circuits, terminals A and H are used to give offset null. They connect a tapped (resistor) potentiometer across the ends of the amplifier to supply lead (usually negative) so giving compensation for inherent offset at amplifier input.

Consider now various configurations applied to Figure 11.15:

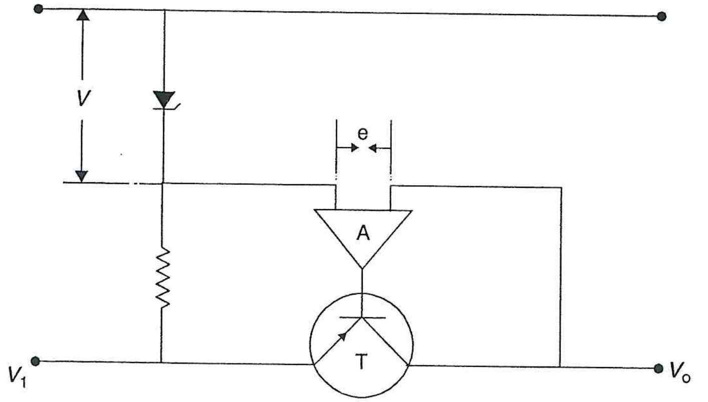
1. Inverter $V_o = -V_1$
   Input voltage signal V_1 through a resistor R_1 to terminal B, terminal C earthed through a resistor R_E. $R_1 = R_F$. Output voltage signal V_o at terminal G (also see Figure 11.1–11.8, upper lead to A is inverting input, lower lead to A is non-inverting input – shown earthed).
2. Inverter summer $V_o = -(V_1 + V_2)$
   As for inverter but input signals V_1 and V_2 in parallel to B. $R_1 = R_2 = R_F$ (also see Figure 11.9).
3. Scalar inverter summer $V_o = -(aV_1 + bV_2)$
   As for inverter summer but $a = R_F/R_1$, $b = R_F/R_2$, $R_1 \neq R_2$, R_F usually adjustable (see previous sketches).
4. Inverter multiplier $V_o = -at\,V_1$
   As for inverter but input potentiometer (resistance R) connected across V_x and earth, with a tapping lead to R_x then to B. $a = R_F/R_1$, $R_1 \neq R_2 \neq R_F$, tapping ratio $t = r/R$, which is less than unity.
5. Inverter divisor $V_o = -V_1/t$
   As for inverter but output potentiometer (resistance R) connected across V_0 and earth, with a tapping lead to make the feedback loop through R_F to B, tapping ratio $t = r/R$, which is less than unity.
6. Non-inverting summer $V_o = V_1 + V_{2.}$
   V_1 input through R_1 in parallel with V_2 input through R_2 into C, which is led to earth via resistor R_3, B earthed through resistor R_4. $R_1 = R_2$, $R_4 = R_F$, $R_3 = R_1/2$ (as two inputs).
7. Subtracter $V_o = V_1 - V_2$
   V_1 through R_1 to C, earthed via resistor R_3. V_2 through R_2 to B. All resistances equal.
8. Non-inverting multiplier $V_o = cV_1$
   V_1 through R_1 to C. B earthed through R_4. $R_1 = R_4$. $c = (R_F + R_4)/R_4$.
9. Integrator

The circuit has already been sketched in Figure 11.10. The amplifier C terminal could be earthed through R_E and terminals A and H connected.

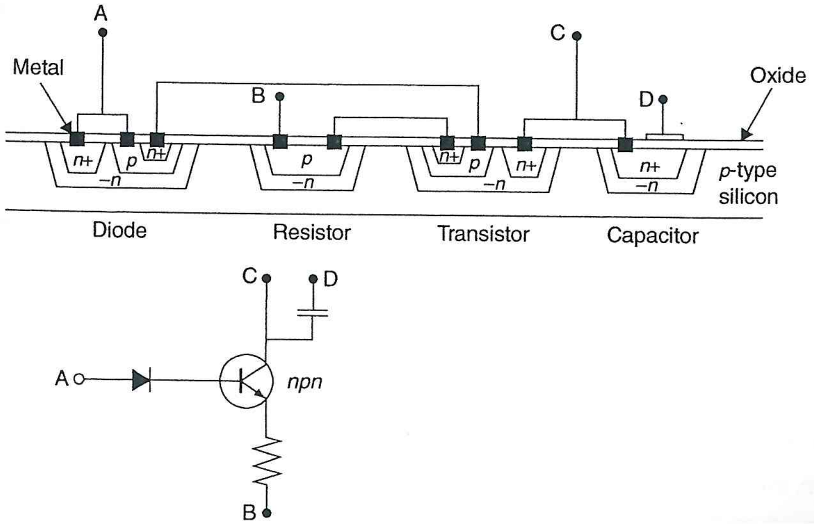
The analysis could be

Transistor stabilisation control

The constant current (shunt) stabiliser utilising a zener diode has been described previously (Figure 7.10). Voltage (or series) stabilisation based on an integrated circuit, that is, transistor, gives better results. The principle is to use the transistor (T) as a variable resistor by a feedback control loop (see Figure 11.16). Transistor resistance depends on emitter-base potential which is controlled by output voltage. Output (V_o) and standardised (zener) voltage (V) are compared and error voltage (e) is fed to the transistor base through a difference amplifier (A).

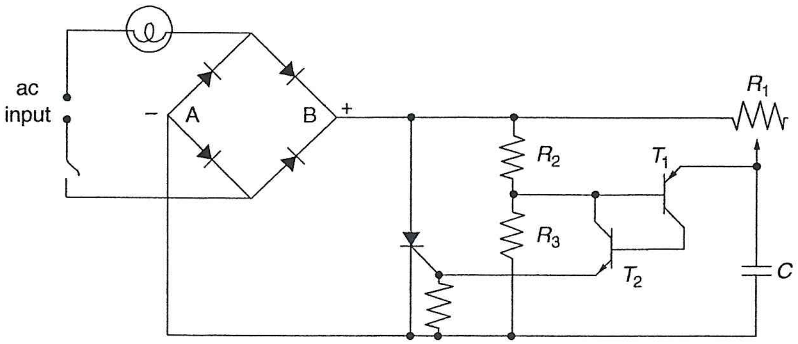


▲ **Figure 11.16** *Transistor stabilisation control*



Integrated circuits

These were originally developed for non-linear or digital (logic) circuitry but are increasingly used for linear amplifiers, including operational amplifiers. The circuit components are produced by oxidising, etching and diffusion on a silicon chip (see page 191) as shown in Figure 11.17. A MOSFET (see page 110) is often utilised within printed circuit boards. A microprocessor is a very large integrated chip circuit.



▲ **Figure 11.18** *Time delay circuit*

Test Examples

1. Derive an expression for the gain of an inverting op-amp.
2. A non-inverting op-amp is configured with $R_{in} = 10$ kΩ and $R_F = 47$ kΩ. Calculate the value of A_v.
3. Describe a three-term electronic controller. Show on a diagram the variation in controller output due to:
   (a) proportional action,
   (b) integral action,
   (c) derivative action,
   (d) combination $P + I + D$.
4. Describe, in detail, an electronic operational amplifier. Discuss the various methods of adjusting gain and comment on the uses of this device in control or measuring

---

5. Show, by means of simple sketches, how an electronic controller arranged for proportional control action can be modified to include:
   (a) integral action,
   (b) derivative action.
6. Figure 11.18 illustrates a time delay circuit which includes a rectifier and a rhyristor. The network varies lighting intensity, that is, it is a typical dimmer switch circuit. Describe in detail the principle of operation.

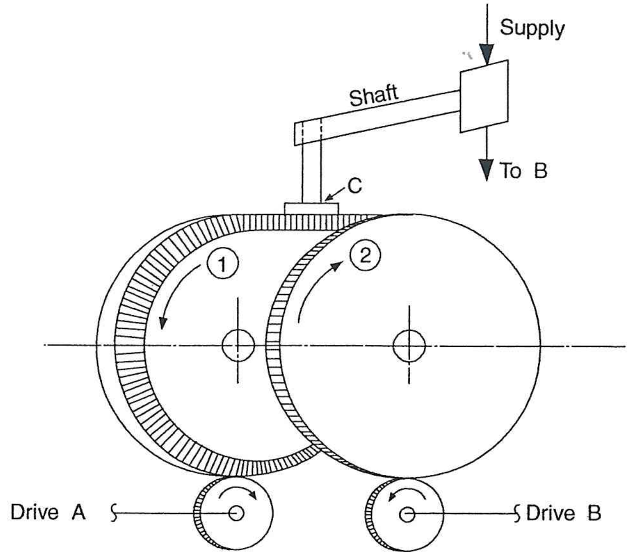
12

ACTUAL CONTROLLER TYPES

There are numerous forms of controllers produced by a large number of specialist instrument and control equipment manufacturers. As a representative selection of well-proven practice twelve types are discussed here: one mechanical, one mechanical-hydraulic, one electro-pneumatic, three electronic and six pneumatic. In some controllers the action is given as ($P + I + D$). It should be remembered that the simplest control suitable ought to be used and the controllers described are also available as simple (P) or ($P + I$) or ($P + D$). The description so given is mainly to cover the more complex cases, which can then be easily simplified.

Mechanical Controller

Utilises a lever principle extended to a mechanical differential. A drives (1) anti-clockwise and B drives (2) clockwise. If A and B have the same speed then C revolves but the shaft has no linear motion. If A tends to speed up then C follows (1) and the shaft moves linearly to alter the supply and increase the revolutions of B. A proportional action exists, synchronism reduces movement to zero and a distinct anti-hunt characteristic exists (see Figure 12.1).



▲ **Figure 12.1** *Mechanical controller*

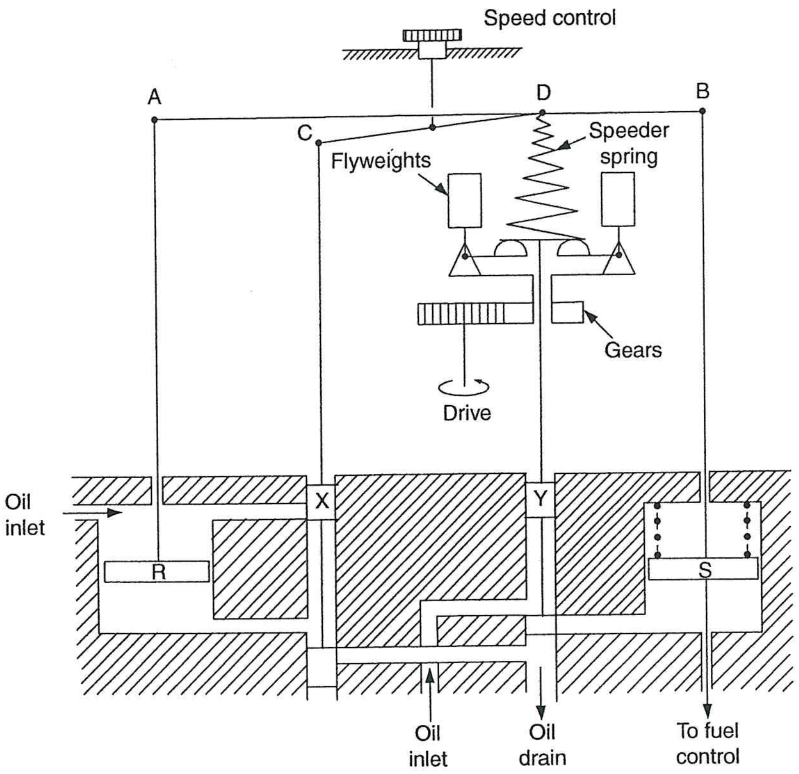
Mechanical-Hydraulic Controller (Governor)

The device is illustrated in Figure 12.2.

For say an increase in engine load the flyweights move radially inwards and pilot valve Y moves down so allowing the servo-power amplifier (S) to move up under admitted oil pressure. This increases the fuel control setting and also rotates feedback link AB and reset link CD anti-clockwise about pivot A (initially fixed as reset piston R has equal pressures on each side).

Due to CD rotation pilot valve X moves down allowing R to move down due to oil escape to drain. As R moves down to a new equilibrium position, AB pivots about B and rotates CD clockwise so closing X, locking R and restoring D to its original position. The engine is now running at original speed but at a different load. The governor is $P + I$, that is, isochronous. To reduce the governor to simple proportional pivot A is fixed, R and X eliminated and link CD removed. The conical form spring gives linearity to the speed measuring system.

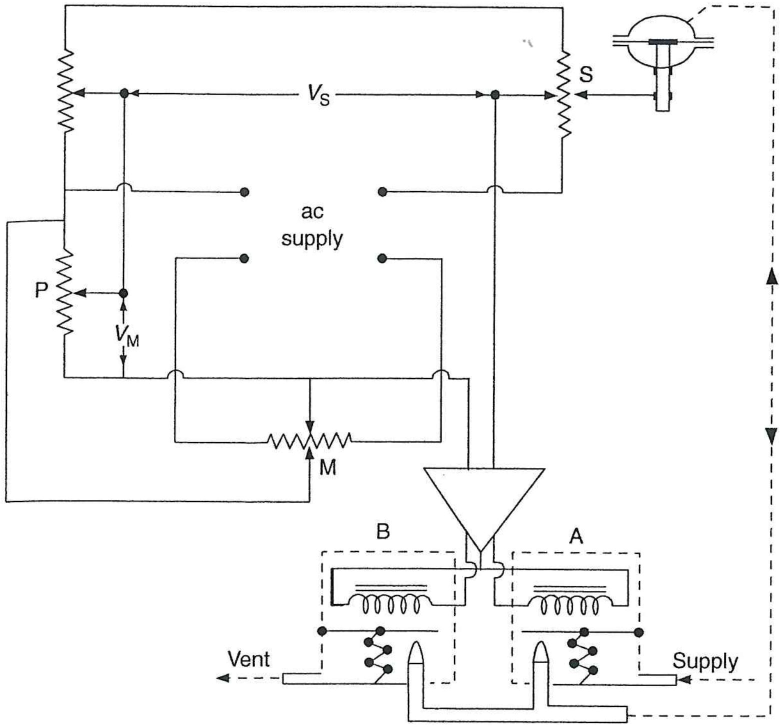
A similar device is shown in Figure 14.9 and an electrical alternative in Figure 14.10.



▲ **Figure 12.2** *Mechanical-hydraulic controller (governor)*

Electro-Pneumatic Controller

The controller shown in Figure 12.3 is a converter. A sliding contact resistor S is moved by the valve spindle to form the position feedback and the input measure signal is at contact M. If Say $V_M + V_S > 0$ then relay A is energised and supply air flows to the diaphragm top to move the spindle down. If $V_M + V_S < 0$ relay B is energised and air from the diaphragm top is vented, so allowing the valve spindle to move up. Movement ceases as soon as V_M and V_S equate to zero when both nozzles are closed and no current flows. Proportional band, for the valve positioner, is adjustable at P.

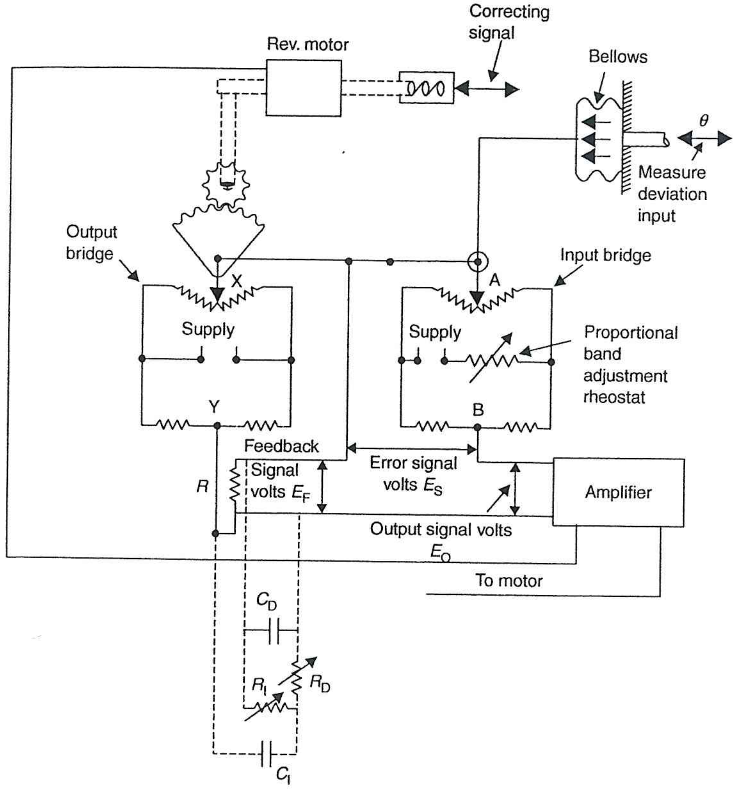


▲ **Figure 12.3** *Electro-pneumatic controller*

Electronic Controller (1)

Refer to Figure 12.4 (and also refer back to Figure 11.7). Considering first just the proportional action. The deviation (by the transducer) causes movement of the adjustable rheostat at A so that A and B now have a voltage difference, that is, the input Wheatstone bridge circuit is unbalanced and current therefore flows between A and B.

This current produces an input voltage which is an indication of the error (deviation) magnitude from the desired value. Current flows to the amplifier, then to the electric motor. As the motor moves to alter the controlling element it moves the adjustable rheostat at X so that X and Y have a voltage difference, that is, the output bridge is unbalanced; current therefore flows between X and Y. This current is arranged to be opposite in direction to the current between A and B. The *fixed* resistance *R* therefore has opposing current flow and when the volt drop across the output bridge equals the



▲ **Figure 12.4** *Electronic (P + I + D) controller*

volt drop across the input bridge (i.e. feedback equals input) the voltage across the amplifier is zero and motion stops. Therefore for each A position there is a *proportional* X position.

For output to equal zero, feedback volts equals supply volts and is opposite in direction, that is, $E_F = -E_S$ or as E_S is adjustable, due to the adjustable rheostat for proportional band, and introduces linkage and rheostat proportionality factors:

$$\Phi = -\mu\theta$$

To add integral action *replace* R by an adjustable resistor R_1 and a capacitor C_1. Thus there is a continuous adjustment of feedback. Current flow charges the capacitor which then resists further current flow.

To add derivative action *retain* R and *add* an adjustable resistor R_D and a capacitor C_D. The capacitor must be charged at a rate equal to the rate of change of input supply E_C.

To give (P + I + D) omit R and *replace* by the dotted circuit containing C_D, R_D, C_1, R_1 as shown in the sketch. A more modern design of this type utilises photo cells and electronic valves (or transistors) but the principle is much the same as above.

Note. Mathematics could be introduced to show:

$$E = E_F + E_C$$

$$E = E_F + \frac{1}{R_I C_I}\int E_F\,dt \text{ (integral)}$$

and

$$E = E_F + E_D$$

$$E = E_F + R_D C_D \frac{dE_F}{dt} \text{ (derivative)}$$

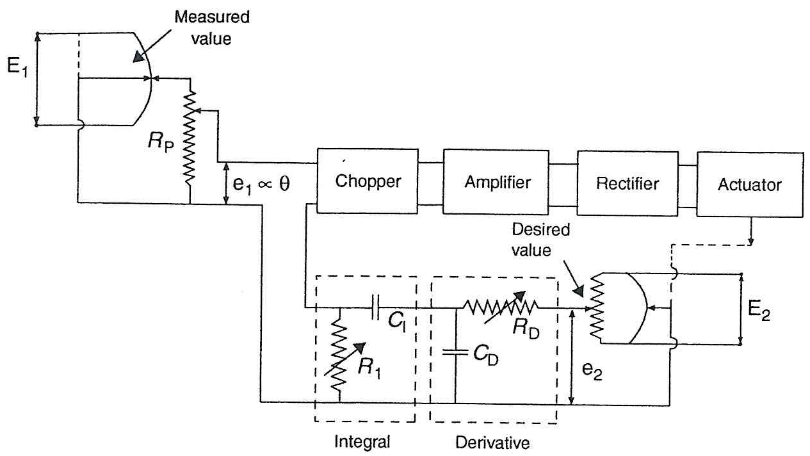
where *E* is voltage on output bridge, E_C is volt drop across capacitor C_1 and E_D is volt drop across resistor R_D.

Possibly a more simplified sketch arrangement of an alternative type of electronic controller is shown in Figure 12.5.

Electronic Controller (2)

Refer to Figure 12.5. The detector element transmits a dc signal (measured value) which is usually amplified and may then be in the range 0–40 V, 0–10 mA. Similarly the desired value from a fixed resistor is supplied in opposition to the first signal. The two signals are compared and the difference between them is obtained by passing the two currents in opposite directions through a common resistor, thus voltage across the resistor is proportional to deviation. The resistor acts as a sensitivity control potentiometer in that the proportional band can be varied by varying the ratio between the two parts of the potentiometer, the variation is 2–200% range, or more. Thus pure proportional action is obtained with *direct* action from the measured value and *negative feedback* from the desired value.

The signal is then passed through a transistorised chopper (capacity modulator) to give ac which is then amplified in an ac amplifier and (if necessary) rectified for use at the



▲ **Figure 12.5** *Electronic (P + I + D) controller (2)*

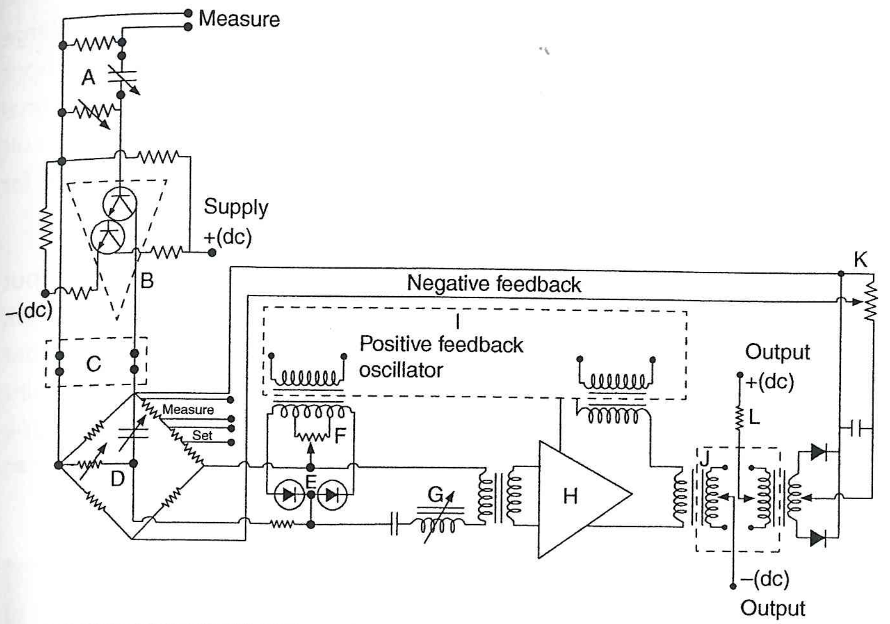
actuator. This procedure is usually necessary as dc amplifiers are subject to drift which at zero true input would affect the deviation and hence the controller output.

The voltage developed across the correcting unit signal from the actuating unit is fed back through the derivative and integral networks in cascade. Some interaction occurs which is reduced by an auto-resistor in the derivative unit. Note that the final positioner action gives signal feedback whereas an alternative described in *all* controllers given previously has the feedback signal straight back after the amplifier itself. An obvious advantage of electronic controllers is their flexibility, high speed of signal transmission and high gain. As automatic controls develop, more complex controller actions, further than *P* + *I* + *D*, will certainly be required and electronic controllers will provide the most convenient method. Voltage difference $e_1 \alpha \theta$ and feedback voltage is e_2, equilibrium exists when $e_1 = e_2$. *I* and *D* actions are generated by resistance capacity systems $C_1 R_1$ and $C_D R_D$. Action times are adjusted by variable resistors R_1 and R_D.

With R_D equal to zero then only *P* + *I* action is generated, that is, integral action shunted via C_D. If R_1 is made infinite then *P* + *D* action is generated, $C_D R_D$ and C_1 are in series.

Electronic Controller (3)

The circuit is much simplified to facilitate the description of this modern unit. Refer to Figure 12.6.



▲ **Figure 12.6** *Electronic (P + I + D) controller (3)*

The derivative (rate) circuit is shown at A, B, C. Time adjustment is by adjustable resistor-capacitor (A) to the measure input. Rate amplifier (B) is transistorised (solid state), two stage, *npn*, dc type, of overall gain about 10, and introduces a signal to the bridge network (D) proportional to the rate of change of measurement. Separate derivative addition gives no interaction and rapid action as the unit is in the forward loop and not in the feedback loop. A filter (C) gives smoothing (RC network).

The dc measure signal (10–50 mA) and set point signal are developed across resistors and any error signal will unbalance the bridge until the amplifier output and negative feedback rebalance. A resistor (K) decides the gain by controlling feedback so proportional action and variable bandwidth are achieved. The function of the bridge is to impress the resultant error and feedback signals on the main amplifier (H) until equilibrium occurs.

The adjustable resistor and capacitor across the bridge determine the rate at which output changes (hence feedback) to drive the measurement to coincide with set point, that is, integral (reset) action.

The controller amplifier part of the circuit is E, F, G, H, I, J. The main amplifier is similar to the rate amplifier but is four stage, ac, gain about 2000. The main amplifier bridge circuit dc voltage change across them, initial set bias and arranged in opposition for large unbalance to small signal, plus the split inductive transformer winding (F). Error input causes amplifier bridge unbalance (due to capacitance change) and an ac mV signal will enter H due to the oscillator (I). H is providing a positive feedback oscillating circuit for bridge excitation developed in the oscillator loop, tuned to resonant circuit for bridge (G).

Output level is demodulated and raised by a two-stage output amplifier (J) to an output signal in the range 4–20 mA, dc power supply, external load (L) and negative feedback (2–15 V) via diodes and resistor K. Note transformer couplings to isolate controller input and output circuits. External switching is provided with internal circuitry for set point change, limits automanual transfer, etc. Essentially the unit described is a chopper-type dc amplifier fully transistorised. It consists of a transistor input chopper, a high gain ac amplifier and a transistor output chopper (demodulator) with feedback.

Pneumatic Controller (1)

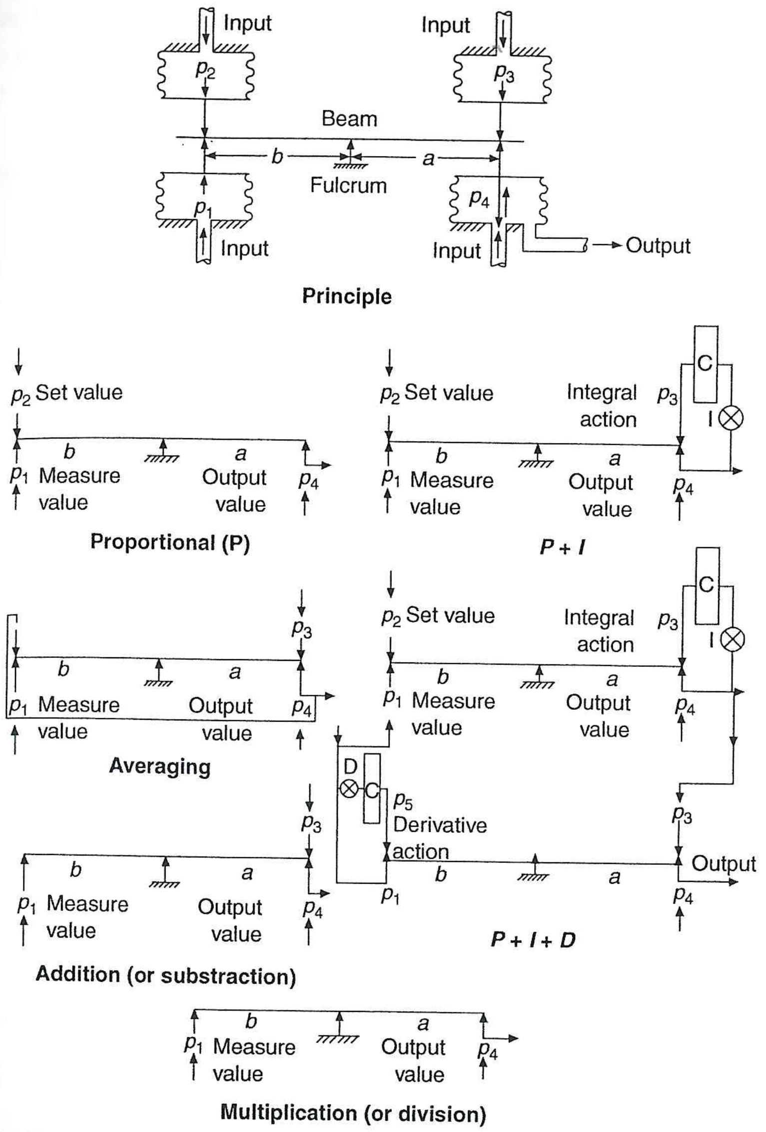
This unit gives (*P*), (*P* + *D*), (*P* + *I*), (*P* + *I* + *D*) control actions and also provides addition (or subtraction), multiplication (or division) and averaging computing actions, as may be required. *This controller is an ideal example to illustrate all the basic actions in as simple a manner as possible.*

Refer to Figure 12.7. The principle is that of the simple lever using force-balance. Four bellows act on the beam (lever) and variations of bellows forces or level fulcrum ratio (*a* : *b*) will affect the magnitude of the output signal.

$$(p_4 - p_3)a = (p_1 - p_2)b$$
$$\therefore p_4 = \frac{b}{a}(p_1 - p_2) + p_3$$

variations of *a*, *b*, p_1, p_2 or p_3 obviously affect the value of p_4 (output). Bellows forces or level fulcrum ratio (*a* : *b*) will affect the magnitude of the output signal.

$$(p_4 - p_3)a = (p_1 - p_2)b$$
$$\therefore p_4 = \frac{b}{a}(p_1 - p_2) + p_3$$



▲ **Figure 12.7** *Pneumatic controller (1)*

variations of *a*, *b*, p_1, p_2 or p_3 obviously affect the value of p_4 (output). When used for proportional action:

$$p_4 = \frac{b}{a}(p_1 - p_2) \quad \text{with } p_3 = 0$$

When integral action is added, the restrictor I and capacity tank C give the necessary integral action via p_3 bellows. When derivative action is also added, the restrictor D and capacity tank C give the necessary derivative action via an extra p_5 bellows on the extra (lower) totaliser. The $P + I$ output from the upper totaliser p_4 bellows is fed to the p_3 bellows of the lower totaliser to give $P + I + D$ output from the lower totaliser p bellows.

For averaging:

Taking $a = b$ then as $p_2 = p_4$

$$p_4 = \tfrac{1}{2}(p_1 + p_3)$$

For addition:

Taking $a = b$ then as $p_2 = 0$

$$p_4 = p_1 = p_3$$

Subtraction can be arranged utilising the other bellows p_2 in place of bellows p_3. For multiplication:

with $p_3 = p_2 = 0$

$$p_1 b = p_4 a$$

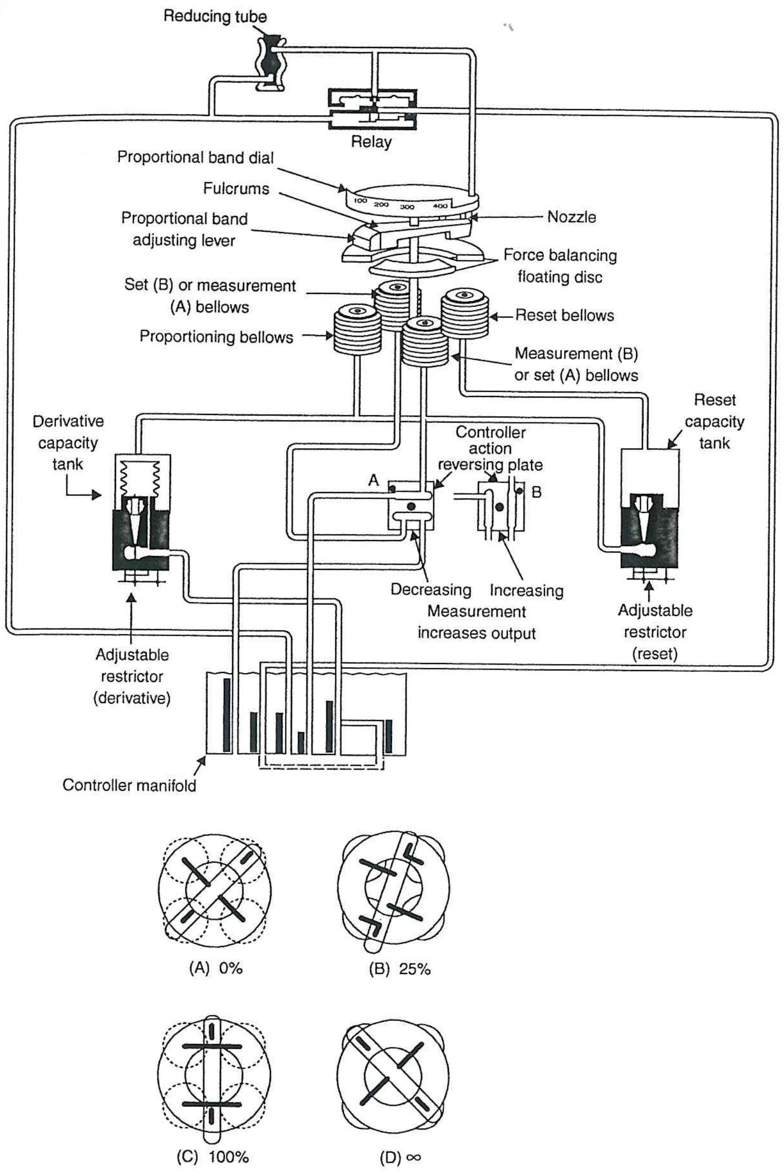
$$p_4 = \frac{b}{a} p_1$$

and ratio ($a : b$) decides multiplication factor if over unity. Division can be arranged by making the ratio ($a : b$) less than unity.

Pneumatic Controller (2)

This unit gives ($P + I + D$) actions (Figure 12.8).

Forces exist due to four bellows on the force balancing floating disc which acts as the flapper, and the resultant moments of bellows forces determines the throttle position. With the fulcrums over the proportional and reset bellows there is no feedback effect and the distance between the centre line of the adjusting lever and the other two bellows is a maximum so giving 0% proportional band (see A). With the centre line



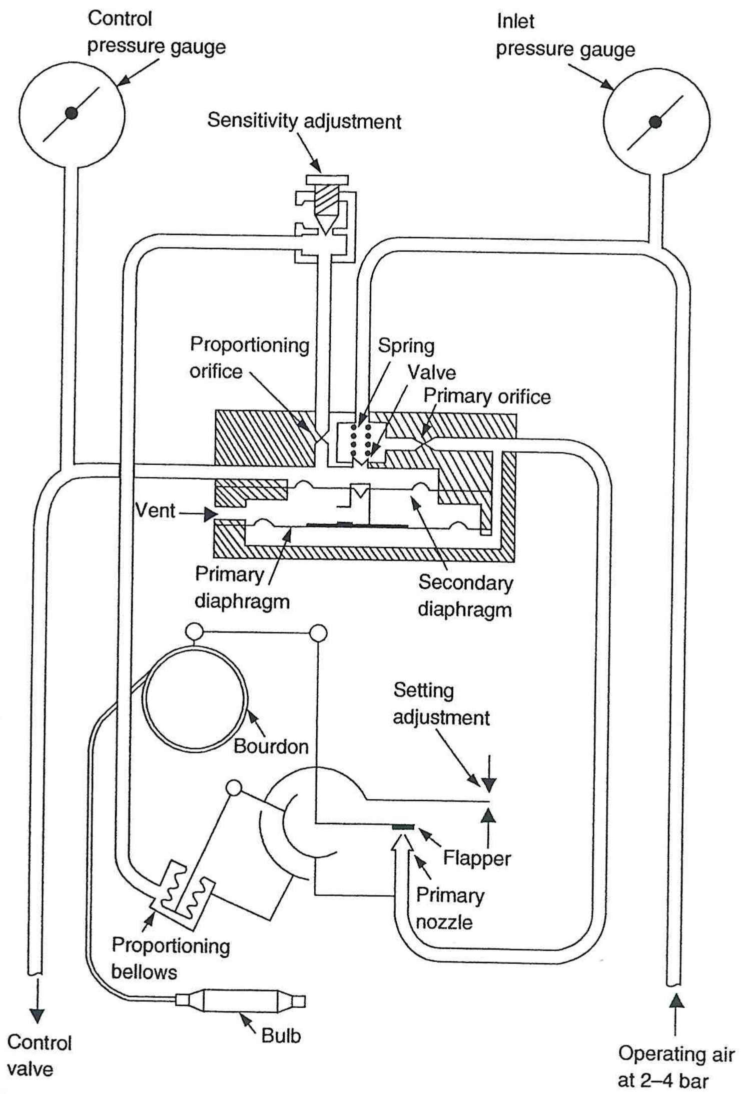
(A) 0% (B) 25% (C) 100% (D) ∞

▲ **Figure 12.8** *Pneumatic controller (2)*

from the set bellows gives a 25% proportional band (see B). 100% proportional band exists for C. Infinite proportional band exists for D. Note the reversed controller action available if required. Derivative addition gives delayed feedback with differential across the resistor where flow is proportional to rate of change of deviation. Integral addition

Pneumatic Controller (3)

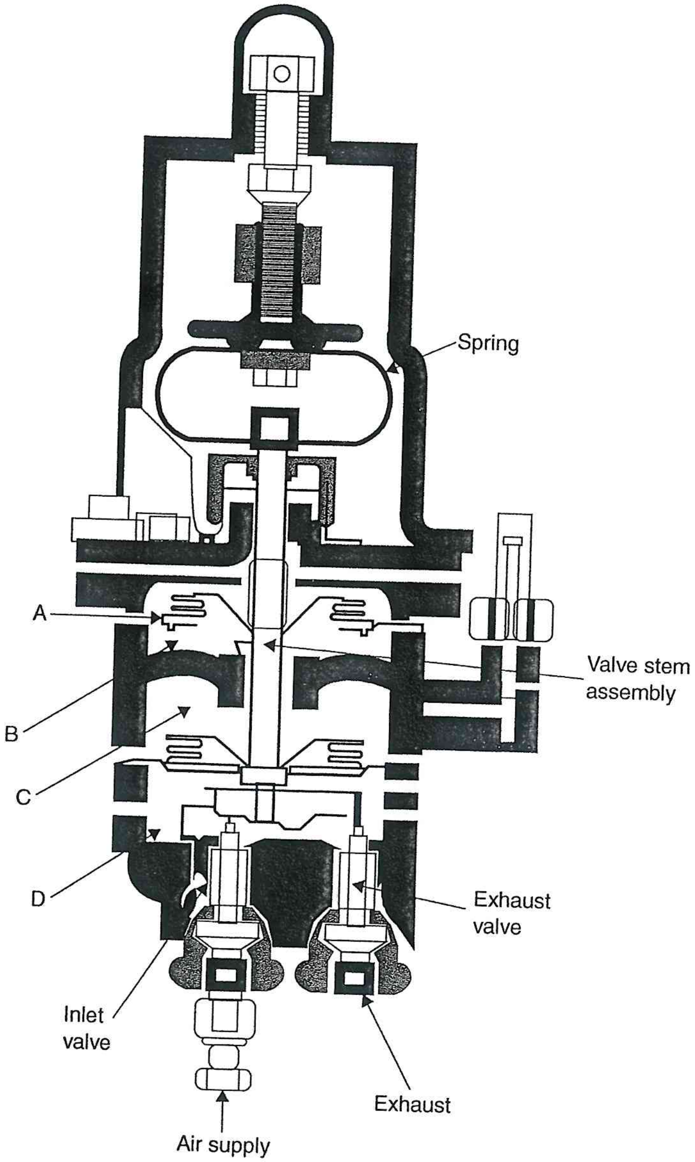
Refer to Figure 12.9. The sketch is for a proportional controller but other types are available with integral or derivative action added. The sensing element, in this case thermo-sensitive system, on a change of conditions will, via the Bourdon tube, alter the flapper position. This decides the control pressure, which is led back via the proportioning orifice and sensitivity adjustment to the proportioning bellows. For maximum sensitivity this pressure feedback is vented and no pressure acts on the bellows. If sensitivity is decreased the resulting pressure builds up on the proportional bellows, contracts the bellows and moves the nozzle away from the flapper. This means a greater flapper travel is required to close the nozzle, that is, a wider proportional band. The relay pilot valve assembly shown has a null position non-bleed action. When the flapper approaches the nozzle the control pressure increases, this lifts the primary diaphragm causing the valve to open and allow air pressure above the secondary diaphragm to the outlets (3). Increase of pressure above the secondary diaphragm will tend to balance pressure under the primary diaphragm; at balance the diaphragms return to the original position, the valve closes on both seats and balanced pressure acts on the control valve. For flapper travel away from the nozzle, pressure above the secondary diaphragm will vent until balance is restored.



Pneumatic Controller (4)

The relay (Figure 12.10) receives a proportional signal as input and modifies it to proportional plus integral. The relay consists of four chambers isolated from each other internally by metallic diaphragms connected to a central post, spring loaded at one end and operating inlet and exhaust valves through a beam at the opposite end. Alteration in chamber A pressure will affect a similar change in chamber D due to the repositioning of the valves caused by beam movement from the bellows. Flow also occurs to C via the restrictor throttle valve, as C is at a lower pressure, so giving a similar effect to the initial down movement but at a rate dependent on the deviation, that is, integral action (adjustable by throttling valve). This regenerative effect continues until there is a return to the required setting when the supply proportional controller restores A chamber to balance giving a balance of C and D chambers and repositioning at the new required position. The spring maintains a given set value, and at equilibrium both valves are slightly open.

The relay is easily modified to an averaging relay, that is, taking two signals, combining and giving a resultant output. Loading pressure comes into A as before and also in through the throttling valve to C directly. Thus two effects are combined, and the C signal can employ any time delay dependent on the valve orifice opening. C and D are not connected.



▲ **Figure 12.10** *Pneumatic controller (4)*

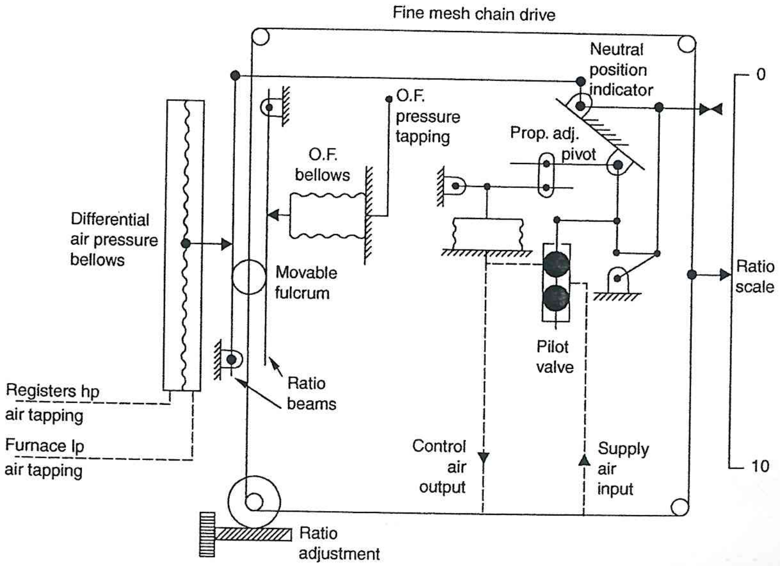
Such a relay controller is characteristic of many similar designs usually called *stack* type (often without use of beams, that is, valve and diaphragm action in one line only). They are sometimes termed *blind* controllers as they are often sited close to the control function to minimise distance-velocity lags.

Pneumatic Controller (5) (Fuel–Air Ratio)

Change in combustion air flow is measured in terms of pressure difference across the air register, and is transmitted via the large bellows to the ratio beam (Figure 12.11). Change in fuel oil pressure, caused by the master pressure controller due to variations of steam pressure, is fed to the smaller OF bellows. These two signals are in opposition when applied to the beam system.

Between the beams there is a movable roller fulcrum the movement of which, by the ratio adjustment screw, gives different equilibrium conditions and the ratio is indicated on the ratio scale. Beam lever position operates a linkage to the pilot valve which varies control air output signal. This output signal is fed to the averaging relay where it 'trims' the signal being fed through to the air damper actuators. The adjustable proportional band and negative feedback bellows should be noted. This type of controller utilises proportional control only.

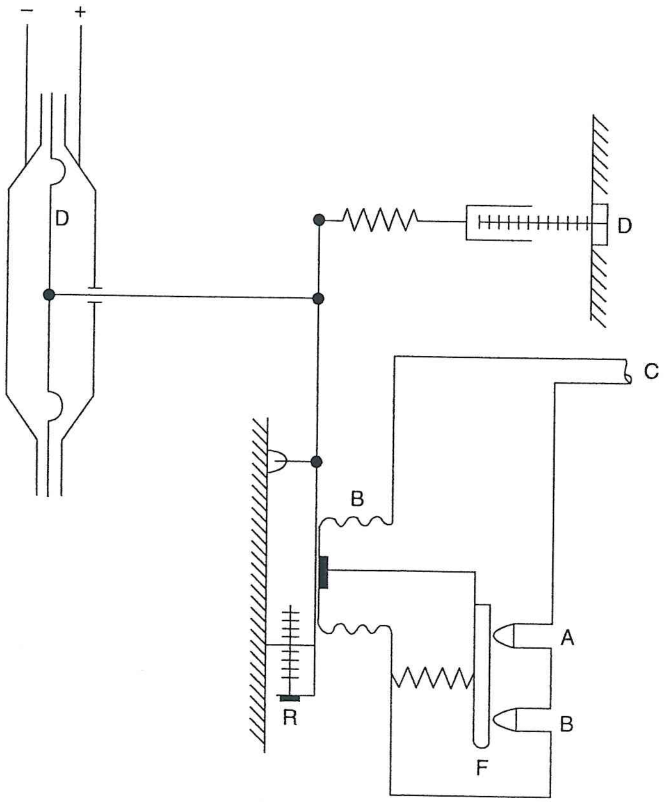
The correct fuel : air ratio can be maintained irrespective of the numbers of burners in use provided that air registers are closed on burners which are not in use.



Pneumatic Controller (6) (Viscosity)

The viscosity sensor has been described previously (Figure 5.2). The high pressure connection (+) and low pressure connection (–) is led to a D/P cell. Consider Figure 12.12.

Differential pressure is applied across the diaphragm D of the transmitter (cell). Increasing D/P (increasing viscosity) causes the diaphragm and balance beam to move to the left. The inlet supply nozzle B is opened by the flapper F which allows build up of air pressure in the feedback bellows B. This gives a restoring action on the balance beam until equilibrium is again reached. Discharge nozzle A is shut. Air pressure in the feedback bellows is the output signal of the controller through C to a diaphragm valve regulating steam to the oil fuel heater.

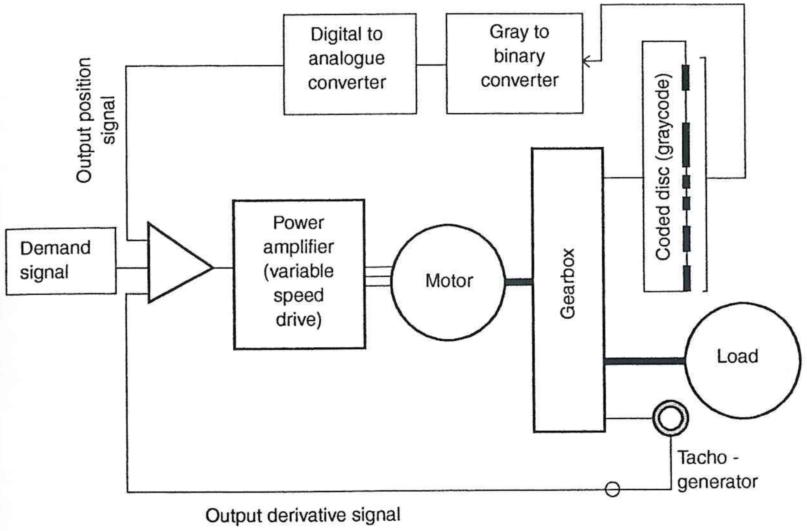


▲ **Figure 12.12** *Pneumatic controller (6) (viscosity)*

For decreasing viscosity, discharge nozzle A is opened giving air bleed, and inlet nozzle B is closed. At equilibrium nozzles are virtually closed which reduces air wastage. Zero adjustment is at Z and range adjustment at R. The proportional action is readily extended to include integral action by adjustable reset control on the feedback bellows. Sensor and controller are described as a control circuit, see Figure 13.19.

Electrical Positional Control

Closed-loop control systems using an electric motor as the main actuator are well established. Figure 12.13 shows a typical arrangement using an optical encoder as the position sensor.



▲ **Figure 12.13** *Electrical position control system*

Test Examples

1. Sketch and describe an instrument to maintain the viscosity of a fuel at a constant value. Explain how it corrects any deviation of the viscosity from the desired

2. Explain why load sensing governors are usually fitted to engines driving alternators. Sketch a governor for this duty and explain its action.
3. Describe, with the aid of a sketch, a specific type of three-term pneumatic controller. Discuss how the separate control actions are generated and adjusted.
4. An electronic controller incorporates an integrating and differentiating network. Sketch each circuit. A square wave input is applied first to one circuit and then to the other with display on a CRO. Illustrate the input and output (2) wave forms on a common time base diagram.

13

TYPICAL CONTROL CIRCUITS

The number of different control loops utilised is large. Applications for each of steam, motor (IC engine), general, engineering knowledge sections will now be considered. Much process control is still pneumatic, and illustrations are mainly biased to this type. Electronic sensing and control devices can easily be substituted but the final power control element is often pneumatic. Control of displacement, velocity and acceleration using electrical-electronic servo-mechanisms are detailed in the next chapter.

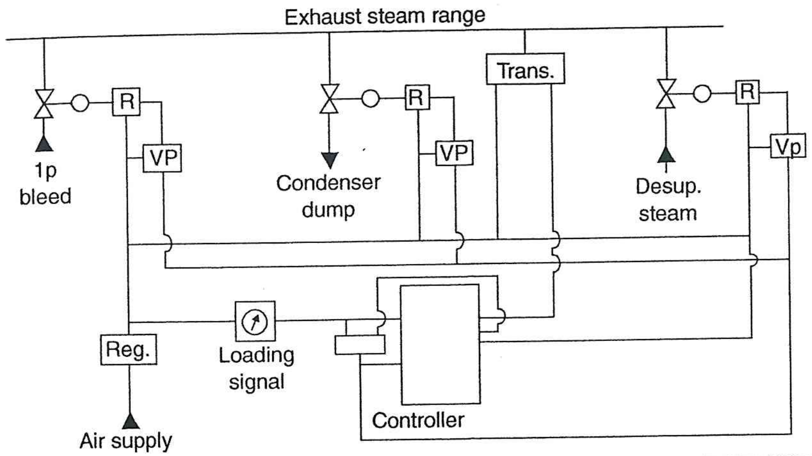
Steam Plant

Auto-combustion and feed system control have been used for many years. Modern sophisticated sub-systems for temperature, pressure, level, flow, etc. are interlinked into boiler and turbine overall control systems suitable for remote and transient conditions.

Exhaust range pressure control

This utilises sequence operation with valve positioners, see Figure 13.1.

Range pressure (1 bar) is sensed and converted to a pneumatic pressure signal by the transducer. This signal is transmitted and compared with the set value and any

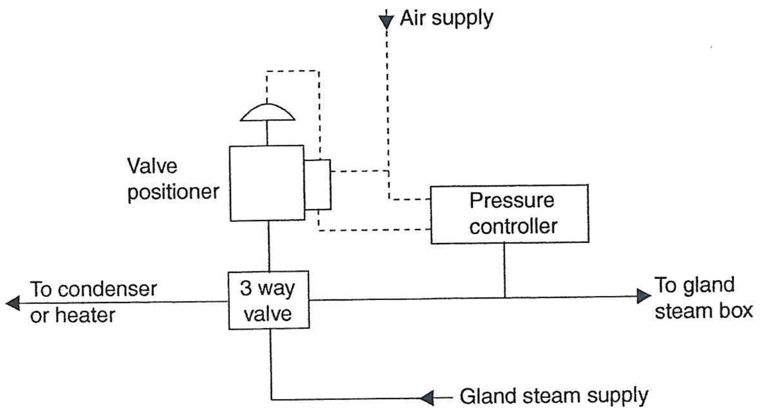


▲ **Figure 13.1** *Exhaust range pressure control*

deviation. Output signal 2 to 1.75 bar gives dumping to condenser, 1·75 to 1·5 bar 1p bleed is fed in, 1·5 to 1·25 bar desuperheated steam is fed in while bleed remains full open. Thus exhaust range is constant pressure maintained. In the diagram R is for relay and VP is for valve positioner. This is split range control.

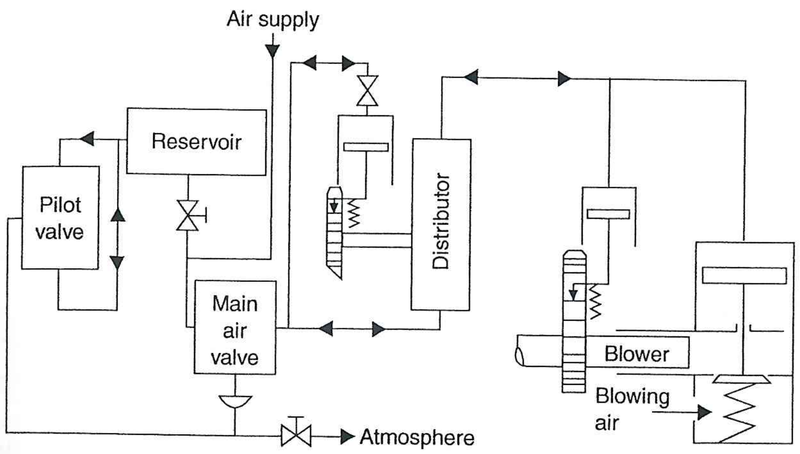
Turbine gland steam pressure control

Such an arrangement is given in Figure 13.2 from which it will be noted that gland steam pressure is sensed and supply is either increased or dumped.



Sootblower control

The sootblower system utilises air for both control and blowing. Operational rotation of the blower head is achieved by means of an air piston ratchet mechanism. The sequence of operation is governed by the distributor operated by a similar air piston ratchet mechanism. The supply air to both pistons comes from the pilot valve whose operation is dependent on the charging and discharging rate of the air reservoir. Adjustable control orifices are provided at entry to reservoir (charging) and on the atmosphere line (discharging). Each impulse or air puff blast rotates both ratchet gears by one tooth and gives a blowing blast for a few seconds (Figure 13.3).

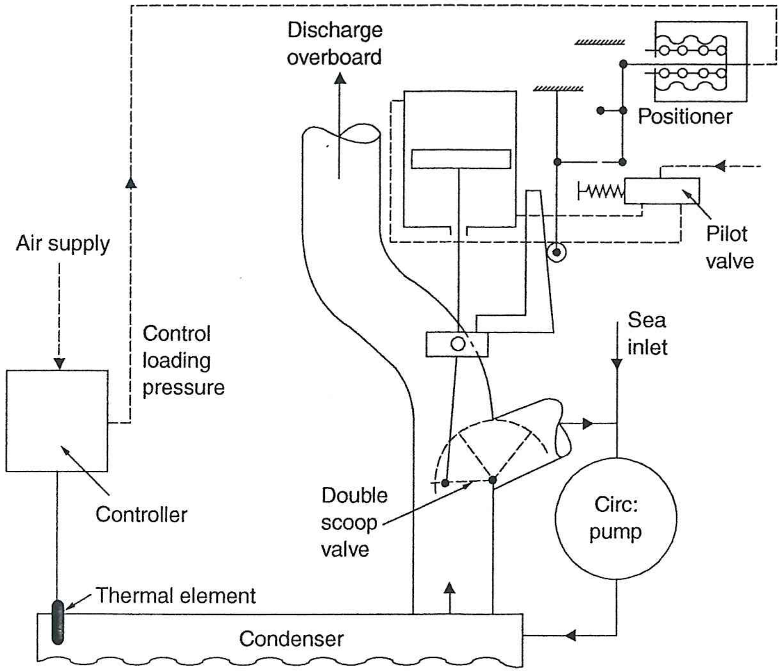


▲ **Figure 13.3** *Sootblower control*

Condenser circulating water temperature control

This system utilises constant pump speed with water recirculation. For reduced power or low sea temperature operation the condenser may be operating far from design conditions. Excessive high vacuum results in possible turbine erosion, and low temperatures give excessive undercooling of condensate which reduces plant efficiency.

Refer to Figure 13.4. A fall of sea temperature would generally be arranged to decrease the air loading pressure, giving bellows expansion, which through the positioner allows air to the top of the servo piston so allowing more of the scoop into the discharge pipe



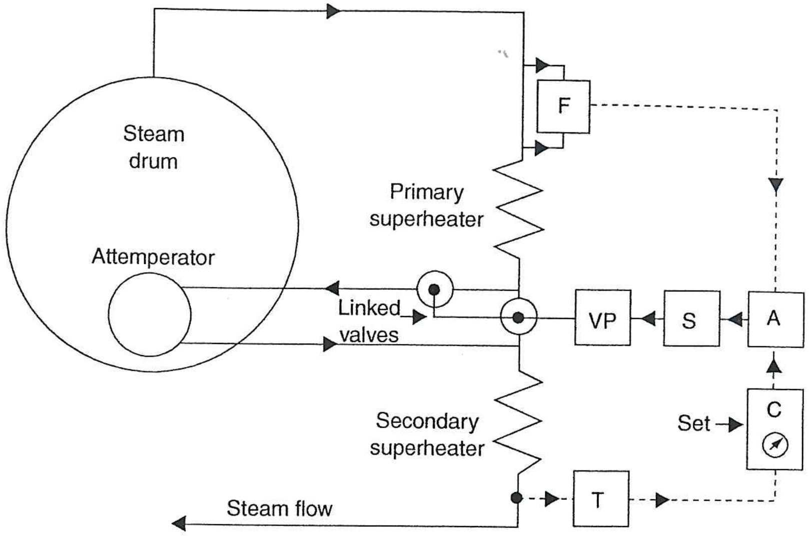
▲ **Figure 13.4** *Condenser circulating water temperature control*

Steam temperature control

Refer to Figure 13.5. Superheat control is based here on the amount of steam flow through the attemperator. The sensing element input signal to the steam temperature transmitter (T) is directed to the recorder-controller (C), which is often three term. Output signal from this controller is combined in an adding relay (A) with the output signal from a steam flow transmitter (F). Relay output signal passes through the control station (S) (hand-auto) to operate the valve positioner with linked control valves to vary attemperator flow rate.

Two-element control allows more effective operation during transients. Increased steam flow would reduce temperature without the second element action which would be reducing flow through the attemperator. Split range control (two valves and positioners) could be used in place of two linked valves from one positioner.

Note. Three term usually means $P+I+D$ and three element usually means a combination of three variables in a controller, for example, pressure, level, flow.



▲ **Figure 13.5** *Steam temperature control*

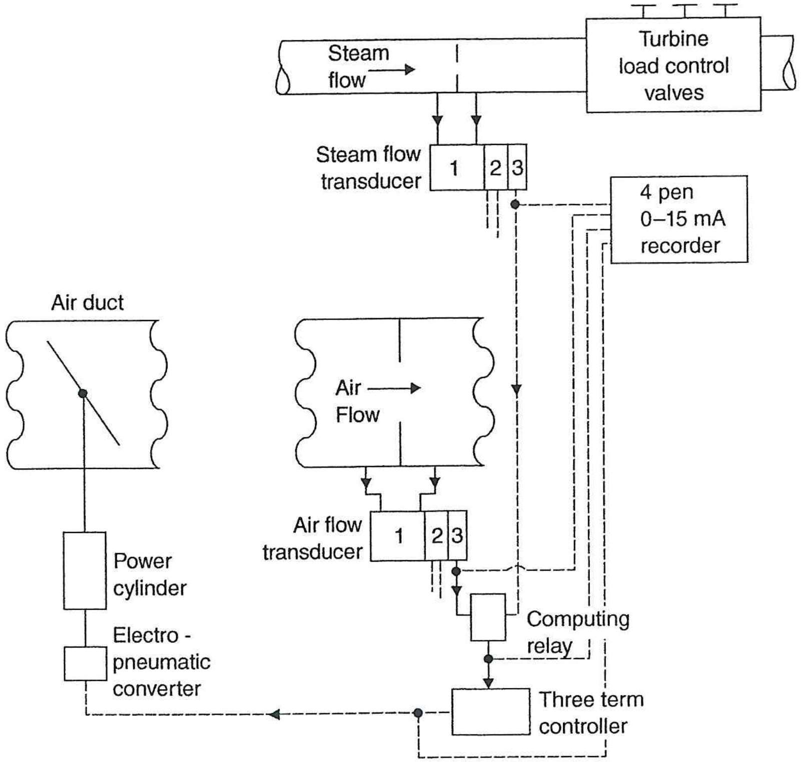
Steam flow/air flow rate control

Refer to Figure 13.6. Steam flow rate is sensed at the orifice plate with tappings to a steam flow transducer consisting of a D/P cell (1) usually supplied with condensed water. The cell would incorporate a square root eliminator, perhaps mercury well type with mechanical linkage to variable inductance (2) operated amplifier (3). The air flow rate is similarly sensed. Outputs from both D/P cells are fed to an electronic computing relay whose output signal is related to required air flow for the measured steam demand. A tapping can be arranged to the burner fuel supply controller. The computing relay output signal enters a three-term electronic controller. The electrical signal output from the controller operates the final control element. This element is a damper in the inlet air duct. An electro-pneumatic converter and power cylinder are required. Note direct signal measures of the four variables at pen recorder.

Bridge control (turbine machinery) instrumentation and alarms

For the bridge console the least instrumentation and alarm indicators the better. Alarms and instruments should be limited to only those that are vitally necessary.

Suggested



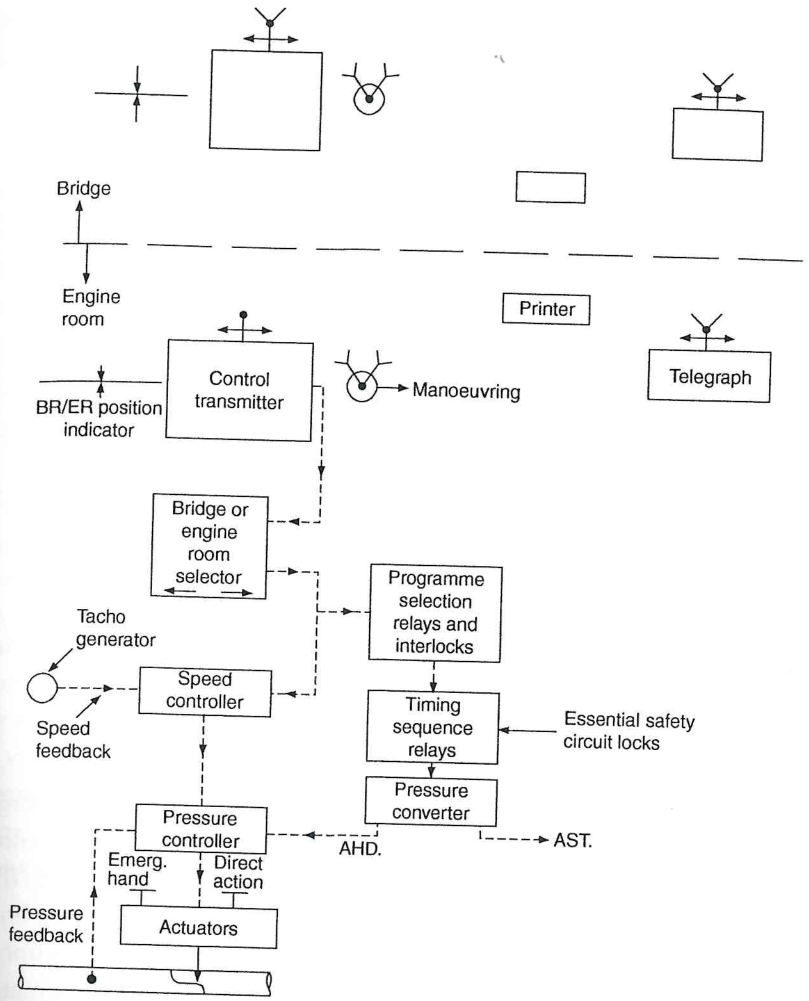
▲ **Figure 13.6** *Steam flow/air flow rate control*

pressure, (6) low level of tank contents. For direct instruments opinion is divided but no more than say another six indications should be necessary. Engine console and alarms would obviously provide full instrumentation. A typical simplified system is given in Figure 13.7. This system has direct control at the steam manoeuvring valves. This is essentially a combination electro-pneumatic although all-pneumatic or all-electric can easily be arranged.

The following points with reference to Figure 13.7 should be noted:

1. It is assumed that all normal safety protection devices and control are provided, for example, loss of lubricating oil pressure, high or low water level in boilers, electrical failure, etc.
2. Subsidiary control loops have been omitted, for example, evaporators, generator, etc.

Consider now the individual aspects relating to Figure 13.7.



▲ **Figure 13.7** *Bridge control (turbines)*

Selector: Bridge or engine room control can be arranged at the selector in the engine room. When one is selected the other is ineffective.

Duplication: Both transmission control systems are normally identical and operation of the one selected gives slave movement of the other.

Manoeuvring: A separate sequence is arranged, for example, opening astern master valve, opening turbine drains, etc., but if this separate control is not applied separately it will be automatically applied from the main transmitter.

Interlocks: Essential blocks are necessary such as no valve opening with turning gear in, etc.