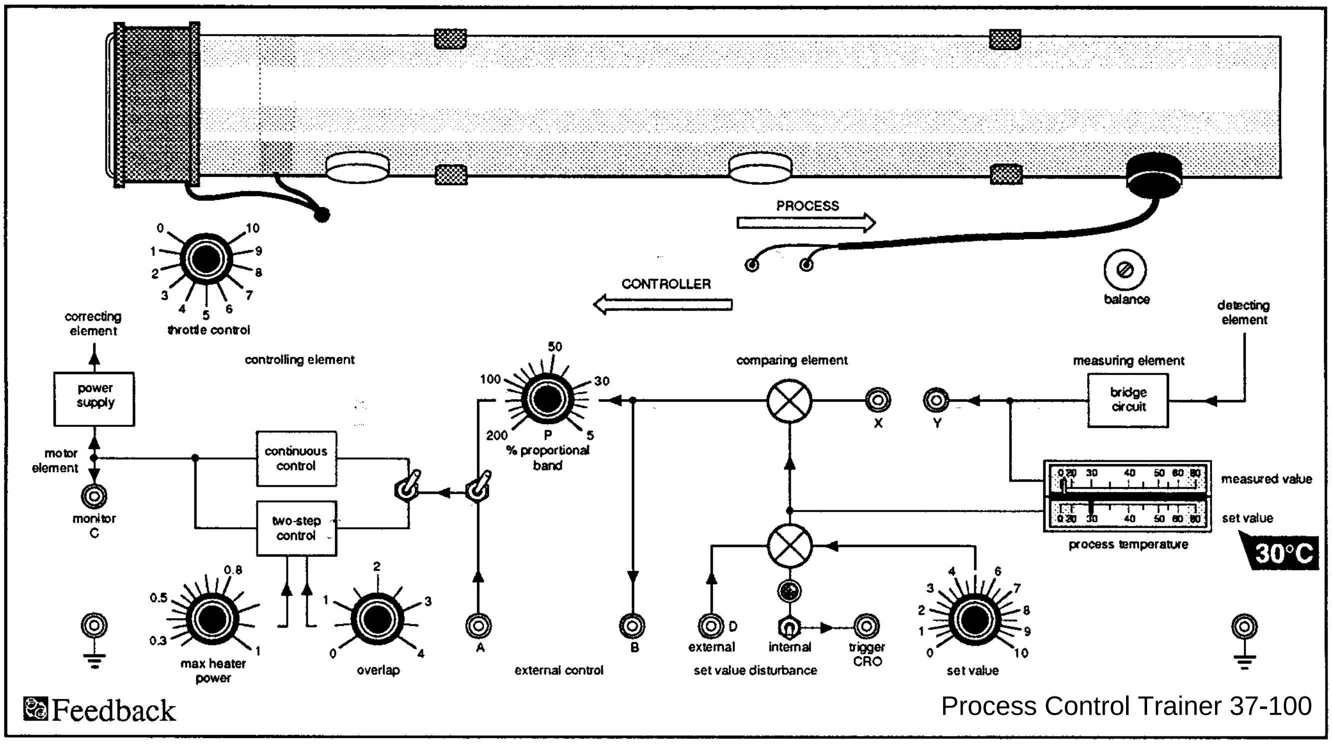


Fig 4.4.2 Connection Diagram

Process Trainer

Make the connections and switch settings given in fig 4.4.2.

Adjust 'set value' to 40°C

Set 'overlap' to 0

Set 'max heater power' to 1.0

Adjust the 'blower throttle control' to 4

Place the 'detector probe' in the 11" position

Set the switch on side of **37-100** to 'heater'.

Oscilloscope
(Preferably with storage facility)

Set Y1 to 5V/div and connect to socket 'Y' on **37-100** .

Set Y2 to 5V/div and connect to socket 'C' on **37-100** .

Set the Time Base to 0.5 s/div, internal trigger.

PRACTICAL

Switch on the Process Trainer and Oscilloscope. The system will oscillate at a frequency of approximately 1Hz as shown in fig 4.4.3a. Observe the effect of alterations in set value and maximum heater power on the frequency of oscillation.

Repeat the assignment 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 4.4.3b.

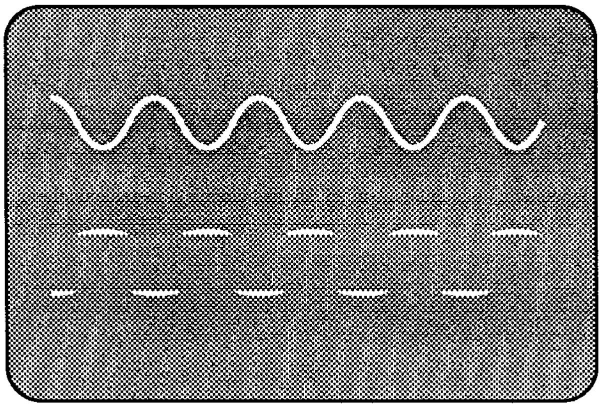


Fig 4.4.3a

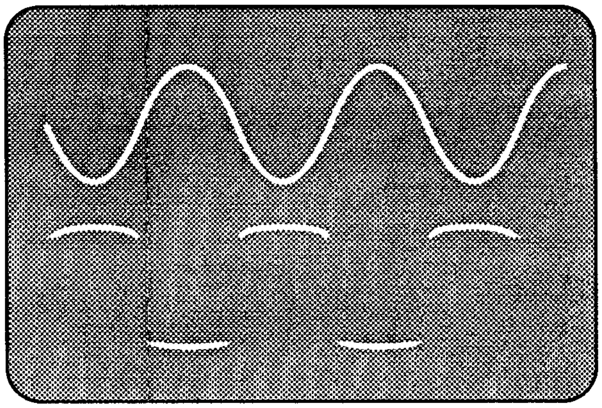


Fig 4.4.3b

NOTES

INTRODUCTION

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 4.5.1

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 can be defined as the range of values 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 bandwidth. As proportional band is decreased, deviation is reduced until a point is reached at which the system becomes unstable.

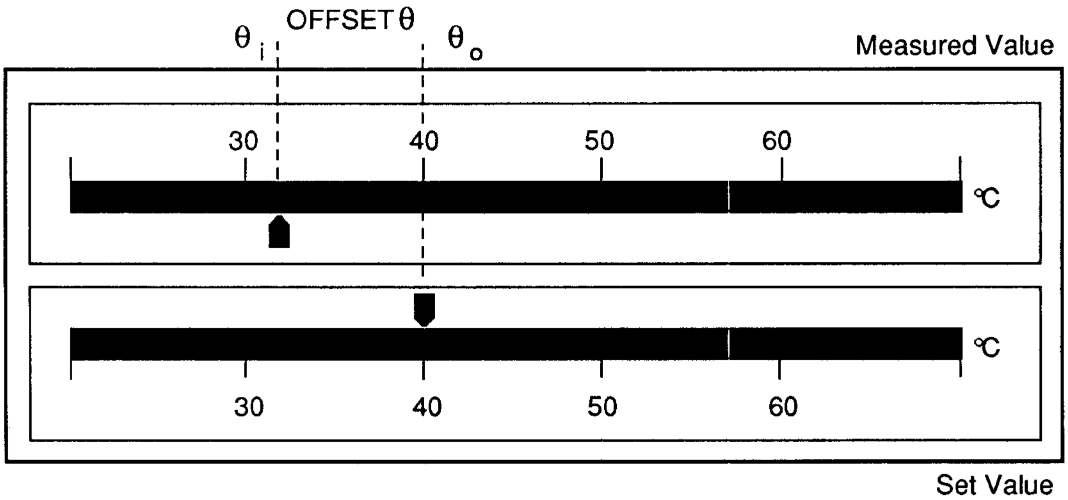


Fig 4.5.1 Reduction in Offset by decrease in Proportional Band

OPERATING NOTES The controller is switched to continuous control with the process temperature set to an immediate level.

Proportional Control **Assignment 5**

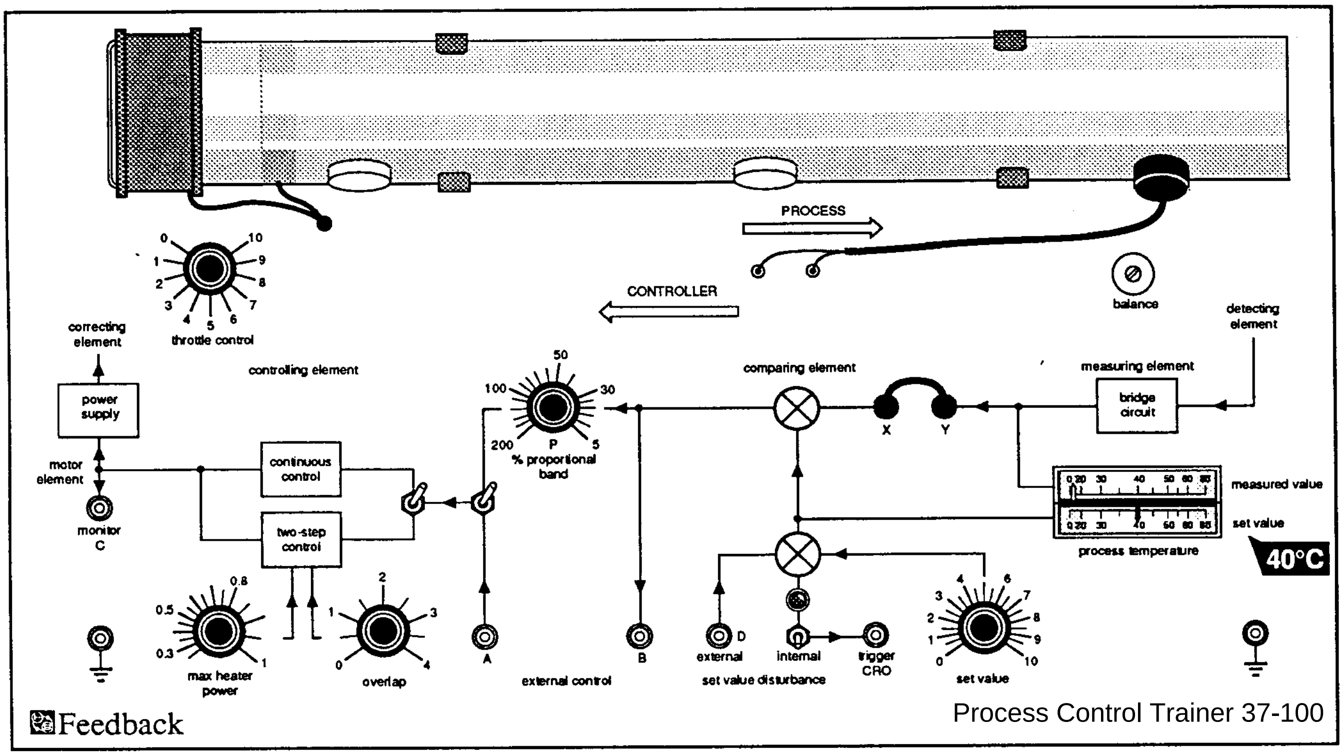


Fig 4.5.2 Connection Diagram

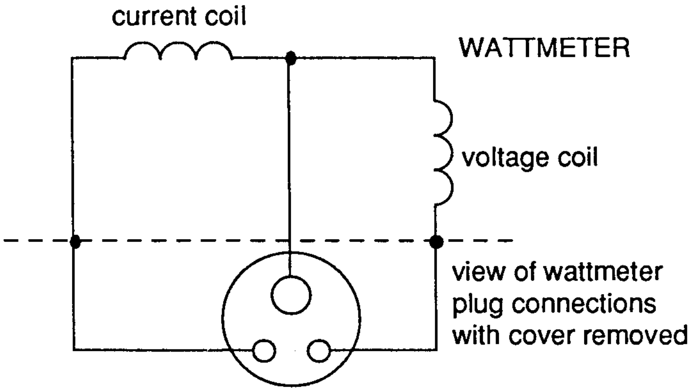


Fig 4.5.3 Wattmeter Connections

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 4.5.2.

Adjust the 'set value' to 40°C

Set '% proportional band' to 100%

Adjust the 'blower throttle control' to 4

Place the 'detector probe' in the 11" position

Set the switch on the side of **37-100** to 'heater/wattmeter'

Oscilloscope
(Preferably with storage facility)

Set Y1 to 2V/div and connect to socket 'B' on **37-100** .

Set Y2 to 2V/div and connect to socket 'Y' on **37-100** .

Set Time-base to 0.5 s/div, externally triggered, and connect to the 'trigger CRO' socket on **37-100** .

Voltmeter

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

Wattmeter

Connect to wattmeter plug supplied with **37-100** as shown in fig 4.5.3

Set up to cover the range 10-100Watts.

Max. voltage: 120V AC

Max current: 1.0A AC

PRACTICAL

Switch on the **37-100** and Oscilloscope.

Operate the 'internal set value disturbance' switch and observe changes in set value, measured value, deviation and heater power.

Set the CRO to internal trigger with the settings as in the previous test. Repeat the test adjusting '% proportional band' 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 4.5.4.

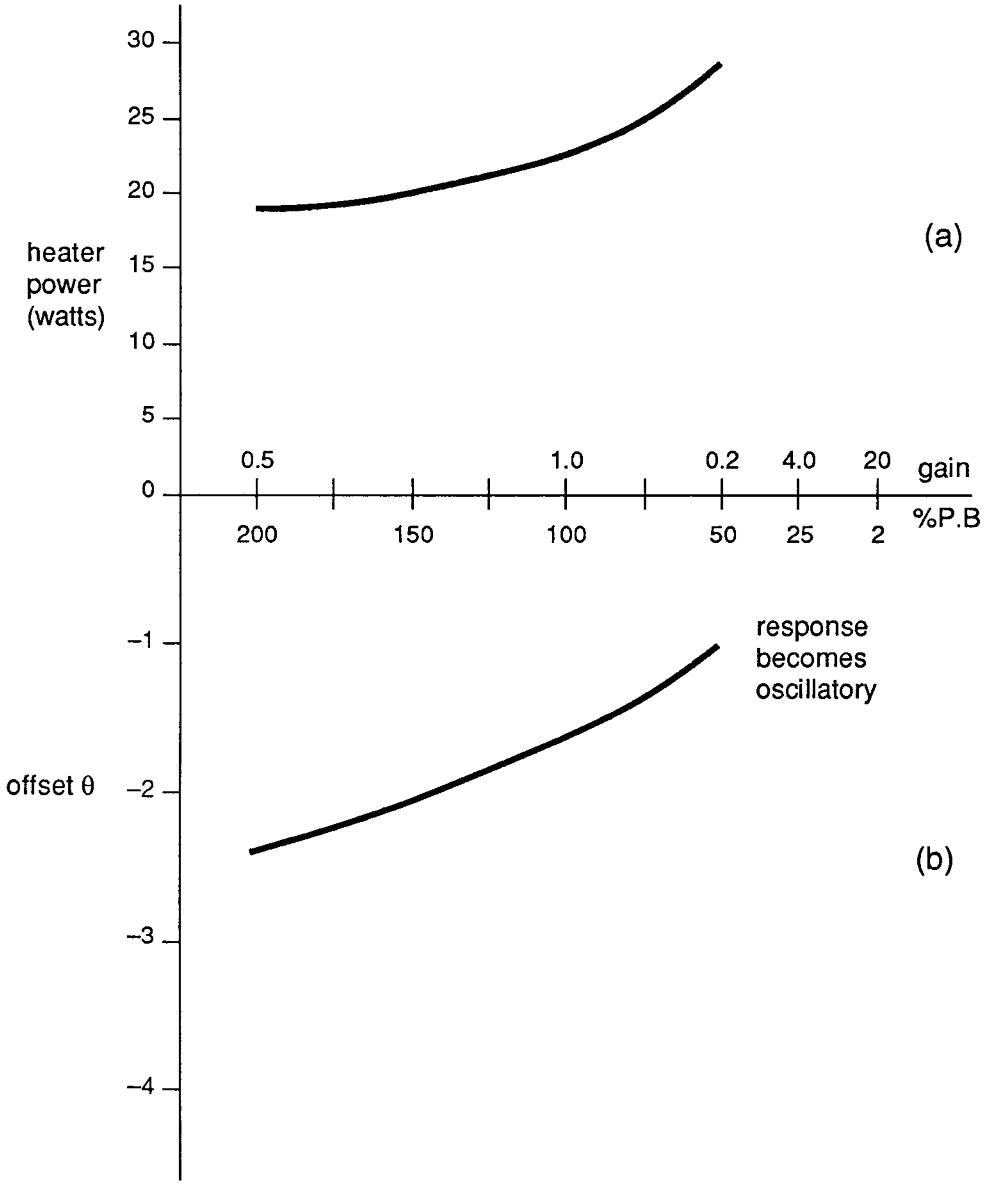


Fig 4.5.4 Offset and Heater Power/Proportional Band

DISTURBANCE AND SYSTEM RESPONSE — ASSIGNMENT 6

INTRODUCTION

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 bandwidth as shown in fig 4.6.1.

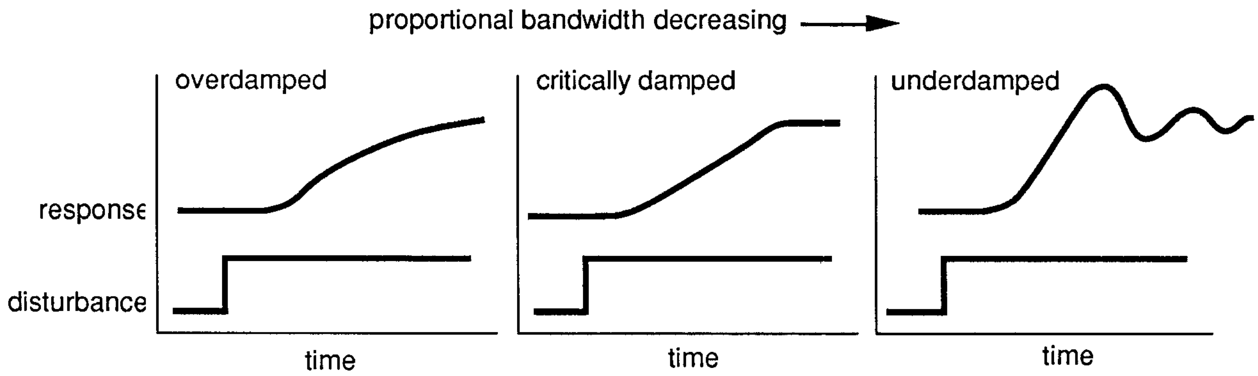


Fig 4.6.1 Response to Step Change Disturbance

OPERATING NOTES

With set value adjusted to an intermediate level and % proportional band set to 100% a rapid increase in the blower throttle control will cause a change in measured value and deviation. The response to the disturbance and subsequent recovery is dependent on proportional bandwidth. 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 function generator can be applied to the 'set value disturbance' socket on **37-100** and the response measured by an oscilloscope connected to socket.'Y'. Alternatively, operation of the 'internal' 'set value disturbance' switch will produce the required step change.

Disturbance and System Response Assignment 6

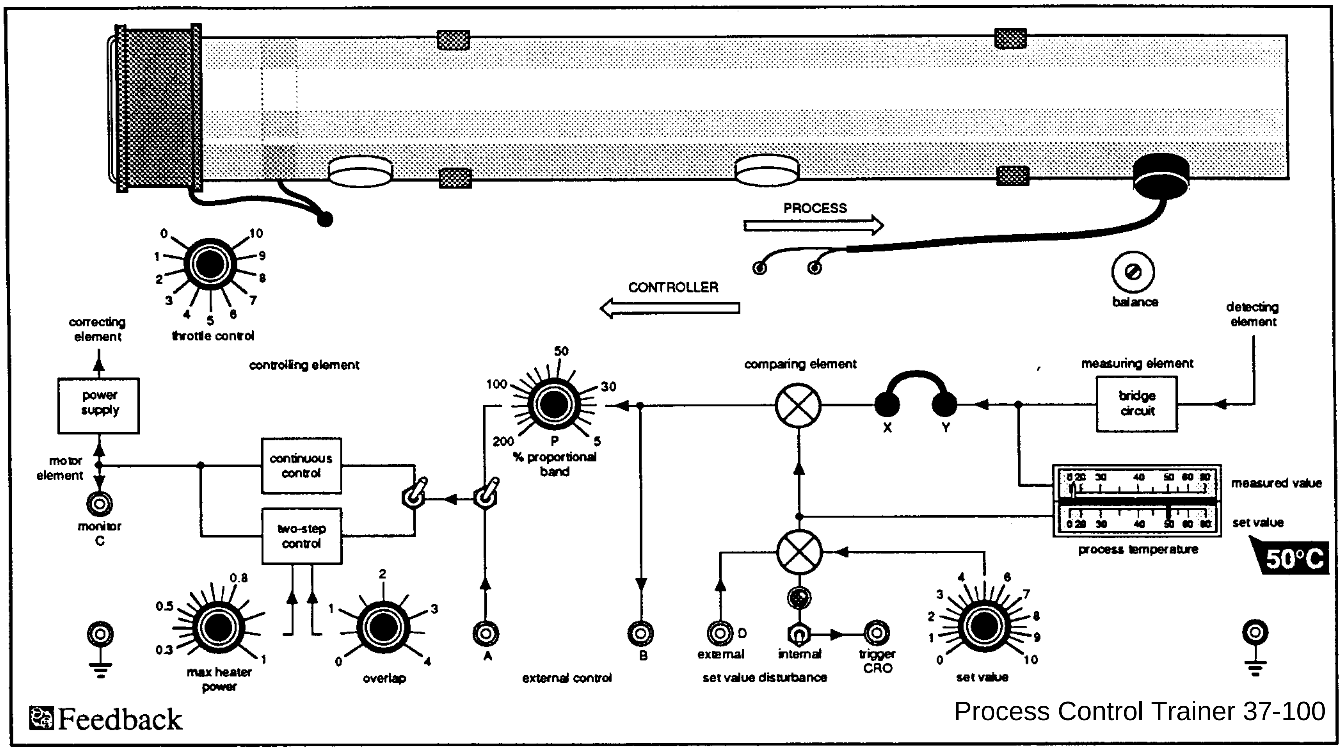


Fig 4.6.2 Connection Diagram

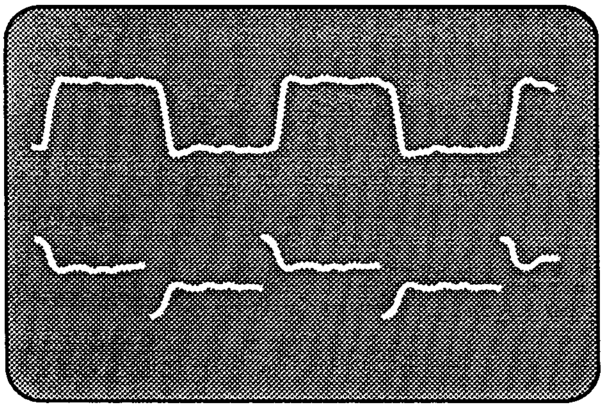


Fig 4.6.3a

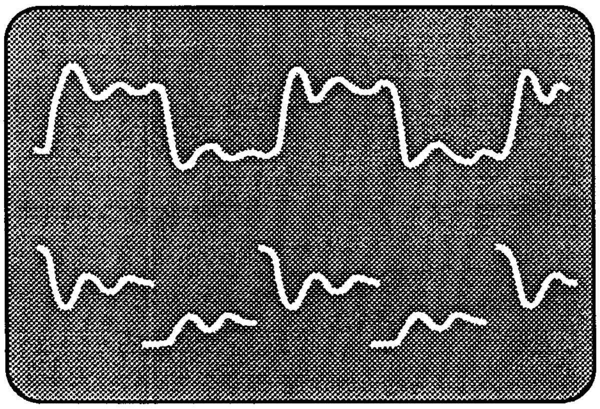


Fig 4.6.3b

Process Trainer

Make the connections and switch settings given in fig 4.6.2.

Adjust the 'set value' to 50°C

Set '% proportional band' to 100%

Adjust the 'blower throttle control to 4

Place the 'detector probe' in the 11" position

Set the switch on the side of 37-100 to 'heater'

Oscilloscope
(Preferably with storage facility)

Set Y1 to 1V/div and connect to socket 'Y' on 37-100 .

Set Y2 to 1V/div and connect to socket 'C' on 37-100 .

Set Time-base to 0.5 s/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.

PRACTICAL

Supply Side Disturbance

Switch on the Process Trainer and Oscilloscope and with the settings given above rapidly change the blower throttle control from 4 to 6. 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 '% proportional band' set at 200% and at 30%.

Set '% proportional band' to 50% and vary the blower throttle control from 2 to 8 in steps, taking readings of measured value and controller output voltage at each step. Remove the link X–Y and repeat with the loop open and plot the results as in the graph of fig 4.6.4.

Set Value Disturbance

The set value disturbance may be provided by a function generator or by operation of the 'internal' switch on 37-100 . If a function 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% proportional band the response is sufficiently damped to give little overshoot or oscillation as shown in fig 4.6.3a. With proportional band decreased to 50% the response is damped oscillatory with some overshoot as in fig 4.6.3b.

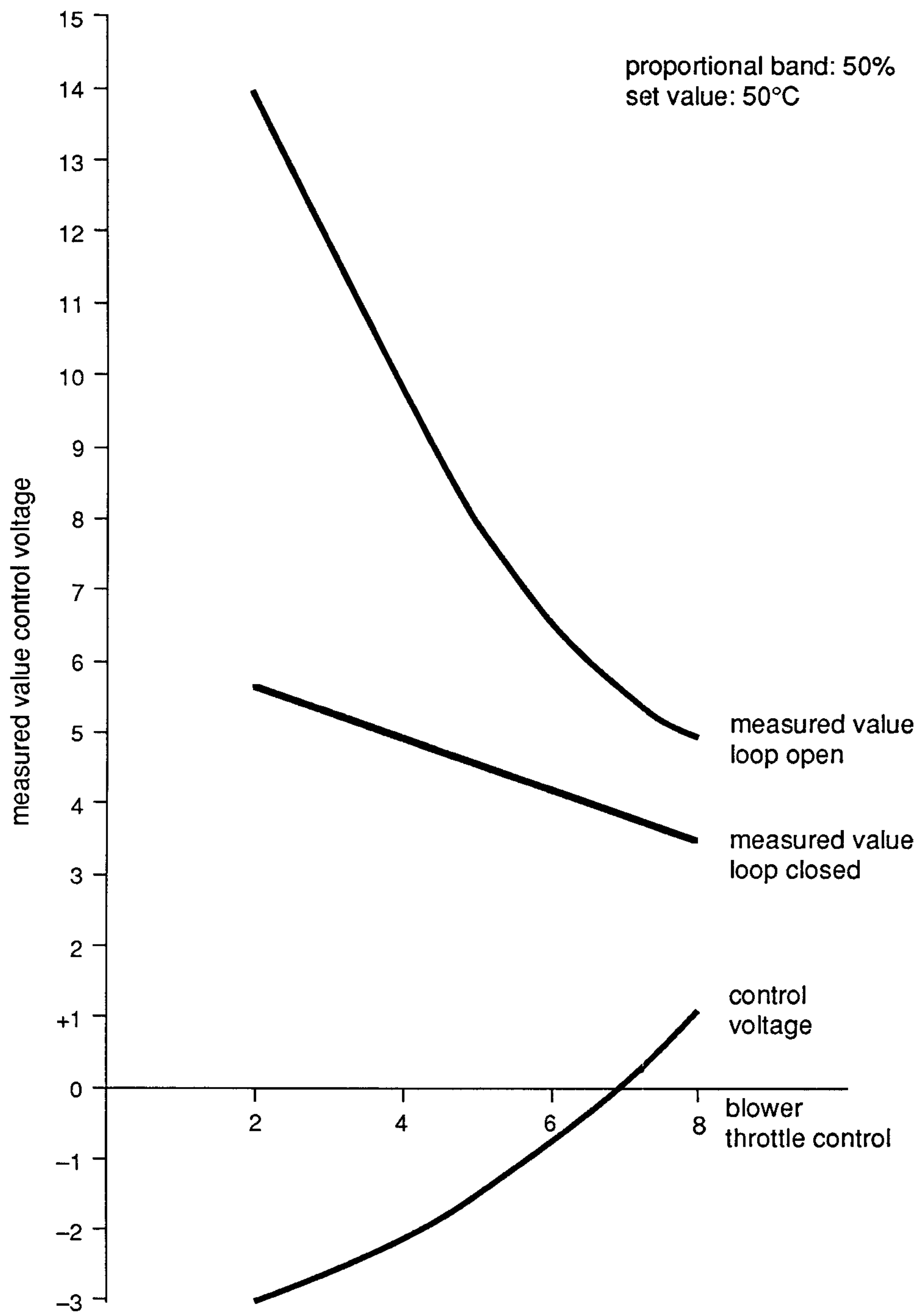


Fig 4.6.4 Measured Value and Controller Output against Blower Throttle Angle

FREQUENCY RESPONSE — ASSIGNMENT 7

INTRODUCTION

A process may be considered to be a series of transfer stages — each with its own time lag, plus a distance/velocity lag. If a control loop is opened as in fig 4.7.1 and a sine-wave 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.

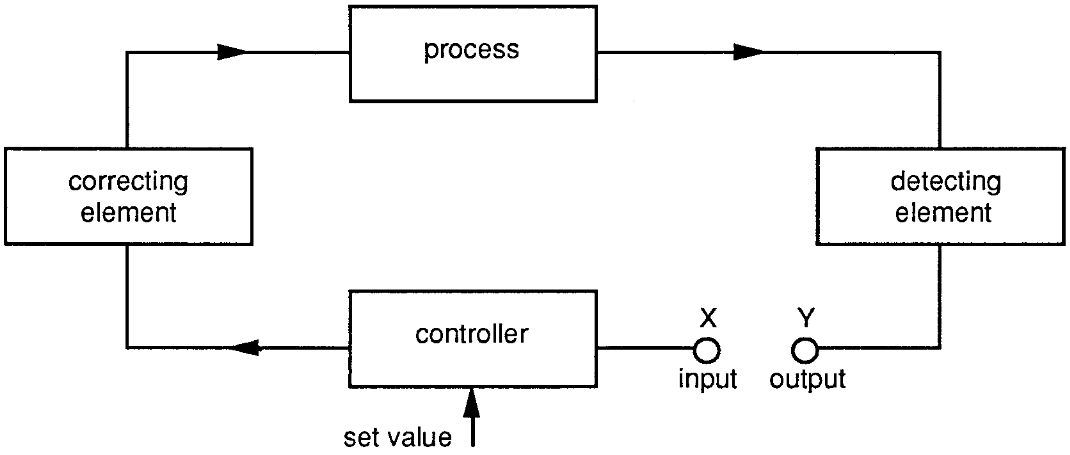


Fig 4.7.1

The results may be plotted on a Nyquist diagram or Bode diagram. In each case the principle 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 can be defined as 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:

$$G = \frac{100}{\%\text{proportional band}}$$

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

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

NOTES

Frequency Response

Assignment 7

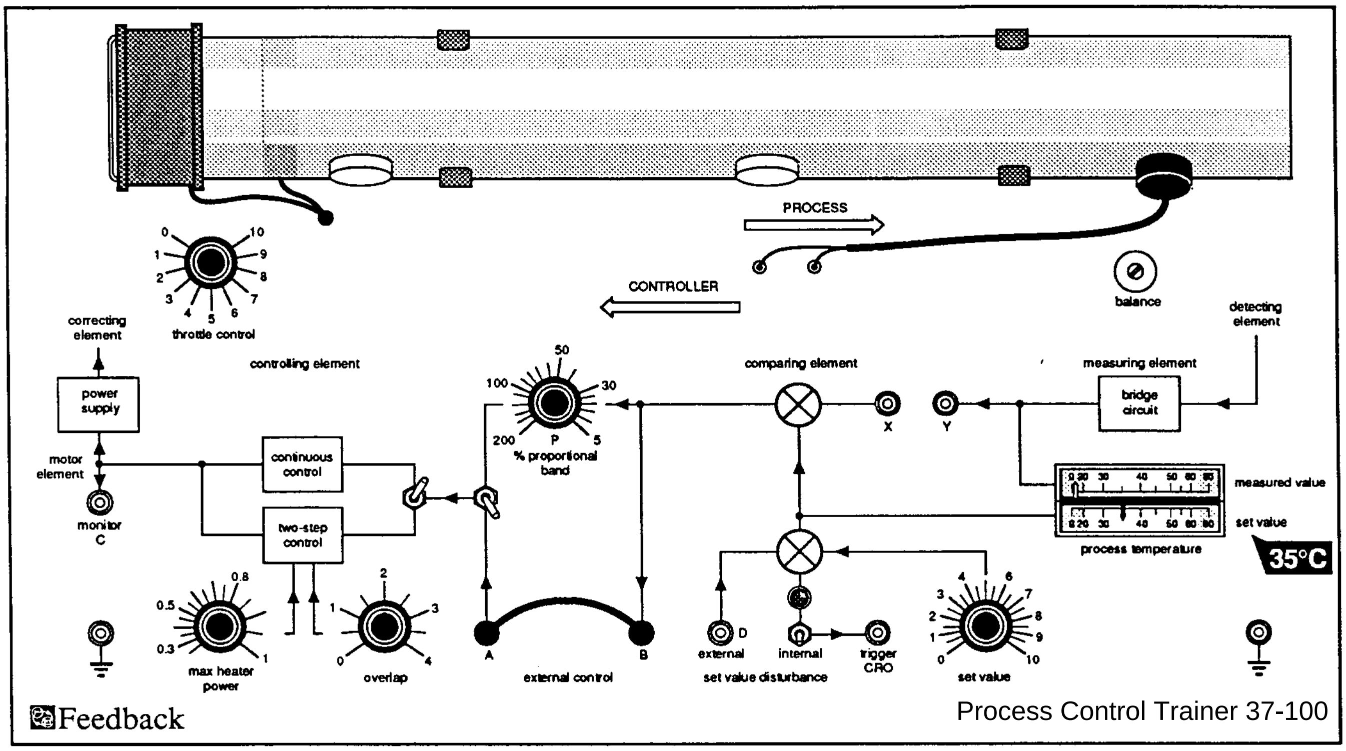


Fig 4.7.2 Connection Diagram

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 unity; the system will oscillate.

OPERATING NOTES

This assignment 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 4.7.4 and 4.7.5.

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:

With Open-loop system gain x Controller gain = 1, where Controller gain is G

$$\text{Open}-\text{loop system gain}\times\frac{100}{\%\text{proportional band}}=1$$

and % proportional band = Open–loop system gain x 100

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

FREQUENCY RESPONSE

Process Trainer

Make the connections and switch settings given in fig 4.7.2.

Adjust 'set value' to 35°C

Adjust the 'blower throttle control' to 4

Place the 'detector probe in the 11" position.

Set the switch on the side of **37-100** to 'heater'

Oscilloscope
(Preferably with storage facility)

Set Y1 to 2V/div and connect to socket 'X' on **37-100**

Set Y2 to 2V/div and connect to socket 'Y' on **37-100**

Set Time-base to 1.0 s/div, internal trigger

Frequency Response

Assignment 7

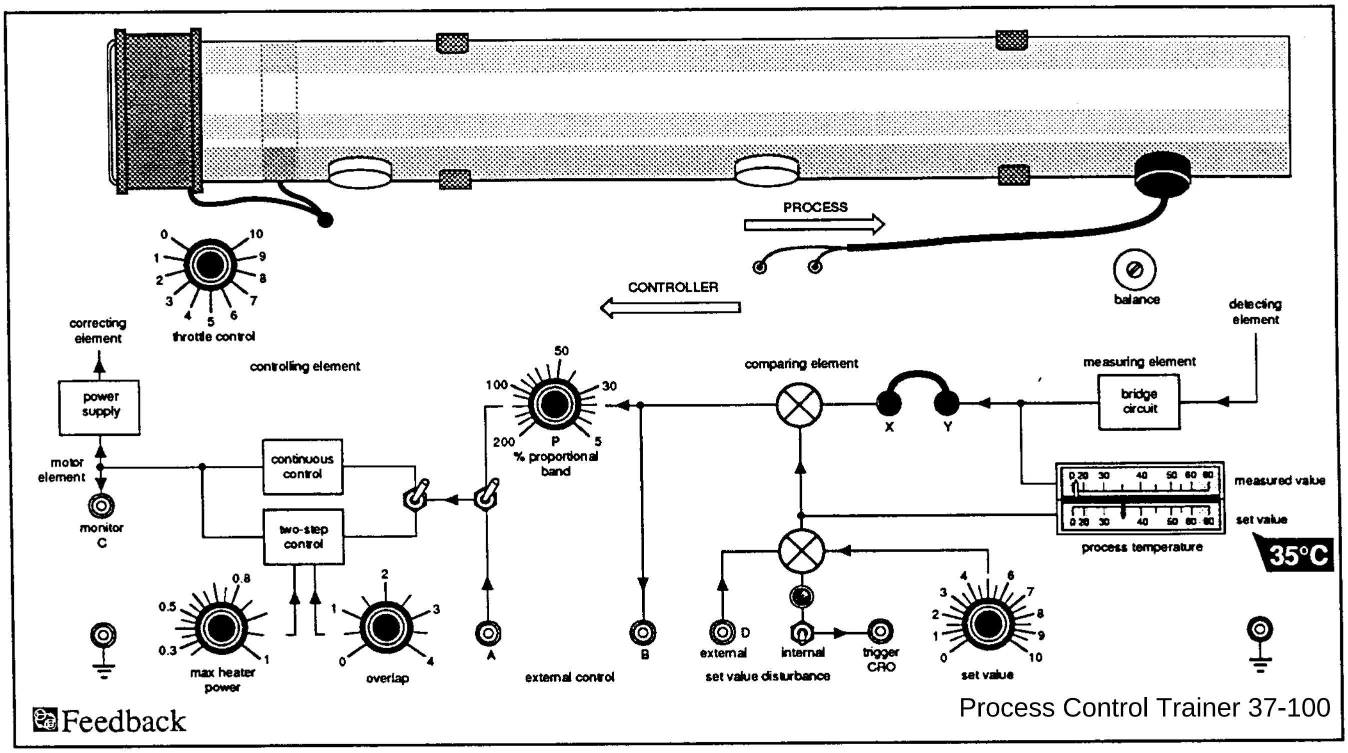


Fig 4.7.3 Connection Diagram

Function Generator Set to sine-wave output, 2V amplitude, 0.1Hz, and connect to socket 'X' on the **37-100** .

PRACTICAL

Switch on the **37-100** and ancillary equipment.

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

Repeat the test over a range of frequencies up to 3Hz.

Plot your results as in fig 4.7.4 or fig 4.7.5.

CONTROLLER SETTINGS

Process Trainer Make the connections and switch settings shown in fig 4.7.3.

Adjust 'set value' to 35°

Adjust the 'blower throttle control' to 4

Place the 'detector probe' in the 11" position

Set the switch on the side of **37-100** to 'heater'

Oscilloscope
(Preferably with storage facility)

Set Y1 to 2V/div and connect to socket 'Y' on **37-100** .

Set Time-base to 1 s/div, triggered by Function Generator.

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

PRACTICAL

Switch on the **37-100** and ancillary equipment.

Adjust '% proportional' band to the value derived from the frequency response test, using the equation:

> '% proportional band' = (open-loop system gain when phase lag is 180°) x 100%

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

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

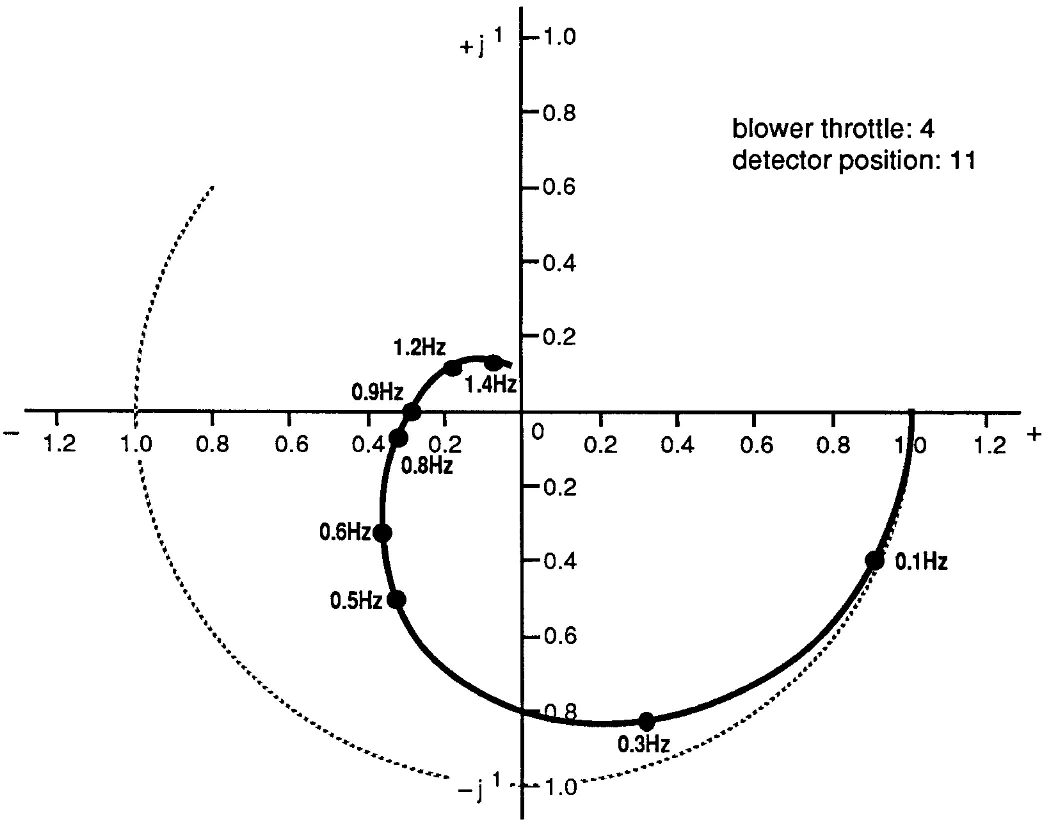
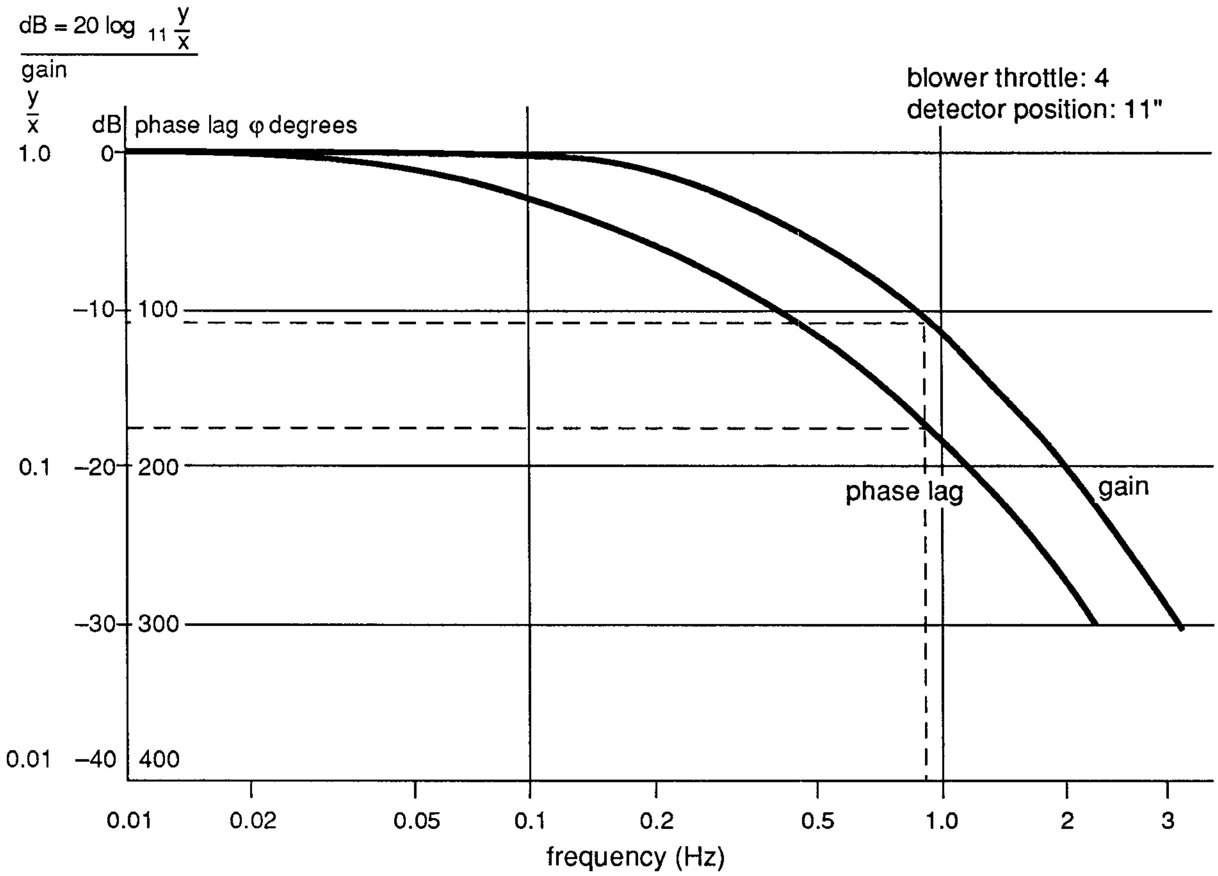


Fig 4.7.4 Nyquist Diagram



When phase lag =180° Gain= –10.5dB ($\frac{Y}{X}$ = 0.3)
and Frequency=0.9Hz

For sustained oscillations $\frac{100}{\text{proportional band}} \times 0.3 = 1$

$\therefore$ proportional band = 30%

Fig 4.7.5 Bode Diagram. Loop Gain and Phase Lag against Frequency

NOTES

COMPOUND CONTROLLER ACTION ASSIGNMENT 8

INTRODUCTION

The 37-100 process trainer is a self-contained process and control equipment drawing air from atmosphere by a centrifugal blower and passing it over 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.

The 37-100 has an internal proportional controller, but three-term (PID) control can be achieved by connecting the PID 150Y module to the external control sockets and switching out the internal controller.

As with other control systems described, the 37-100 and PID 150Y combination gives an error-driven control system with system lags, which with proportional control only will give either a large offset in measured level or oscillatory output depending upon gain.

Introduction of an integral term with low proportional gain will reduce the error to zero but degrade the transient response. Derivative action with high proportional gain will reduce the deadband and oppose overshoot and instability although it also degrades transient response.

Combined proportional, integral and derivative gives the optimum result with minimum deadband, overshoot etc, when correctly adjusted.

Circuit notes for the PID 150Y can be found in Appendix A.

OBJECTIVE

To investigate the application of the PID 150Y module to the temperature control of a heated air stream in the Process Trainer 37-100.

EQUIPMENT REQUIRED

Process Trainer 37-100

PID 150Y Module

Voltmeter 0–30 V

Oscilloscope with long persistence

Power Supply ±15 V 50 mA

Function Generator

Compound Controller Action

Assignment 8

PRACTICAL

Preliminary Procedures

Connect the apparatus as shown in fig 4.8.1 with the ±15 volt power supply connected to the PID 150Y module and the external control sockets of the 37-100 connected to the error input and output sockets of the PID 150Y module.
Initially set the magnitude of the square wave output of the function generator to zero.

Adjust the blower inlet to 40°C, place the detector probe in the 11" position and set the switch on the side of the trainer to 'Heater'.

Switch on the 37-100 and allow it approximately 15 minutes to stabilise.

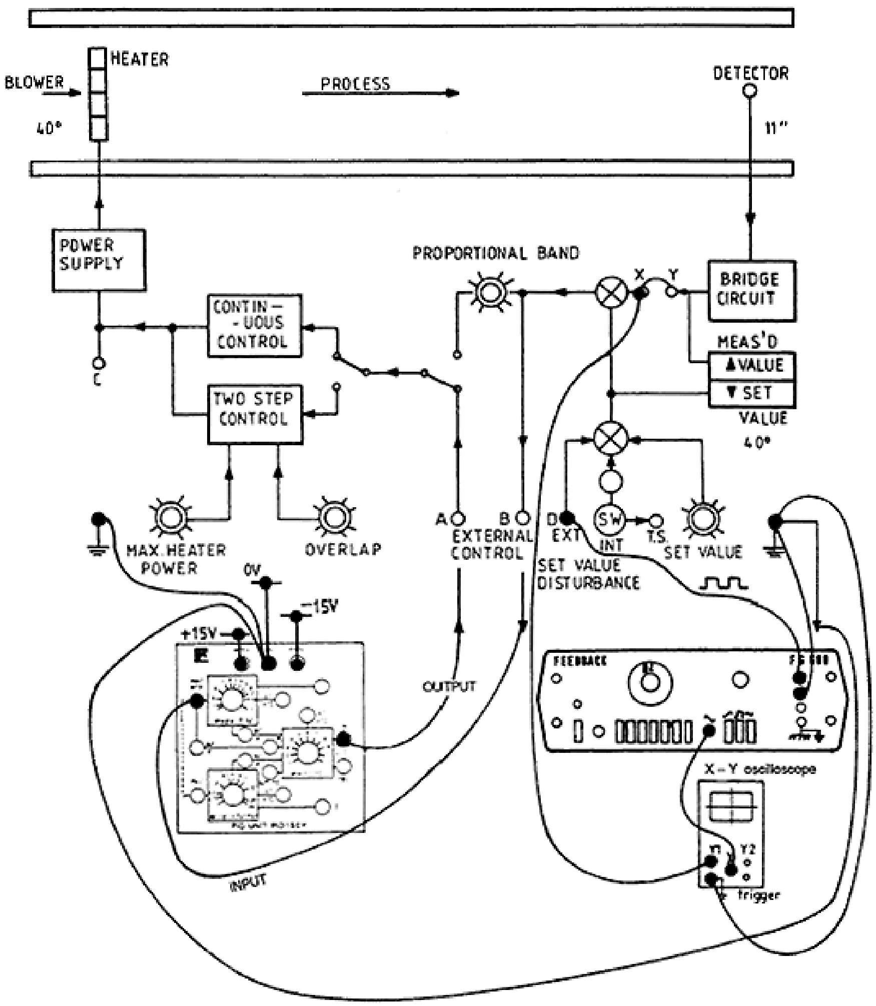


Fig 4.8.1

Method

When the preliminary adjustments have been completed, switch to proportional control only and set the gain to approximately X2 on the X10 range.

Ensure that the function generator output magnitude is set to zero.

Adjust the set value to 40°C.

Observe the measured value of temperature at socket Y of the process trainer with the oscilloscope and on the edgewise meter on the 37-100 panel.

Note the difference between the set value and measured value on the two meters for various settings of the proportional gain control.

Note the gain for which oscillations of the measured value occur and also for the period of oscillation.

Reduce the gain to half this previous value and note the difference between the set and measured values (error).

Switch in the integral path and adjust the integral control so that the difference between set and measured values is reduced to zero.

Adjust the function generator to give an output of approximately 0.5 Hz and 4 volts peak-to-peak square wave to the external disturbance input of the 37-100.

Set the oscilloscope into the X-Y mode with the X axis being driven from the function generator constant amplitude triangle output.

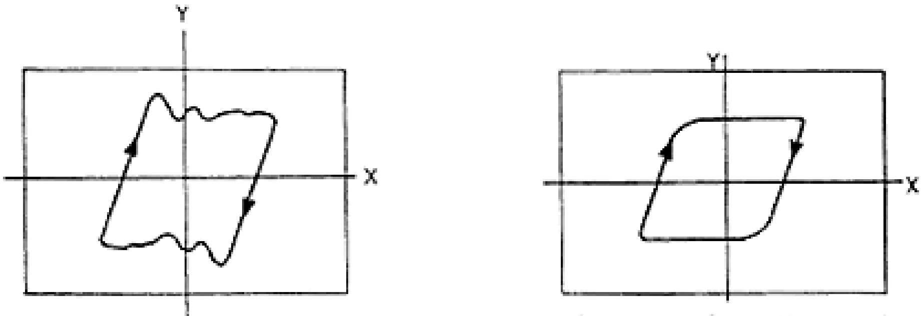
The oscilloscope trace will be typically as fig 4.8.2(a) with some overshoot and a tendency to instability.

Switch in the derivative path and adjust the derivative control to reduce the overshoot as in fig 4.8.2(b).

It will be found that the proportional gain can be increased if a corresponding increase in derivative term is made.

Adjust all three terms of the controller to achieve the best control with minimum error, fastest rise time and minimum overshoot and ringing.

Although the optimum settings for the proportional, integral and derivative terms have been found by trial and error, methods have been developed, particularly with reference to the process control industry, for determining optimum settings for the three terms using various measurement techniques with proportional control only which characterise the type of system being controlled. Reference to these methods is made in Appendix C.



(a) Typical P & I oscilloscope trace (b) Typical P + I + D oscilloscope trace

Fig 4.8.2 Transient response of a 37-100 trainer with PID 150Y module

Refer to fig 5.1

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. 'external 'set value disturbance', socket 'D'

3. 'internal' 'set value 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'.

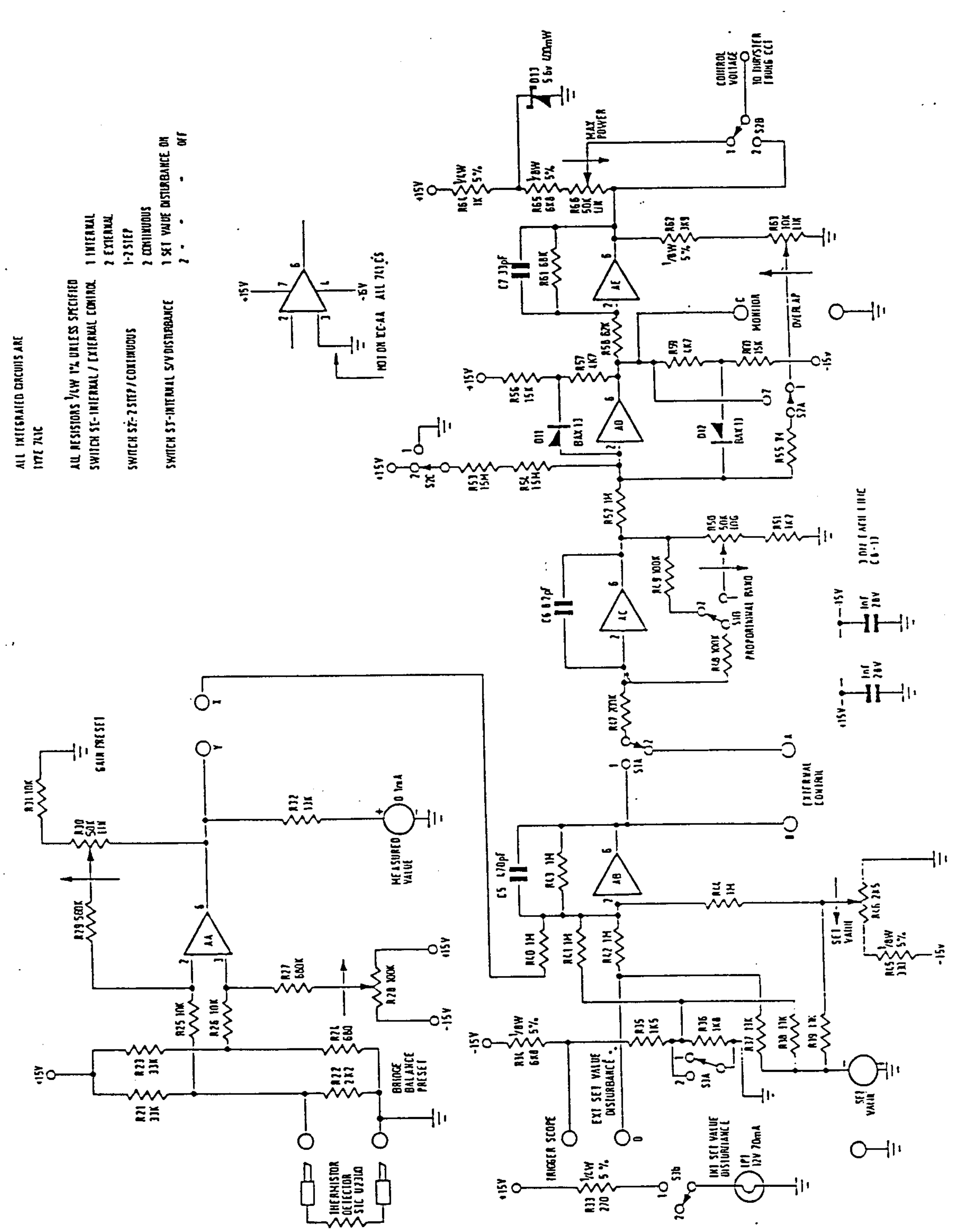


Fig 5.1 Circuit Diagram Bridge Amplifier and Controller
(Drg no. 3–326–5077 Iss 6)

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 AD 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 Fig 5.2

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.

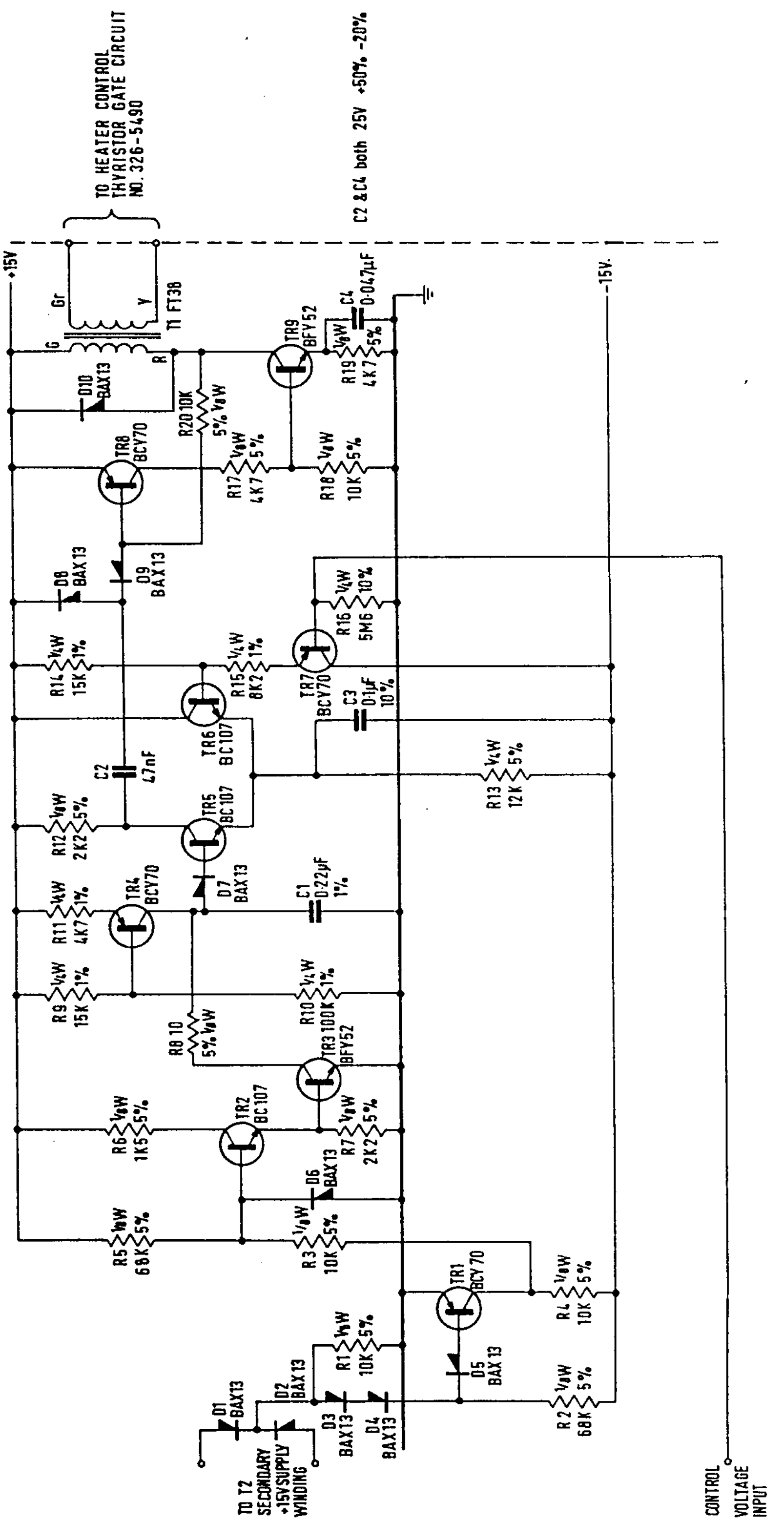


Fig 5.2 Circuit Diagram — 326 Thyristor Firing Control Circuit (Drg No. 3–326–5490 Iss 8)

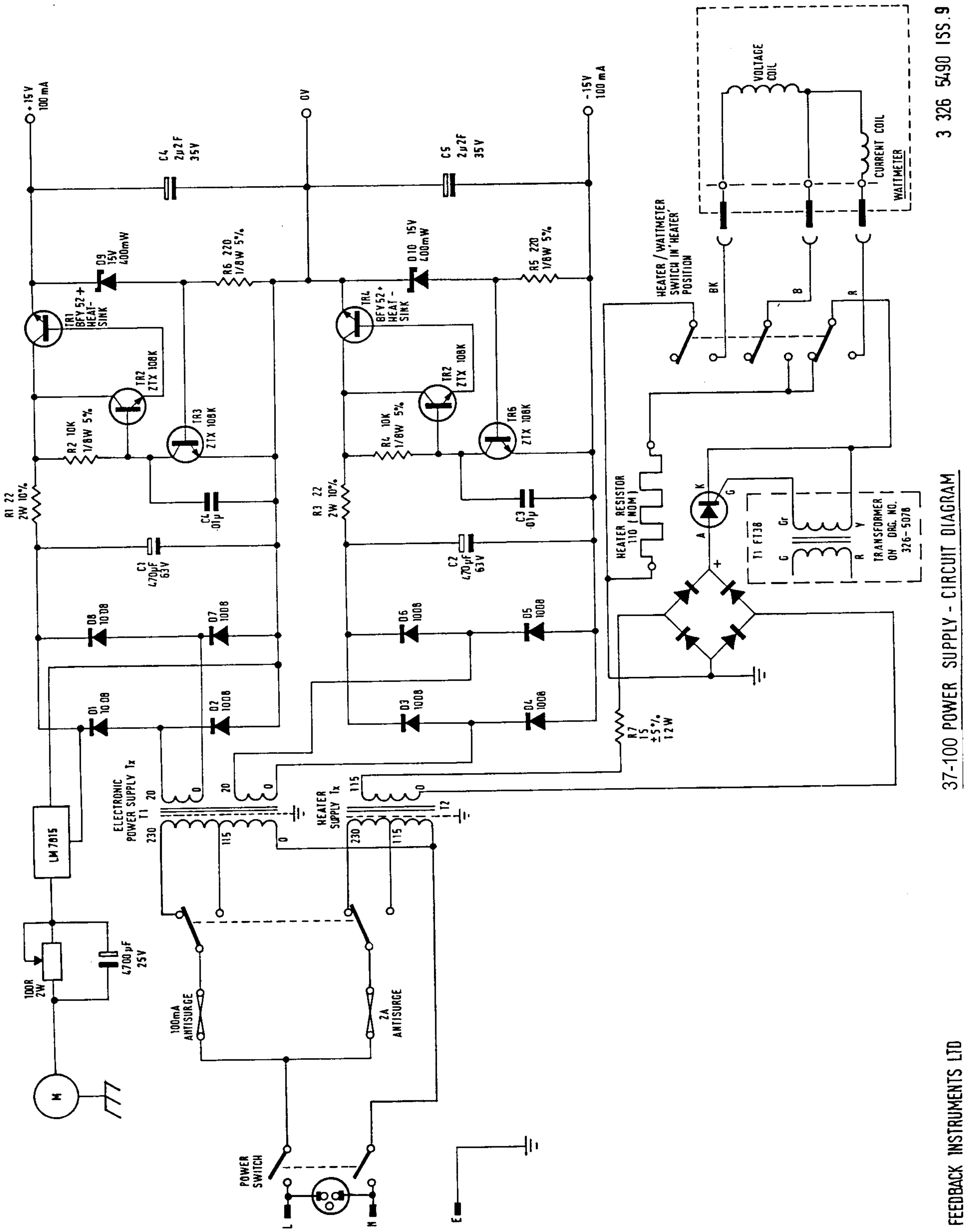


Fig 5.3 Circuit Diagram — Power Supply (Drg No. 3–326–5490 Iss 9)

NOTES

CIRCUIT NOTES FOR THE PID 150Y MODULE APPENDIX A

With reference to the circuit diagram shown in fig A.1, the circuit action of the PID 150Y module can be described.

The error input at the left-hand side of the circuit is connected to the three paths—proportional, integral and derivative—with derivative input being connected by an external jumper to allow non-standard control configurations to be achieved.

The proportional path is first inverted by a section (pins 1, 2, 3) of the quadruple operational amplifier AA, after which the signal passes through a disable switch, which allows the user to isolate individual paths, and is applied to one input of a summing amplifier AA (pins 12, 13, 14). This summing amplifier serves a dual purpose as it also provides simple low-pass filtering – essential to counteract the high-frequency enhancement characteristic of the differentiator circuit. The cut-off frequency of this filter is switched between 50 Hz and 500 Hz by an extra pole of the differentiator range switch.

After summation, the proportional signal is applied to the proportional gain stage, whose gain is continuously variable over a 10:1 range, with X10 and X1 multipliers giving an overall gain range of X0.1 to X10.

In applications that require a non-inverting transfer from input to output, this is achieved with the inverter driving the 0° output.

The input to the integral path is applied to a standard integrator using a conventional operational amplifier AB. Adjustment is achieved by attenuating this input with a potentiometer. Two ranges of integration rate are provided by switching the 1 μF and 10 μF feedback capacitors. The integral disable switch is connected across the feedback of the operational amplifier in order to zero the integrator and prevent large disturbances when switched in. The integrated error is then applied to another equally weighted input to the summing amplifier and thence on to the 0° and 180° outputs. A positive error input to the integrator will cause a positive-going output at the 0° output terminal.

The derivative path has a separate input terminal which is normally connected to the error input terminal externally. R13 is necessary to stabilise the feedback around the derivative amplifier AC, but has little other effect. The derivative input signal current is therefore determined mainly by the signal voltage and C3 or C4 (selected according to the required range of action times).

This current flows into a virtual earth provided by amplifier AC, where it is balanced by feedback from the resistive network R14, R16, R17. The feedback is equivalent to half the amplifier's output voltage, in series with R14 + 10 kΩ.

The differentiated signal is then applied to another equally weighted input of the summing amplifier via an isolating switch and through to the two outputs. A positive-going ramp signal applied to the derivative input will cause a positive dc output at the 0° output socket. An offset potentiometer is provided to zero the differentiator circuit with no applied signal.

Monitor sockets are provided to allow display of each term of the three-term control signal whilst operating although it should be noted that these monitor signals are inverted compared with their contributions to the 0° output.

Protective diodes in each supply lead prevent damage to the operational amplifiers if the supplies are inadvertently reversed in polarity.

Circuit Notes for the PID 150Y Module

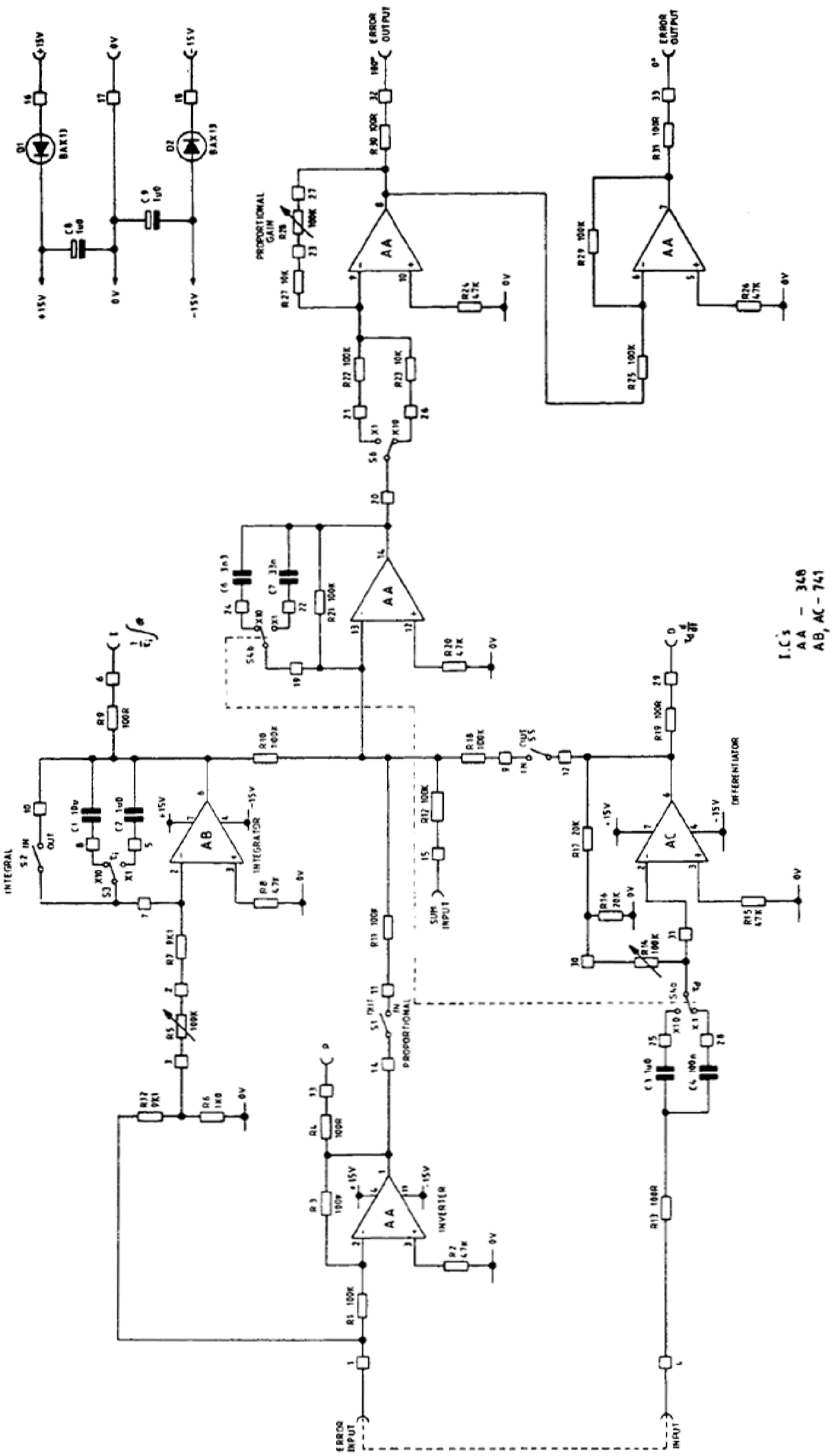


Fig A.1 PID 150Y circuit diagram

PROPORTIONAL BAND APPENDIX B

In process control work the gain of the proportional action is often expressed in term of *proportional band*. This is defined as the range of values of the controlled variable which (using proportional control only) will operate the correcting device over its full range. A large proportional band corresponds to a low gain. Suppose for instance that the PID 150Y unit were driving something which responded fully with a range of signals from 0 to 10 volts. If the proportional gain were set to 1 (output volt per input volt), the proportional band would be expressed in terms of input to the PID 150Y as 10 V. But if the gain were 5, it would require only 2 volts change of input to produce 10 volts output; the proportional band would be 2 V (or the magnitude of deviation which produces 2 V).

Note that the value of the proportional band cannot be defined without knowledge of the signal range which will fully operate the correcting device. On some occasions this range may not be very clearly defined; it will then be necessary to establish a (possibly somewhat arbitrary) figure for the range before considering proportional band.

PERCENTAGE PROPORTIONAL BAND

Quantities such as the deviation are frequently converted by measuring unit into signals such as voltages or air pressures. These usually have a definite range, and the proportional band may then be expressed as a percentage of it:

$$\%\, proportional\ band = \frac{change\ of\ input\ required\ to\ produce\ 100\%\ correction}{measuring\ unit\ range}\ x\ 100$$

This is shown in fig B.1.

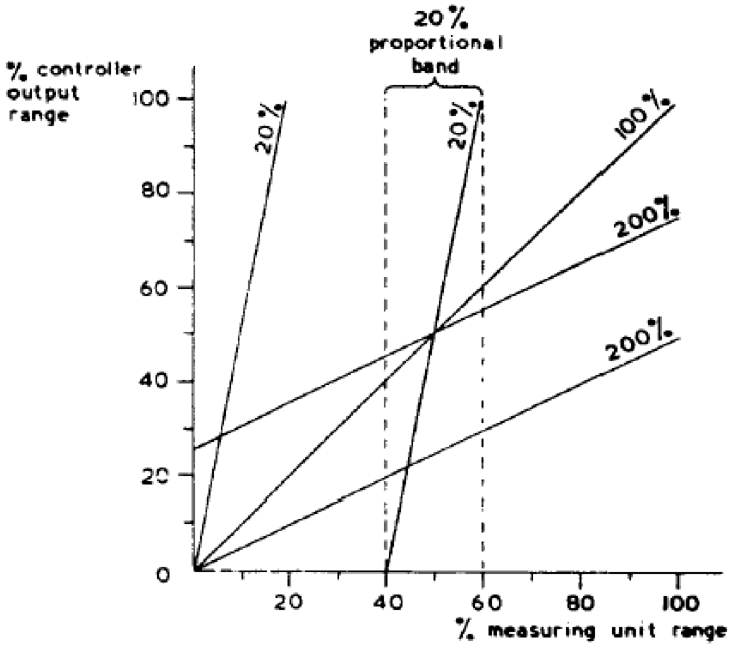


Fig B.1 Proportional band

Proportional Band

The use of standard ranges of signals enables standard controllers to be applied to a wide variety of different processes. Calibrating the controllers in percentages then enables the calibrations to apply equally well to the various different applications.

It may be noted that where the percentage proportional band exceeds 100%, proportional control alone can never exercise 100% correcting action. The use of integral action in such a situation is especially helpful.

If (and only if) the input and output ranges are the same, then the gain of the proportional element of the controller is:

$$\frac{percentage\ of\ maximum\ correction\ applied}{percentage\ of\ measuring\ unit\ range\ which\ applies\ it}$$

When the PID 150Y module is used with the Process Trainer 37-100 the range of effective signal at both the input and output of the PID 150Y is 0 to 10 volts.

EMPIRICAL METHODS OF SETTING PID CONTROLLERS

APPENDIX C

The following empirical methods of setting the proportional, integral and derivative terms of controllers are aimed mainly at the process control industry although applicable also to control system settings.

The calibrations referred to however are those of the process control industry being % proportional band, integral action time, and derivative action time.

All the following methods are based on two preliminary measurements, namely the percentage proportional band required to give continuous oscillation with proportional control only and the period of such oscillation.

For each of these methods the following terms are used:

P_o = % proportional band that causes oscillation, proportional control only

P = % proportional band to be set

T_i = integral action time

T_d = derivative action time

T_o = period of oscillation, proportional control only

Each of these methods may be employed on the PID 150Y module and the response to a step input studied.

ZEIGLER AND NICHOLLS (THREE-TERM CONTROLLER)

Measure P_o and T_o

Set $P = 1.67P_o$

$T_i = T_o/2$

$T_d = T_o/8$

$\therefore \quad T_1/T_d = 4$

ATKINSON (THREE-TERM CONTROLLER)

Measure P_o and T_o

Set $P = 2P_o$

$T_i = T_o$

$T_d = T_o/5$

$\therefore \quad T_1/T_d = 5$

These settings should give a response with $M = 1.3$, i.e. the amplitude of the closed-loop output should at the resonant frequency be 1.3 times that at zero frequency. This can be checked either by normal frequency response or by studying the step response which should give an overshoot of approximately 20%.

Empirical Methods of Setting PID Controllers — Appendix C

YOUNG

Proportional only

Increase P from P_o until the subsidence ratio is about e:1 (approx 3:1) and call this value P_x.

The maximum offset (steady state deviation) that can occur is $(P_x/2)$% of full scale.

If this is unacceptably large but a reduction to $(P_x/3)$% would suffice, add derivative term which will then allow the percentage proportional band to be increased to reduce offset. In any case add derivative term if the response is too slow.

Proportional + Derivative

When derivative term is added the period of the oscillation will reduce to about $0.8T_o$.

Initially set T_d to $1/10$ period = $0.8T_o/10$

$T_o/T_d = 12$

Then reduce P to give a subsidence ratio of 3:1.

If the offset is still too large, the period too long or the reduction of disturbances insufficient, T_d may be increased; at each stage P should be reset to give a subsidence ratio of 3:1.

T_d should not be increased above $T/4$ where T is the period of the damped oscillations.

Proportional + Integral

If the offset cannot be reduced to an acceptable level with proportional term only, integral term can be added. This will increase the natural period by between 10 and 30%.

Initially set T_i to be equal or less the T_o and adjust P to give a subsidence ratio of 3:1.

Proportional + Integral + Derivative

To obtain a required response both integral and derivative terms can be added. As the derivative term T_d is added, T_i should be reduced to maintain $T_i = T$ where T is the period of damped oscillations.

Young gives no specific figures for the relationship between T_i and T_d.

The conventional 3-term controller, in which the control signal is proportional to the sum of the deviation and of terms derived from the deviation by integration and differentiation, is still widely used.

However, some simple variants of this are already available in many industrial controllers and many other configurations are possible and have been discussed in technical papers on the subject.

A common variant, for example, is to obtain the derivative term not from the deviation but from the measured value. This avoids the injection of a large disturbing signal if a sudden change to set value is made.

To accommodate this and other configurations which it may be of interest to study, two facilities are provided on the PID 150Y module:

a) the derivative action circuit input can be isolated by removal of a link
b) a spare input to the summing amplifier is available on the front panel

Proportional + Integral + Derivative of Measured Value

This configuration is the equivalent of velocity or tacho-generator feedback in a servo system.

We can write the following equations for this system:

$$M = -G(D)A\left[E(1 + \frac{1}{T_i D}) + MT_d D\right]$$

and

$$E = M - S$$

Substituting for E and re-arranging we obtain:

$$\frac{M}{S} = \frac{A(1 + \frac{1}{T_i D})}{\frac{1}{G(D)} + A(1 + \frac{1}{T_i D} + T_d D)}$$

This is the characteristic equation from which the system response can be predicted. For comparison the characteristic equation for a conventional Proportional plus Integral plus Derivative of deviation control is:

$$\frac{M}{S} = \frac{A(1 + \frac{1}{T_i D} + T_d D)}{\frac{1}{G(D)} + A(1 + \frac{1}{T_i D} + T_d D)}$$

The only difference being the AT_dD term in the numerator, which is the term that gives rise to large control signals when a step change in S occurs.

If the integral action term in this mode is removed and $G(D)$ is a combination of one lag and integrator, thus:

$$G(D) = \frac{1}{T_1 D(1 + T_2 D)}$$

where T_1 is the integration time-constant and T_2 is the lag time-constant, then the system represented is dynamically very similar to an idealised position control servo-mechanism with tach-generator feedback, such as Feedback MS150 with the defined time-constant unit in use.

The correspondence between constants is then as follows:

T_1 corresponds to the shaft speed for unit input voltage to the motor amplifier

T_2 corresponds to the defined time-constant of the motor

T_d corresponds to the tacho-generator rate in volts/rpm.

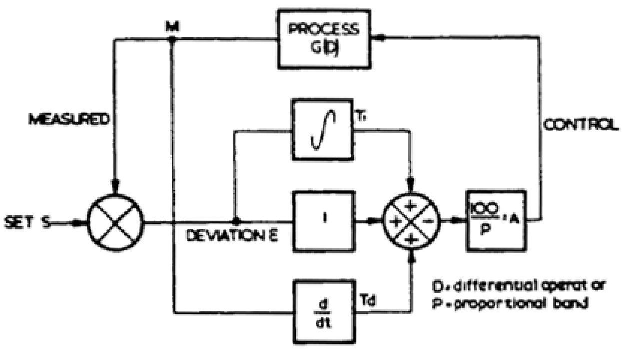


Fig D.1 Proportional + Integral + Derivative of Measured value