Table 16.1

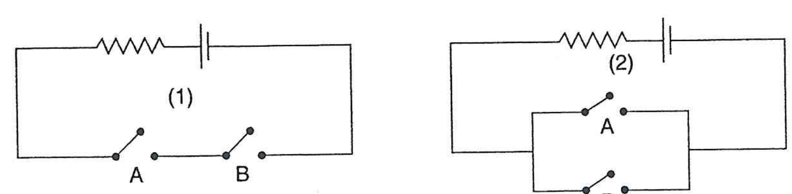
Set theory	Sentence logic	Switching circuits
$a \cap b$ Intersection of a and b	$a \wedge b$ a and b	$A.B$ 'and'
$a \cup b$ Union of a and b	$a \vee b$ Either a or b or both	$A+B$ 'or'
a' Complement of a	$\sim a$ Not of *a*	$\bar{A}$ 'not'

The laws of Boolean Algebra and the use of Truth Tables greatly facilitate the simplification of electrical logic circuit design.

Switching circuit logic

Devices using electromagnetic relays in control systems have been used over a long period of time for such functions as sequential starting, protection interlocks, counting circuits, etc. A simple application of electrical circuits is shown in Figure 16.4.

The truth table is given (Table 16.2) where 'true' is referred to as state 1, that is, relay closed, closed circuit, current flows, voltage across load; 'false' is referred to as state 0, that is, relay open, open circuit, no current flows, no voltage across the load. In electronics, power supply connections are often +6 V, −6 V, 0 V. Voltage used depends on devices and circuitry requirements.



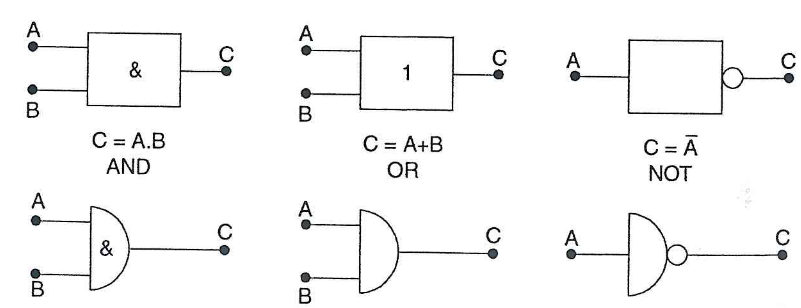
▲ **Figure 16.4** *Switching circuit logic*

Table 16.2 *Truth table*

A	B	$A \cdot B$	$A+B$	$\overline{A \cdot B} = \bar{A} + \bar{B} = A+B$	$\overline{A+B} = \bar{A}.\bar{B}$
0	0	0	0	1	1
1	0	0	1	1	0
0	1	0	1	1	0
1	1	1	1	0	0
INPUTS		AND	OR	NAND	NOR

Note:

1. A series circuit is the AND function for output, that is, output signal is the same sense as inputs only when *all* inputs are the same.
2. A parallel circuit is the OR function for output, that is, output signal is the same sense as input change for any one or all input changes. *Inclusive* disjunction (gate) means either *or* all for the OR function and *exclusive* means either *not* all (symbol ⊕).
3. The single relay, or switch, is the NOT function, that is, contact closed gives output (closed circuit, state 1, *A*) and contact open gives no output (open circuit, state 0, $\bar{A}$). Similarly the unity ratio operational amplifier (inverter) is a NOT function.
4. In electronics the provision of a unity ratio operational amplifier (inverter) in series with an AND circuit gives a NAND circuit (NOT–AND) with output opposite in sense to input only when all inputs are the same. Similarly the inverter in series with an OR circuit gives a NOR circuit (NOT–OR) with output opposite in sense to input change for any one or all (inclusive) input changes. Compare output states in Table 16.2. Logic symbols vary, two conventions are shown in Figure 16.5 and other forms are

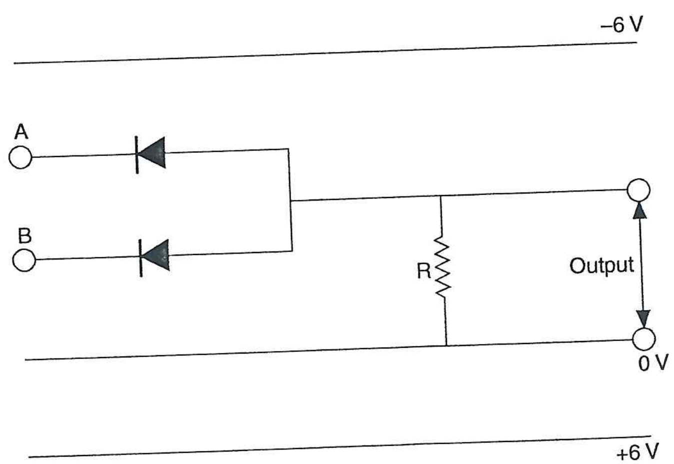


shown in the text to illustrate the variations, such as small circles at output change AND to NAND and OR to NOR.

Solid state logic

Such logic circuits (gates) are being increasingly used in place of relays and thermionic valves. The convention for relays of 0 (off) and 1 (on) has to be modified because input and output have non-clearly defined states less simple than on–off. 1 may represent higher (or more positive) voltage and 0 lower (or less positive) voltage. This is *positive* logic which is usually used with *npn* transistors because collector potential (and output) becomes more positive when the transistor is cut off. The reverse applies with *pnp* transistors and *negative* logic is used; *this convention is adapted in this chapter, that is, negative true logic*, logical 1 negative with respect to logical 0 from a voltage level aspect. Digital logic functions can be achieved by the use of diodes and transistors, the former simpler and the latter more effective.

Refer to Figure 16.6. With A and B at say –6 V (state 1) no current flows through R and output is –6 V, that is, output state 1 for coincidence of state 1s at input. With any input at say 0 V (state 0), that is, any diode conducting, output voltage is small, near 0 V (state 0). A diode, to earth across output, is sometimes fitted to ensure output 0 V. Reversing polarity of both input and output signal requirements gives an OR circuit, that is, A or B or both at 0 V (state 0), with any diode conducting, means output is 0 V (state 0). Resistors are sometimes fitted at inputs (see Figure 16.11).



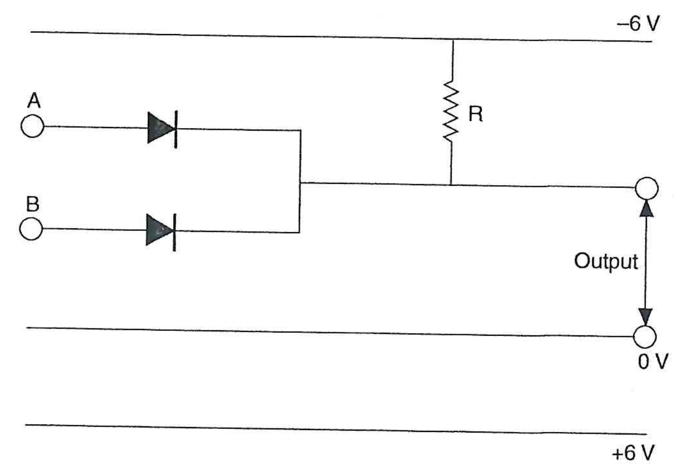
OR gate (diode) negative true logic

Refer to Figure 16.7. Output volts are zero until one or both diodes conduct, when –6 V is applied to either or both inputs, the output is then –6 V, that is, output state 1 for any combination of state 1 inputs.

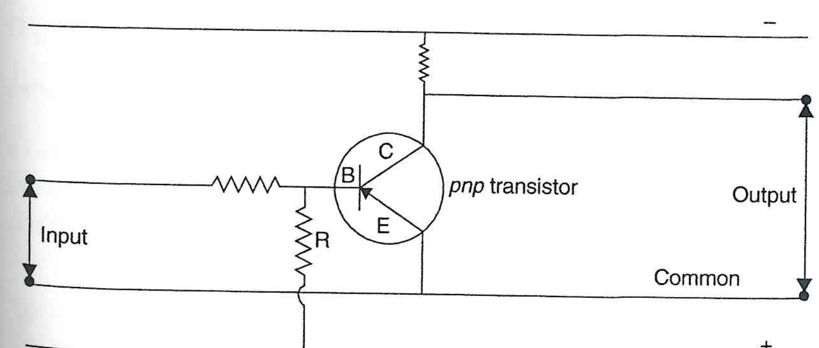
Again reversing polarity reverses role (becomes AND) and resistors are sometimes fitted at inputs (with or without diodes – see Figure 16.8). Diodes ensure that inputs cannot affect each other.

NOT gate

Refer to Figure 16.8. This is the inverter amplifier, single input, with output for no input and if any input no output. Input say –6 V (state 1) gives output 0 V (state 0), that is,

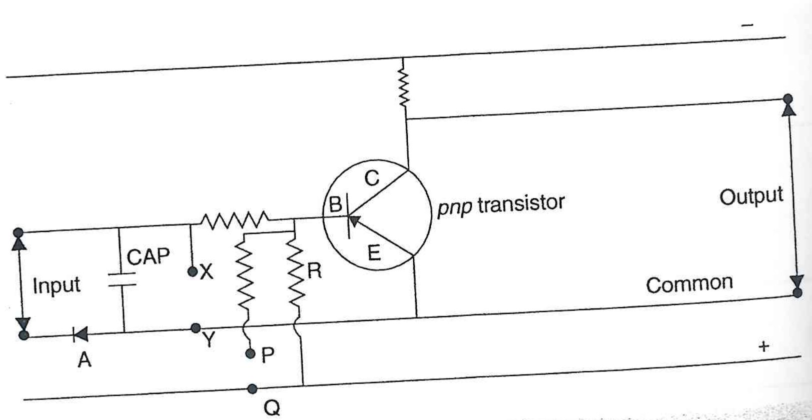


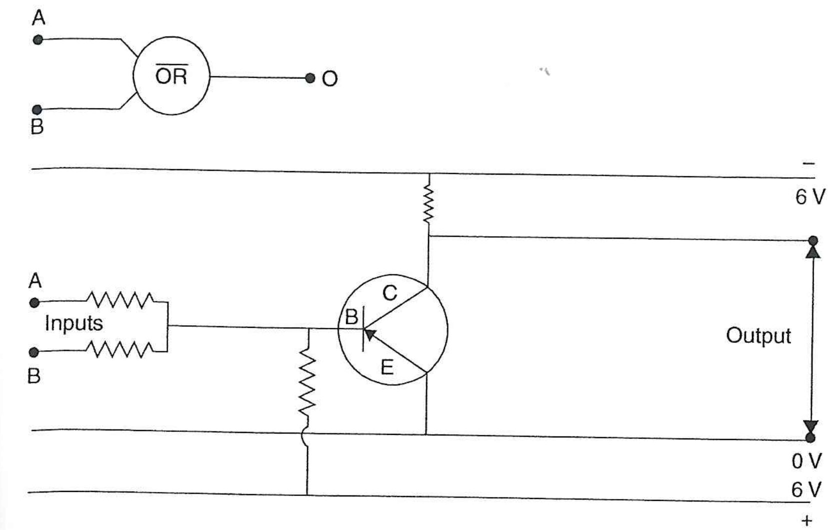
▲ **Figure 16.7** *Diode gate (OR)*



antiphase, or input 0 V output –6 V. For the configuration shown (*pnp* transistor) when there is 0 V input signal the base is slightly positive with respect to the emitter (reverse bias) and no current flows. The transistor is then essentially a high resistance impedance-resistance between emitter and collector with an output voltage approximately equal to the negative supply voltage. When an input signal of sufficient negative magnitude is applied the base swings to negative with respect to the emitter and current flows to the collector. If such current is arranged to cause saturation of the transistor then the resistance across emitter and collector is negligible so that the volt drop is negligible and output volts are almost zero. Thus the bi-stable amplifier with common emitter connection (as distinct from an alternative common base connection sometimes utilised) acts as a switch circuit with on-off limits. The emitter could be regarded as earthed. This device is often used in annunciator systems (see Figure 16.19). Supplies may be ±6 V.

Refer to the *time delay* switch in Figure 16.9 where operation is similar to the above. With no input volts, output volts approximately equal negative supply volts. When the input signal is applied and causes the base to become negative then output the becomes zero as the transistor activates and the capacitor (CAP) charges. When the input signal is removed the capacitor discharges through the transistor emitter circuit as the rectifier (A) blocks any outlet (anode is negative) through the input circuit. So there is a time delay before the output reappears; the delay depends on the resistor and the capacitor values (i.e. RC time constant). A variable resistor between P and Q allows shorter time delays and a capacitor between *X* and *Y* allows longer time delays, both resistor and capacitor being adjustable. Supplies may be ±6 V for power source, and the common line may be earthed.





▲ **Figure 16.10** *(Inclusive) NOR gate*

NOR gate (inclusive)

See Figure 16.10: The gate has one output and two or more inputs. Output changes if one or more, input states change and the output change is anti-phase potential to input change. This is a negative sign output OR gate. If –6 V is applied to A or B or both, the *pnp* transistor base is negative so that a large collector current flows and output volts are almost zero (small resistance across emitter–collector) if appropriate circuit values are designed in. With 0 V applied to inputs the output is –6 V (transistor biased to cut off at near +6 V). A symbol sketch is shown at the top of the diagram. Notation on such sketches often varies. An alternative often used is a semi-circle, base to inputs, with small circle (sometimes blacked in) or bar line on circumference leading to output to indicate inversion (Figure 16.5).

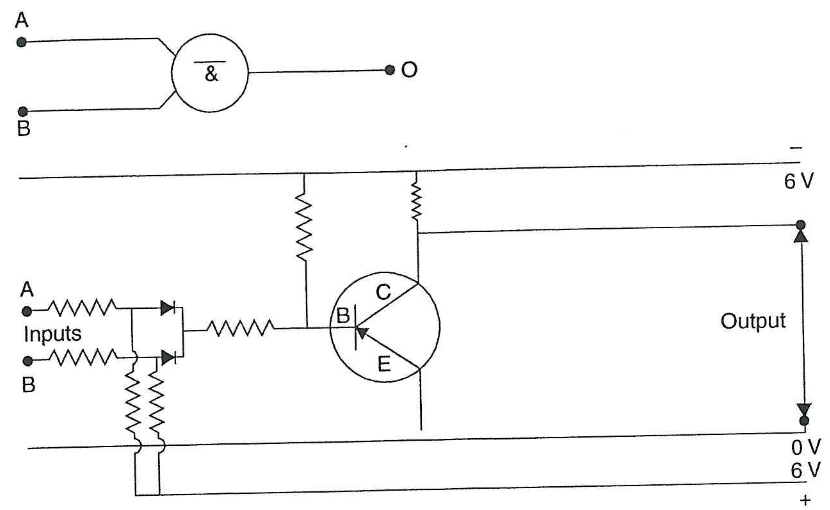
NAND gate

This is shown in Figure 16.11 with symbol sketch above (see Figure 16.10).

Single output changes only if all inputs change. With inputs at 0 V output volts are –6 V and transistor is biased at cut off. If all inputs are –6 V then bias is removed and the output is 0 V. Output and input are anti-phase. This is a negative sign output AND gate.

Note:

1. Circuit simplification will be apparent if only one (or two) gates are used for all

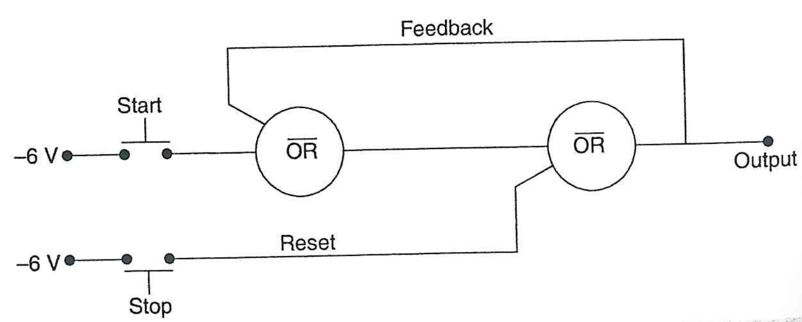


▲ **Figure 16.11** *NAND gate*

2. Reversing polarity of gates reverses the role of the device.
3. NAND gates can act as inverter NOT gates when only one input is applied. If a NAND gate output is fed to another single input NAND gate in series final output is in phase, that is, AND gate. Combinations of NAND gates can also provide OR, NOR, HOLD circuits.
4. Remarks similar to (3) apply in general for NOR gates.

HOLD (memory) circuit

A time delay circuit has been considered previously (Figure 16.9). The remaining logic circuit commonly used is hold, or memory, which can now be considered. Feedback holds in the circuit even after input signal is removed. A reset signal then restores the state of the system. Consider Figure 16.12.



Closing the start button momentarily allows −6 V input and the first NOR gate conducts with output 0 V. The second NOR gate gives output −6 V and this signal is fed back to the first NOR gate. This circuit output is maintained when the start button is released, that is, held or remembered from the initial signal instruction. Closure of the reset (say stop) button changes the 0 V line input from reset to −6 V. The second NOR gate, previously with two inputs at 0 V, now has one input at −6 V and conducts, so output is 0 V. Final output becomes 0 V and feedback at 0 V means both inputs to the first NOR gate are 0 V and its −6 V output maintains the non-energised state when the stop button is released.

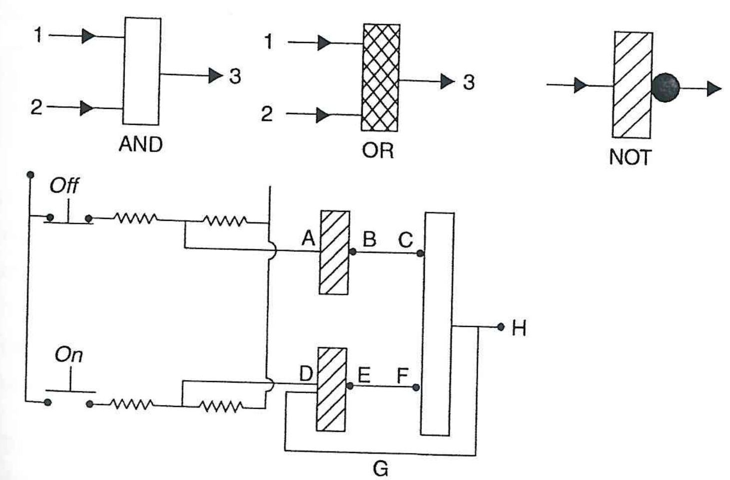
An alternative example is given in Figure 16.13.

Electronic transistor gates are similar to relays. Functions can also be achieved using diodes powered by the input signals. However transistor gates, as amplifiers, have the decided advantage of utilising a separate circuit of supply for output power which increases the scope greatly.

Note: In logic circuitry entire circuits are packaged and it is not necessary to know the exact circuit configuration of a particular device (chip) because it is encapsulated. Signal tracing is impossible and it is only necessary to understand the relation between overall input and output signals and repair is by replacement (the black box philosophy).

NAND and NOR are obviously combinations of the three given actions and various 'tree' type circuits can be quickly built up for otherwise complicated functions.

For example, the logic illustrative circuit shown as a combination in Figure 16.13. The circuit may be interpreted as follows: 'if the *off* signal is not interrupted at the button



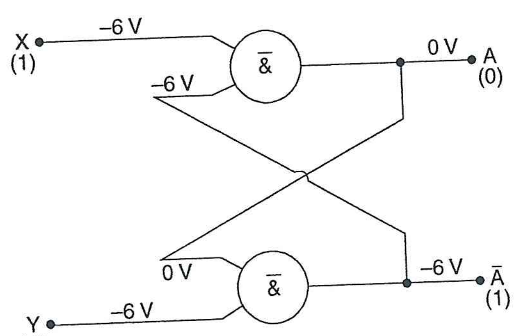
and the *on* signal or the *feedback* (or interlock) signal G is energised there will be an output at H. Pressing the *on* button gives inputs at A and D, hence an AND function and output at H (the two NOT functions at B and C cancel, that is, like two negatives make a positive; similarly E and F). Release of the *on* button still allows output to be maintained through the *feedback*, that is, the alternative input of the two element (OR) circuit. Pressing the *off* button cuts off one of the signals in the AND circuit and cuts off output H. Strictly the combined sketch is NOT (A), NOR (*D*), NAND (CF) but redundant items (BCEF) simplify to OR (D) and AND (CF) and the shading section on *D* would then be crossed.

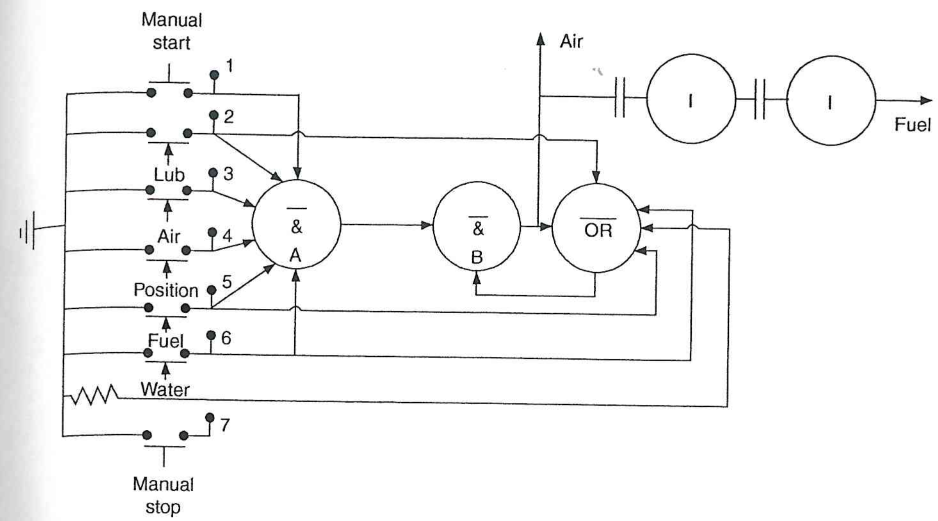
Flip-flop circuit

Multi-vibrator circuits have been discussed in Chapter 7. The univibrator circuit as sketched in symbolic form in Figure 16.14 is used in computers. With inputs *X* and *Y* at state 1, say –6 V, the feedbacks at state 0 (0 V) and state 1 (–6 V). For the lower gate feedback (0) and input *Y* (1) through NAND gives state 1 (–6 V). For the upper gate feedback (1) and input *X* (1) through NAND gives state 0 (0 V). Connecting inputs to state 0 will give stable reversing. A positive pulse to one input reverses output potentials again. For counting both inputs are connected so that two positive input pulses are necessary for each positive output at the outer transistor, that is, each successive binary changes at *half* the speed of the one driving it.

Logic sequence engine system

Figure 16.15 is a practical illustration of applied logic. All inputs, points 1–7, can be regarded as –6 V through input resistors. With all essential start criteria 2–6 satisfied, the transducers will have closed these input relays and operation of the start button 1





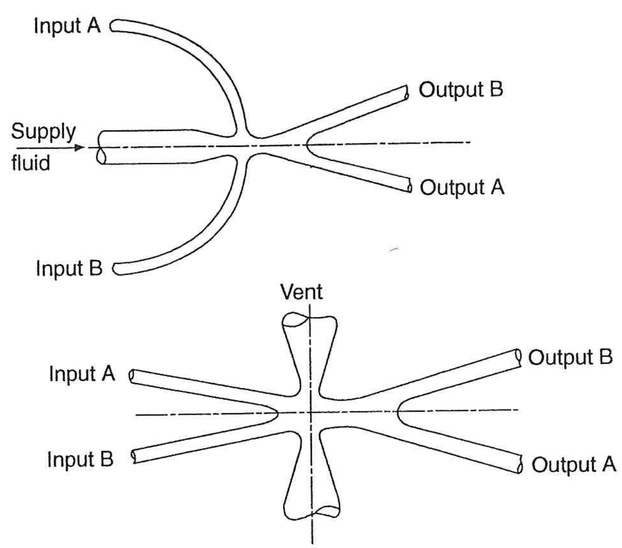
▲ **Figure 16.15** *Logic sequence engine system*

gives all 0 V inputs (earth) to gate *A* whose inverted output is –6 V. Gate *B* inputs are –6 V from *A* and –6 V from the inverted feedback NOR gate (whose inputs are all 0 V). Gate *B* output at 0 V supplies the air start signal pulse and via double inverters *I* (single input NOR or NAND gates) gives a delayed fuel supply pulse (delay by capacitors in circuit) at 0 V. All inputs to NOR gate at 0 V. If any feedback input to NOR gate becomes –6 V (due to stop button operation or fault on circuits 2, 5, 6) its output becomes 0 V to gate *B*. Gate *B* will stop conducting and its output signal will become –6 V so shutting off fuel by signal change. A time delay, not shown, can easily be arranged to shut off only the air start signal after use. Many versions of the above circuit can obviously be built with various logic gates.

Fluidic logic

Devices use fluid flow in sensing, logic computation and actuation. A commonly utilised principle is the Coanda effect, that is, the tendency of a jet stream to attach itself to the pipe surface (wall). A complete range of devices can be built up and are widely used in industry. It is not possible to cover all designs but to illustrate principles two types are chosen. The bi-stable multi-vibrator (flip-flop) has been considered electronically and fluidic principles are illustrated in Figure 16.16.

Referring to the top sketch the fluid can be regarded as attached to the wall of tube *A* at output. Input signal at *B* separates attachment and diverts flow to tube *B* output. This



▲ **Figure 16.16** *Fluidic logic devices*

condition will hold (memory) if input *B* signal is removed and can be reset by an input *A* signal to the initial state.

The lower sketch illustrates an exclusive OR device, that is, input *A* or *B* will give output *A* or *B* but not both. If inputs are zeros output is zero and if inputs are applied together the jets impinge, flow goes to vent, output to zero.

If output change for this momentum type device is greater than input (control) change it is amplification. A turbulence amplifier utilises a cross-control jet to change from laminar flow.

Digital Computer

It is first necessary to consider simple computer-counting in binary terms.

Scales of notation

The *denary* scale (base 10) is in general use but any number base can be used in a scale. Consider the following:

Scale 10	$\ldots 10^3$	10^2	10^1	1	$\frac{1}{10}$	$\frac{1}{10^2}$	$\frac{1}{10^3}$	…
Scale 3	$\ldots 3^3$	3^2	3^1	1	$\frac{1}{3}$	$\frac{1}{3^2}$	$\frac{1}{3^3}$	…
Scale *n*	$\ldots n^3$	n^2	n^1	1	$\frac{1}{n}$	$\frac{1}{n^2}$	$\frac{1}{n^3}$	…

51 denary in the scale 3.

$51 = 1 \times 3^3 + 2 \times 3^2 + 2 \times 3^1 + 0 \times 1 = 1220$ (base 3)

248 denary in the scale 5.

$248 = 1 \times 5^3 + 4 \times 5^2 + 4 \times 5^1 + 3 \times 1 = 1443$ (base 5)

1475 denary in the scale 12.

$1475 = \text{ten} \times 12^2 + 2 \times 12 + \text{eleven} \times 1 = t2e$ (base 12)

(*t* and *e* to be new digits representing ten and eleven in the denary scale)

19 denary in the scale 2.

$$19 = 1\times 2^4 + 0\times 2^3 + 0\times 2^2 + 1\times 2^1 + 1\times 1$$
$$= 10011\,(\text{base } 2)$$

The latter, base 2, is the *binary* scale.

Binary scale

The reader should first verify for practice:

$$101011 \text{ base } 2 = 43 \text{ base } 10$$
$$39 \text{ base } 10 = 100111 \text{ base } 2$$

This scale has the advantage of expressing any number in terms of two symbols, 0 and 1. If 0 is taken to represent current off and 1 to represent current on (or two voltage states) then it is possible to use many electrical currents to perform calculations. This is the basis of the *digital computer* counting in digits, pulses or bits.

Addition and subtraction

htu		2^6	2^5	2^4	2^3	2^2	2^1	1
43			1	0	1	0	1	1
+ 39		+	1	0	0	1	1	1
1	Carry figures	1		1	1	1	1	
82		1	0	1	0	0	1	0

Addition is as illustrated above. If the digit sum in any column totals 2, carry 1 to the next column and leave 0; if 3, carry 1 leave 1; if 4, carry 1 two columns and leave 0; etc.

Subtraction is as illustrated below. When subtracting 1 from 0 borrow (10) that is, *2* from next column, change 0 to 1 working to the left until a 1 is reached, change this to a 0, and continue the subtraction.

htu		2^6	2^5	2^4	2^3	2^2	2^1	1
	Borrow figures		1	(10)	(10)	1	1	(10)
88		~~1~~	~~0~~	~~1~~	~~1~~	~~0~~	~~0~~	0
−63		−	1	1	1	1	1	1
25				1	1	0	0	1

Multiplication and division

Procedure exactly as denary using final addition or subtraction techniques above.

```
      1 0 1 1
    × 1 0 1 0
    ---------
      0 0 1 0
    1 0 1 1 0
  0 0 0 0 0 0
1 0 1 1 0 0 0
-------------
1 1 0 1 1 1 0
```

```
                1 0 1 0
         ---------------
1 0 1 1 | 1 1 0 1 1 1 0
          1 0 1 1
          -------
                1 0 1 1
                1 0 1 1
                -------
```


Component units

A brief introduction to constituent elements of the digital computer can first be considered. Refer Figure 16.17.

Input unit

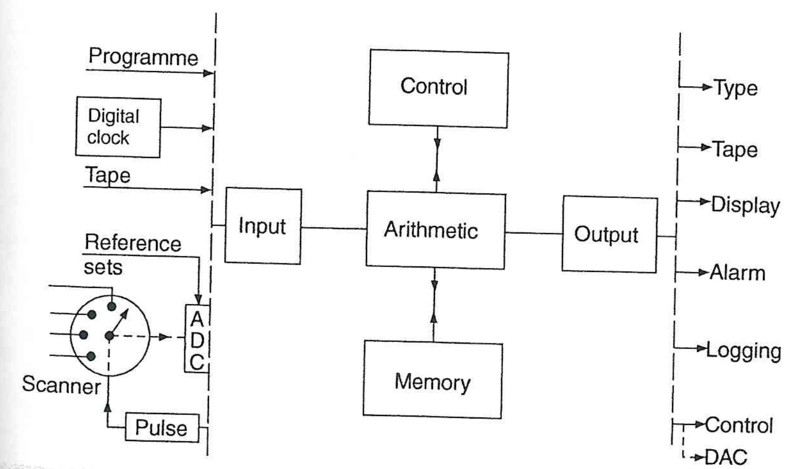
Functions to accept input data coded information in the form of either punched or magnetic tape or converted analogue signals and transmit the electronic signals in digital form to the arithmetic unit. The connecting link between units is called a *bus*. *Programs* are typed in on a keyboard and displayed on a *video display unit* (VDU).

Arithmetic unit

Processes input to desired arithmetic functions such as addition, averaging, etc. Assembly of bi-stable devices for binary operation including binary counter (flip-flops in series, extending range), shift register (flip-flops driven by clock), accumulator and buffer store, etc.: all pulse-operated combinational and memory devices. Grouped with memory and control units to form the *central processing unit* (CPU) which if a single chip would be the microprocessor in a microcomputer.

Memory unit

Store information with two basic stable state elements. Storage can be paper or magnetic tape spools, magnetic drum or magnetic core stores. Magnetic cores are of two state ferrite core rings, grouped into lines (*words* or *bytes*) with up to 36 digits (*bits*)



per word. A store with 12 bit (cores) per word and 2^{12} words (4096) has almost 50 k cores and is known as a 4 k memory store. This would be classified as small with 64 k as quite large. *Random access memory* (RAM) contains instructions. ROM is *read only memory*.

Control unit

Essentially the brain element of the computer. This is sometimes referred to as programme unit. The programme input is decoded, addressed and so internal transfer involving memory and arithmetic functions is carried out. Programmes involved in the central processor may be specific *language* for a particular type of machine or generalised high-level language code such as Algol, Cobol, Fortran or C+ which is then processed to machine code. Input and output units are also controlled. Assemblers and compilers translate between languages.

Output unit

Receives computed outputs as electrical signals, transmits directly to control functions of plant, operates digital logging units, displays alarm devices and presents output for typewriter or as tape. Outputs may require reconversion digital to analogue for control action to analogue computers, plant controllers, etc.

Peripheral units

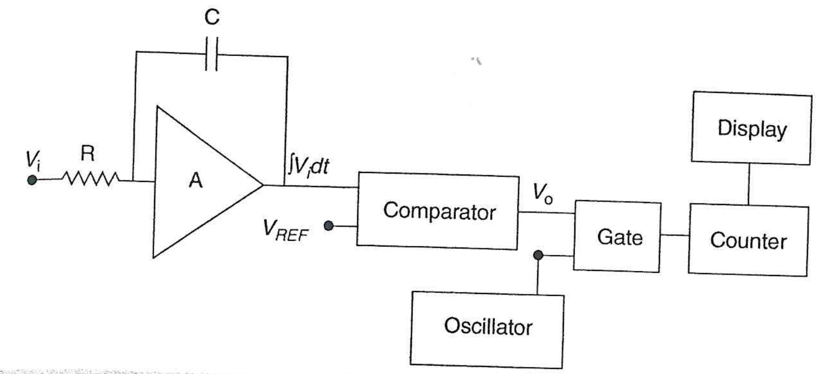
In this case refers to units outside the digital computer itself, that is, outside the input-output boundaries shown as dotted chain in Figure 16.17.

For general purpose computers requiring high speeds and used mainly for data processing in business, systems inputs and programme inputs would be tape and outputs would be tape and type. The programme input and digital pulse timing clock are obviously essential peripheral equipment to any digital computer.

Engineering computers require reference sets, scanners and analogue-digital converters. Outputs would be type logging on paper tape, display, alarm and control functions.

Reference sets

Amplified transducer inputs from scanners are compared to manually set high-low level limits by potentiometers arranged as multi-position rotary switches before analogue inputs to the converter. Alternatively comparison is arranged digitally by direct programme control on desired values or manual set by pins inserted on a matrix patch board.



▲ **Figure 16.18** *Digital instrument*

Scanner

Measurements are sequentially selected by transistor circuits. The transistors are operated by an input signal from the scan control device regulated by pulses from a pulse unit digital clock. Scan speeds can reach 400 points per second if required.

Analogue to digital converter

Analogue display is illustrated by a car speedometer, that is, continuous, and digital display by the distance device, that is, discrete steps. One design of converter has a reference voltage potentially divided by resistance binary steps 2^0, 2^1 2^2, etc. which are compared to the input voltage signal in sequence, until parity, when output from tapped resistances is then digital. A similar principle can be applied by a balance bridge comparing input and output resistances. There are many types of converters available and a typical digital instrument is shown in Figure 16.18. The comparator provides an output when the reference voltage is greater than the integrated input voltage. This output opens a gate circuit allowing the oscillator pulses (proportional to input voltage) to the counter. The range is variable, with an RC time constant.

In large computers it is necessary to have maximum utilisation of computer time. Batch processing utilises storage until a suitable time for handling the programme. Real-time operation requires instant response to priority input when required. Time sharing to consumers is generally necessary in present digital systems.

Data Processing

In engineering, digital data processing equipment provides an integrated system of monitoring plant process and includes alarm scanning, centralised display and data recording.

Data logger

This is essentially centralised instrumentation only. As such has now only a secondary function of measuring and logging with display. Useful for continuous monitoring and documentation of records of, for example, large refrigeration storage plants. Generally refined and superseded by an integrated system to include alarm scanning which provides malfunction protection in complex machinery installations.

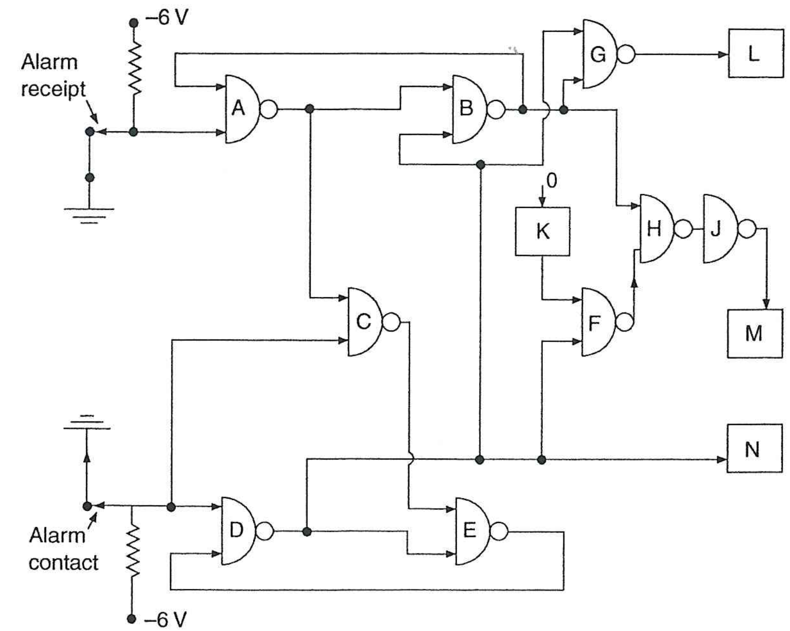
Annunciator systems

Are central surveillance-collection points. An off normal condition results typically in the following sequence:

Condition	Green Lamp	Red Lamp	Klaxon
Normal	On	Off	Off
Fault	Off	Flashing	On
Receive	Off	Steady	Off
Normal	On	Off	Off

Figure 16.18 shows a diagrammatic circuit for a single-point annunciator system. State (1) is –6 V and State (0) is 0 V, NOR gates are used (except J–NOT). Consider Figure 16.19.

Under normal conditions the alarm contact is closed, D output (1) which operates the green light N, G output (0) and J output (O) so klaxon L and red light M are off.



▲ **Figure 16.19** *Annunciator system*

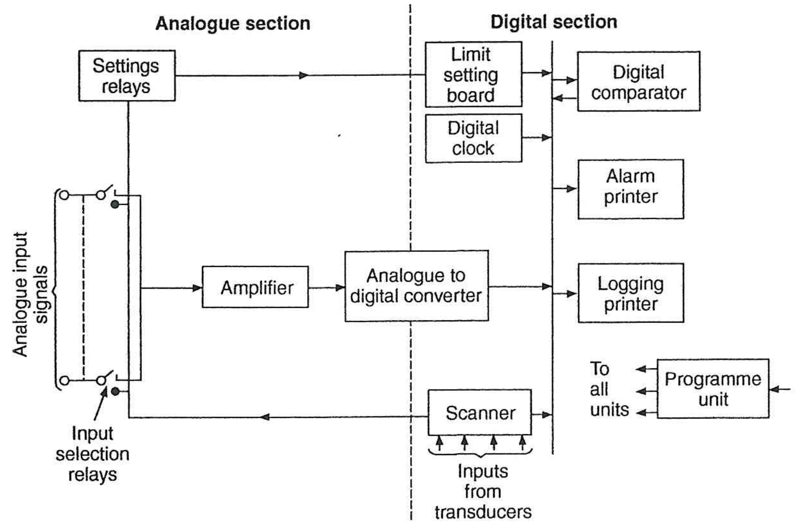
At fault, alarm contact opens, D output (0) and N off, E output (1) which feeds back to hold D. Input to F is (0) and signal generator K also enters pulses into F so that M flashes. Outputs from D and B are both (0) so output from G is (1) and operates L.

When the alarm receipt button is operated a (1) signal is fed into A and B, output is (1) which feeds back to hold A; also overides flash input to H so M exhibits constant red light and switches L off via G.

When the alarm contact returns to normal and closes, both inputs to C are (0) and its (1) output resets the hold circuit DE, then AB, so M is extinguished and N lights up.

Integrated system

Includes data logging as one function. Essentially a digital computer but of a fairly simple design, peripherals are as already described. The programme is designed and fixed so that programme input, control, arithmetic and memory units as shown in Figure 16.20 are simplified and combined into one central processor. A very brief outline description will now be given and reference to Figures 16.16 and 16.19 should be made.



▲ Figure 16.20 *Schematic diagram of electronic alarm scanning and data logging system*

Primary inputs

Analogue signals from transducers represent variables such as pressure, level, flow, etc. Each transducer has a plug-in printed circuit module for measurement range, limits, etc. and is switched in by the scan control unit.

Signal selection

A scanner unit. Sub-units may be used at local points in the installation for say 40 points which reduces cable runs to the central control room and relieves space requirement of the processor.

Signal processor

Provides amplification, analogue to digital conversion, limit sets analogue or digital, scaling, linearising, etc. with outputs to digital (or analogue with d-a conversion) display, routine logging and alarm circuits.

Output devices

Visual and audible alarms are required. A logging typewriter records alarm conditions and events, until cleared. The typewriter can log by routine all points on demand or at time intervals. *Display* requires careful consideration with a minimum of gauges restricted to essential observation. Mimic diagrams of plant circuits with indicator lights

design for comfort, correct instrumentation and alarm indication plus good effective lighting. Construction of components is modular with plug-in circuit cards for fault rectification. Process plant subject to such surveillance provides accurate and regular records and machinery protection with reduced watchkeeping staff.

Computer Control

This is a full digital computer programmed so as to maintain output variables at the design condition by providing outputs to controllers. At present most controllers work on analogue inputs so the digital computer requires an output digital-analogue converter. Direct digital control is however coming into use where the computer output acts directly as control action on the final correcting element. Simple computers generally include controllers. Data processing is now well established, it follows that computer control is very relevant. In marine practice a computer can be so programmed as to provide, for example, complete preparation of machinery plants for sea together with computer control on passage. Built-in emergency action is provided. Such a large computer could of course cope adequately with cargo handling in tankers and navigational route placing with suitable addition to store and provision of correct programming. Until recently (and in principle) the analogue computer is faster on a complex run but the digital computer is accurate, repeatable and suited to short runs.

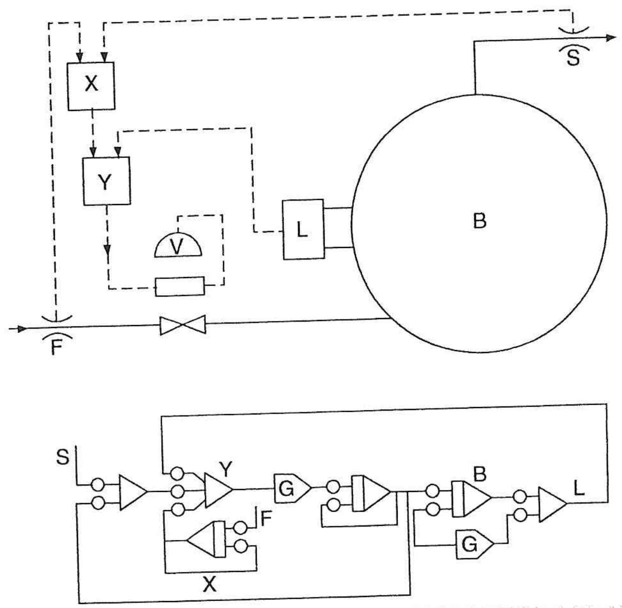
Recent developments have led to increased automated mass production of miniaturised and highly sophisticated functional complexes of circuits at decreasing costs and volumes (size). Mini computers of large potential computing power are now used with time sharing links to central large mainframe computers. Microprocessors, with a memory chip (storage, programme) and input/output devices linked to the central processing unit chip, are increasingly used virtually as microcomputers dedicated to one particular control system and function. Programmable Logic Controllers (PLCs) and microcontrollers are now standard components of control systems.

Computer simulation

Overall system performance, including interaction between components and loops, at the initial design stage is becoming increasingly important. Analysis and simulation of the dynamic (transient) performance, as well as steady state behaviour, is required. Mathematical models, based initially on linear analysis for frequency response and by

The upper sketch of Figure 16.21 illustrates a boiler water-level control loop. Boiler (B), steam (S) and feed (F) flow transmitter signals are to the *P* computing relay (X) with output, joined by level transmitter signal (L), arranged to the *P* + *I* computing relay (Y). The output signal from Y operates the feedwater control valve and positioner (V).

A computer simulation can be set up and a suitable patch diagram is shown in the lower sketch of Figure 16.21.



▲ **Figure 16.21** *Boiler water level control and simulation*

Test Examples

1. Describe, with sketches, an electrical panel for use in monitoring the alarm conditions of a set of diesel generators.
2. With references to data logging systems, explain the meaning of the following terms:
   (a) sensing device,
   (b) scanner

   (d) scaling unit.

   Sketch the components interconnected in the logger.
3. Write down in logic symbols, for input and output, the following functions, each with two inputs A and B:
   (a) OR gate,
   (b) NOR gate,
   (c) AND gate,
   (d) NAND gate.

   Sketch, in logic symbol form, each gate.

   Draw a circuit diagram for the OR and AND gates and briefly describe the modifications to give NOR and NAND functions respectively.
4. For a data logger system:
   (a) What is meant by time division multiplexing?
   (b) Explain the use of a comparator.
   (c) What is the difference between analogue and digital signals?
   (d) Discuss the reasons for A to D conversion.

SPECIMEN EXAMINATION QUESTIONS

Note: Questions on instrumentation and control systems are set within a wide range of subject titles such as Engineering Knowledge (General, Motor, Steam), Instrumentation, Electrotechnology, Power Plant, etc. The specimen questions following are based on expected 30 min answers, which is the most common practice. In some examinations however only short answer questions are set, for example, Class Three (DTp – SCOTVEC) – 10 min, and in others a combination of sections involving 30 min and short answer questions is used, for example, some BTEC and SCOTVEC.

Class Three (DTp – SCOTVEC)

1. Sketch a thermometer suitable for remote reading – indication.
2. Sketch a valve for automatically controlling fluid flow in a pipeline.
3. Describe, with a simple sketch, any level indicating device.
4. An engine alarm sounds intermittently. How would you determine if it is a genuine or nuisance alarm?
5. List any five essential instrument readings, indicating the running condition of machinery, for display on a centralised instrument panel.
6. Describe briefly any two types of pressure measuring device.
7. Sketch a moving coil type of electrical measuring instrument.
8. Briefly describe any method of speed control for an electric motor.
9. Describe, with a simple sketch, how a flapper-nozzle device controls pneumatic pressure in an air line.
10. Describe how remote smoke/fire indication can be located at a central observation station.
11. List four essential parameters of machinery in operation requiring alarm indicators.
12. Describe, with a sketch, any one type of flame or fire or smoke detector.
13. Explain the principle of operation of a pneumatic diaphragm actuator.
14. Describe a device that would automatically activate an alarm if oil feed supply fails.

16. With reference to automatic control technology, define and clarify the following:
    (a) desired value,
    (b) deviation,
    (c) correcting unit.

Class Two (DTp – SCOTVEC)

1. Describe with sketches two methods for increasing the strength of a signal in a control system.
2. Describe instruments used for measuring the temperature in the following spaces:
   (a) refrigerated hold,
   (b) engine room,
   (c) boiler uptake.
3. Describe with sketches, two methods for remotely determining the quantity of liquid in a tank. Compare the accuracy of these methods and explain how the degree of accuracy can be maintained. State one possible source of error for each of the methods described.
4. Sketch and describe three methods of sensing temperature change. Describe how the signals are converted and fed into an automatic control system.
5. Sketch a compressed air system for use with pneumatic controls. Write notes on each component shown.
6. Explain how a temperature sensitive element installed in a refrigerated stores locker can be used for starting and stopping a domestic refrigeration compressor.
7. Describe, with sketches, how the inlet temperature of lubricating oil to main engine or gearing may be automatically monitored and controlled.
8. Describe a bridge/engine room telegraph interconnecting gear. Explain how the system may operate a 'wrong way' alarm.
9. State why a pneumatic control system requires clean dry air. Explain how the following air pollutants are dealt with:
   (a) water,
   (b) oil,
   (c) dust and dirt.
10. Draw a line diagram of an arrangement whereby the pressure of oil delivered to

is pneumatically controlled within set limits. Trace the sequence of events upon deviation in oil pressure.

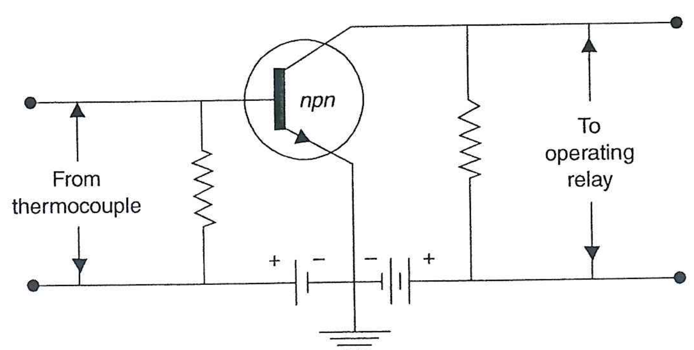
11. Sketch a compressed air system for pneumatic controls labelling all the principal items.

    Describe with sketches an automatic drain on the air compressor. State what routine maintenance and tests are needed to keep the system fully operational.

12. Sketch a pneumatically operated valve for regulating coolant flow.

    Explain how the pneumatic system controls valve movement. State how valve position is indicated at the control station.

13. Figure A illustrates how a transistor amplifies a signal from a thermocouple to operate a relay. Describe the principles underlying this amplification and explain why it is necessary.



▲ Figure A

14. The following terms may be used to describe a boiler feed water controller:
    (a) detecting element,
    (b) servo-motor,
    (c) desired value,
    (d) difference element.

    Relate the terms to practical components and describe their operation in the controller.

15. Sketch a simplified circuit diagram of an *npn* transistor illustrating its use as an amplifier. Give a reasoned account of its operation in terms of the electron theory.

16. Sketch and describe a master controller, operated by variation of pressure in the boiler, for regulating the air and fuel supply to the furnace by a pneumatic control

17. The left-hand side of a small bar of crystalline silicon contains a small proportion of the element phosphorus as an impurity and the right-hand side contains a small proportion of aluminium. Silicon has four valence electrons, phosphorus five and aluminium three.

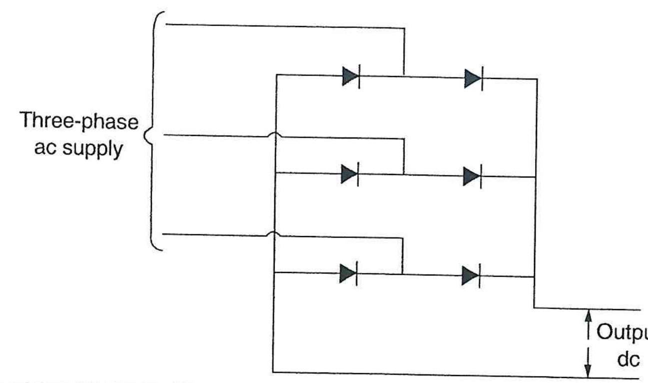
    Sketch the bar, and indicate the *n*-type region and the *p*-type region. Draw a battery connected between the opposite ends of the bar and show the polarity of its terminals which will bias the *p*–*n* junction in the forward direction.

    Explain why no current will flow through the bar when this polarity is reversed.

18. With reference to medium- or slow-speed engines, describe transducers suitable for producing electrical or pneumatic signals to indicate:
    (a) lubricating oil pressure,
    (b) jacket cooling water temperature.

    Explain how each of these transducers can be tested.

19. Figure B illustrates a three-phase fullwave bridge rectifier circuit. Using this diagram explain how an ac voltage is converted to a dc voltage. Draw the graph of output voltage against time for one cycle. State where such a circuit could be used in marine engineering.



▲ Figure B

20. With reference to automatic combustion control, explain with sketches how
    (a) and why pressure differentials across air registers are measured,
    (b) air–fuel ratios are adjusted,
    (c) the boiler can continue to operate upon failure of the fuel flow regulating valve.

21. Sketch in detail a section through a hydraulic governor as fitted to medium speed unidirectional engines. Explain how it operates under frequent and wide

22. Describe with sketches an automatic supervisory and alarm arrangement for the control of bilge water accumulation under periodically unattended conditions.

Explain how the control system is prevented from giving a false alarm due to ship's motion.

23. Explain the term 'semi-conductor' and describe what is meant by '*p*' and '*n*' type materials.

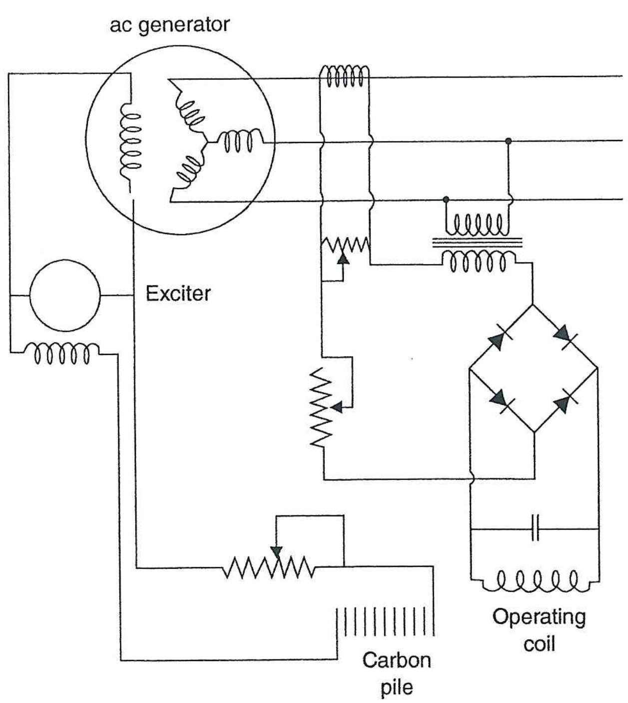
With the aid of a simple sketch discuss the conditions at the junction between a *p*-type and an *n*-type semiconductor.

24. Draw a line diagram of a pneumatic system for control of ballast, labelling the principal components.

Describe how a ballast valve is remotely operated.

State why driers, filters and automatic compressors are preferable to 'bleed off' from main or auxiliary air receivers.

25. Figure C shows a simplified circuit of an automatic voltage regulator. Explain how the arrangement maintains a constant voltage output.



▲ Figure C

26. Describe, with sketches, integrated alarm and control systems for monitoring the following:
   (a) air pressure,
   (b) tank contents,
   (c) oil temperature.

27. Describe with sketches two different methods for the remote measurement of fluid flow through a pipe. Compare the accuracy of the methods. Give one cause of error in each method.

28. Draw a line diagram of a system to operate widely distributed valves from one point.

Describe how any one valve is remotely manipulated.

Suggest, with reasons, a shipboard system which lends itself to such control.

29. Describe how a crankcase oil mist detector operates.

Sketch a mist detector system showing the run of the sampling pipes.

State how sampling is controlled.

30. Draw a line diagram of an automatic sootblower system. Describe the sequential operation of the blowers. Give reasons for the order of operation followed.

State what safety devices are incorporated in the system and why they are fitted.

31. A bridge circuit containing zener diodes may be used in a static automatic voltage regulator to monitor the voltage output of an alternator. State:
   (a) details of operation of zener diodes,
   (b) how the error signal is derived in the bridge circuit.

32. (a) In practice 'two-step' control devices have a small 'dead zone'; illustrate this by means of a control variable–time diagram.
   (b) Explain what is meant by 'two-step' control and give three examples of where such a control system may be used in an engine room.

Class One (DTp – SCOTVEC)

1. Describe how the supervisory equipment for the control of machinery in a periodically unattended engine room is itself monitored for defects on individual channels and as a complete unit.

2. Explain the problems in controlling the upper and lower limits of temperature of

3. State two advantages and two limitations in the use of electrical signals and also in the use of pneumatic signals as transmitting media in data transmission systems.

   Explain with the aid of diagrams the principle of operation of a force balance transmitter employing either electrical or pneumatic signals as the transmitting medium.

4. Describe, with sketches, how electrical signals are converted to pneumatic signals in control systems.

   Suggest a shipboard application featuring this conversion and state the defects to which the arrangement is susceptible.

5. Sketch and describe a system for indicating remotely the propeller shaft speed. Explain how, for the system selected, inaccuracies occur and are kept to a minimum

6. Sketch and describe a method of measuring the pressure differential for fluid flow systems.

   State what are the effects of altering the orifice plate size or the position of the tapping points.

7. Describe the construction and principle of operation of a Bourdon pressure gauge.

   State the factors upon which its operation depends. Outline a sequence of tests and adjustments applied to such a gauge known to be inaccurate and in particular mention at least three of the following:

   (a) leakage,

   (b) hysteresis,

   (c) non-linearity,

   (d) magnification,

   (e) zero error.

8. State what the purpose of each of the following items in a machinery control system:

   (a) portable mercury manometer,

   (b) portable inclined-tube manometer,

   (c) portable temperature potentiometer,

   (d) compressor and vacuum pump.

   Describe in detail any two of these items.

9. With reference to a gyro-controlled hydraulic steering gear, explain its action using control engineering terms making specific reference to:

   (b) feedback,

   (c) actuator.

   State the part played by the cylinder relief valves in the automatic control system.

10. Sketch and describe a fuel meter used with high viscosity fuel. Explain how it operates.

    Explain the value of the readings obtained and how they are used.

11. Sketch and describe how coolant flow may be measured on a linear scale.

    Explain the principle of operation of the instrument concerned. Explain why the values recorded may vary from those expected from calculations.

12. State why the temperature of lubricating oil supplied to an engine needs close control.

    Sketch and describe an arrangement and explain the principle of operation of instrumentation and control equipment for automatically maintaining the temperature of lubricating oil supplied to an engine at its desired value.

13. Sketch and describe in detail the construction and operation of one of the following:

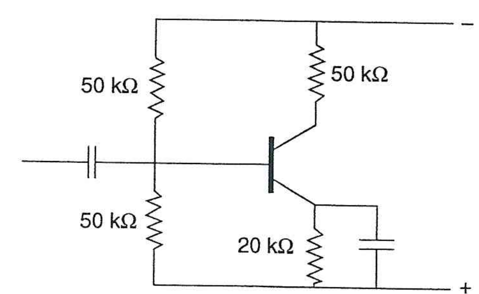
    (a) an electric torsionmeter,

    (b) a preferential trip,

    (c) an electric telegraph.

14. Define the term 'cascade control' as applied to control engineering. Describe, with sketches, cascade control as applied to an engine coolant system. Show on the sketches how pressure and temperature varies at the cardinal points in the system. Give one advantage and one disadvantage of this control arrangement.

15. Figure D shows a circuit of a common-emitter amplifier. The transistor has a high current gain so that its base current is small. If the current through the emitter resistor is 0.4 mA determine the battery voltage. Assume that when the transistor



is conducting, the voltage between the base and emitter is 0.2 V (90.2 V – this is abnormally high, with a 2 kΩ resistor in the emitter circuit the supply voltage is 11 V which is a much more acceptable value).

16. With reference to boiler combustion control explain:

(a) the operation of the master controller following variation in steam pressure,

(b) the importance of pressure drop across the air registers,

(c) how the air: fuel ratio is adjusted,

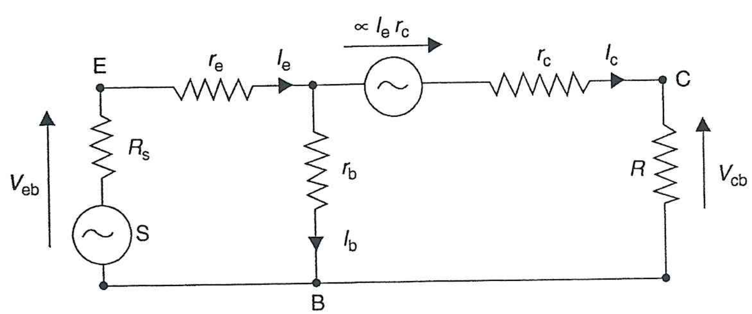
(d) how the boiler operation can continue upon failure of the fuel flow regulating valve.

17. The common-emitter output characteristics for a transistor are as follows:

Collector voltage (V)	Collector current (mA)		
	$I_b = 30\ \mu A$	$I_b = 60\ \mu A$	$I_b = 90\ \mu A$
3.0	1.0	2.1	3.2
7.0	1.29	2.55	3.9
10.0	1.5	2.9	4.4

Draw the graph of collector current against collector voltage and construct load lines to show the operation from a 6.5 V battery with load resistors of 1000 and 1500 Ω, respectively. If a suitable value of base bias current is 60 μA for an input for an input signal of ± 30 μA, determine the current amplification for each load (33.3, 31.6).

18. Figure E shows the equivalent T-circuit of a transistor used in a common-base circuit. The resistances presented to the alternating components of the current by the emitter (r_e), the base (r_b) and the collector (r_c) are 30 Ω, 0.6 kΩ, and 1 MΩ, respectively. If the current amplification factor (α) is 0·98 and the load resistance



(R) is 9 kΩ, calculate the current, voltage and power gain and the input resistance (0.97, 186, 180; 48 Ω).

19. Describe with sketches how the pressure of a fluid is controlled by a pneumatic controller incorporating proportional and integral (reset) action.

Give reasons for instability in the controller action. State how this instability is overcome.

20. Give a detailed diagrammatic sketch of a mechanical-hydraulic governor. Explain how this governor operates. State what advantages it possesses over inertia governors.

21. Draw in detail a diaphragm operated control valve. Analyse the action of the inter-connecting elements, that is, the parts affecting control.

Explain how the load change is communicated to the actuator. State where such a valve may be used in an engine room.

22. Explain why the simple float control feed regulator is inadequate for the present generation of main boilers.

Describe with sketches, or block diagrams, a feed control system in which it is possible to programme a set point for various loads.

23. Give the advantages and disadvantages of data-logging systems used in connection with ship's machinery.

Explain the value of recorded data and how it is interpreted and usefully employed.

24. With reference to automatic voltage regulators discuss the function of the following basic elements:

(a) error detecting element,

(b) correcting element,

(c) stabilising element.

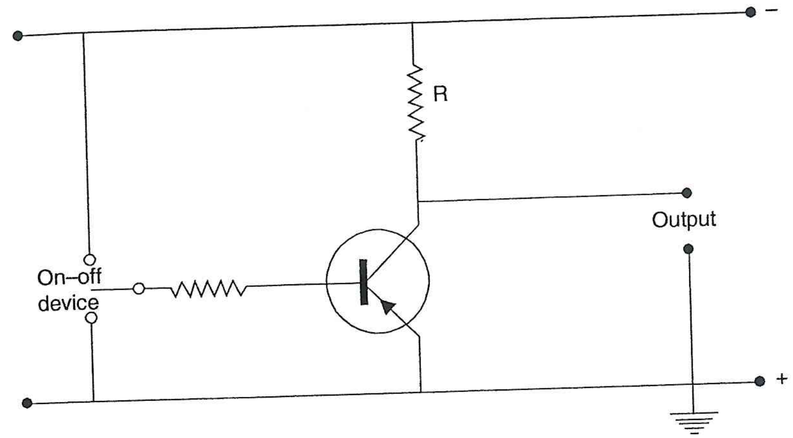
25. A pressure controller is fitted in a fuel line where ultimate state error is minimal and fast response is necessary. Sketch and describe such a controller making reference to components giving the desired characteristics.

26. Figure F shows a simplified circuit of a transistor employed as a switch in a relay operation. Describe how this is accomplished.

27. For the purposes of remote recording give two advantages and two disadvantages of:

(a) electrical signals,

(b) pneumatic signals.



▲ Figure F

Explain which system is best suited for sensing and remote indication of:

(i) lubricating oil pump discharge pressure,

(ii) engine bearing temperature,

(iii) fuel tank liquid level.

State what precautions are necessary when sensors are located in hazardous areas.

28. Sketch and describe a three-element feed water control giving reasons for its location. Explain how unity relationship is maintained between the identified variables. Explain why three-element control is superior to two-element control.

29. Draw a line diagram of a boiler combustion control system labelling the principal items. Explain how the system functions and in particular how feed water supply, fuel supply and air/fuel ratio are regulated to match steam pressure and flow variation. Explain how these controls can be tested for alarm conditions without upsetting the balance of the system.

30. Sketch and describe a hydraulic servo system associated with a controllable pitch propeller. State how loss of fluid pressure occurs and warning is given of impending failure. Explain what happens upon loss of oil pressure and why. State what routine maintenance is necessary to ensure trouble free operation of the propeller.

31. Explain how centralised control is achieved for either the direct reversing slow speed diesel engine or a main boiler and turbine installation. A block diagram could be used to show the principle functions and inbuilt safety features.

32. (a) With reference to primary sensing devices used in conjunction with a data logging system:

(ii) describe, with the aid of a sketch, a device that is suitable for pressure measurement;

(iii) describe, utilising a sketch, a device that is suitable for tank level measurement.

(b) Show, by means of a simple block diagram, the principle of data logging, and state why an Analogue/Digital convertor may be incorporated.

ONC – OND (BTEC and SCOTVEC)

1. Draw a labelled diagram of a flow measuring device to give a remote reading on an instrument panel.

Explain how the device operates to measure and indicate a change of flow.

2. (a) For any expansion type of thermometer, give four factors involved in obtaining a high speed of response.

(b) List three methods of temperature measurement and sketch and describe one method in detail, giving advantages and disadvantages.

3. Describe, with a sketch, the static characteristics of a junction diode.

Sketch the forward and reverse characteristics and write short notes on:

(i) the forward resistance,

(ii) the leakage current,

(iii) zener action.

With the aid of waveform diagrams, illustrate the action of a capacitor connected in parallel with the output of a halfwave rectifier.

4. (a) List four different methods of measuring liquid level.

(b) Sketch and describe a remote reading liquid level indicator suitable for a high pressure boiler.

5. (a) Draw a fully labelled sketch illustrating the principle of operation of a differential pressure transmitter.Describe its operation for a change in the measured differential pressure.

(b) State how zero and range adjustments are made on D/P transmitters and name two different marine applications for such a transmitter.

6. Describe, with the aid of a suitable circuit diagram, a method of obtaining the output characteristics of a junction transistor. Sketch the characteristics and

from them show how it is possible to draw the transfer characteristic and hence determine the current amplification factor of the transistor.

7. (a) Draw diagrams of instruments capable of measuring: (i) carbon dioxide content in a gas sample, (ii) oxygen content in a gas sample.

   (b) Describe in each case, for these two instruments, the principle of operation and indicate typical readings expected in a sample of gas from a boiler uptake.

8. (a) State three essential requirements for any instrument suitable for use in a modern marine power plant.

   (b) Explain, with reference to instrument display, the terms 'analogue' and 'digital'.

   (c) Give two advantages of the oscilloscope over moving iron instruments for the measurement of ac quantities.

9. (a) Draw the circuit diagram, indicating clearly the correct polarity of the electrical supplies, for a *pnp* junction transistor connected in common-emitter mode.

   (b) Draw the circuit diagram, indicating clearly the direction of current through the load, for four silicon diodes connected in a bridge configuration to produce fullwave rectification of current in a resistive load.

10. Sketch and describe a pneumatic diaphragm operated control valve, and clearly label and describe each part.

    Explain what is meant by 'Fail Open' and 'Fail Closed'.

11. Describe fully how you would carry out a calibration test on a Bourdon pressure gauge.

    Sketch a typical calibration curve and comment on possible errors and methods of correction.

12 Describe, with the aid of a clearly labelled diagram, the operation of a direct acting pneumatic relay.

   State, within a measuring system, where such a device is usually used and give the reason for its use.

13. Explain, with the aid of sketches:

    (a) an electrical method,

    (b) a non-electrical method, of measuring fluid flow, listing advantages and disadvantages of each method.

14. What is meant by the term 'system response'? Give three examples of system response.

    How is the 'time constant' or 'system lag' measured?

    ... the time constant of that system?

15. Explain carefully, with the aid of a clearly labelled diagram, the principles of operation of either (i) a motion balance transmitter, or (ii) a force balance transmitter.

    Give two examples where either (i) or (ii) may be found in marine practice.

16. Using U-tube manometer diagrams, explain how the following are measured:

    (a) absolute pressure,

    (b) gauge pressure,

    (c) differential pressure.

    Explain briefly how one such measurement may be transmitted to a remote recording station.

17. Explain, with the aid of sketches, the principle of operation of a nozzle-flapper system. Show graphically the relation between flapper clearance and output pressure. What reasons are there for fitting a feedback bellows in the system?

18. Sketch and describe a strain gauge. What is the principle of operation and for what purpose can the strain gauge be utilised?

19. Describe what is meant by ramp, step and sinusoidal response when applied to a system. Illustrate each with a simple sketch.

20. Sketch a purge or 'bubbler' system which could be used to measure the level of fluid in a tank.

    What other information regarding the fluid would be necessary in order to infer a mass measurement from a level measurement? How could such an instrument be developed to measure the draught of a ship?

21. (a) Draw a circuit diagram to show how junction diodes may be used to give fullwave rectification from a single-phase ac supply.

    (b) A *npn* transistor is to be connected in common emitter mode for use in voltage amplification. Draw a simple circuit diagram to illustrate the configuration.

22. Give an example of level measurements which utilise the following physical principles:

    (a) hydrostatic head,

    (b) float movement,

    (c) displacement.

    Illustrate your answers with suitable diagrams and descriptive data.

23. Change of fluid level in a tank can be detected and measured by the change of capacitance of a capacitance probe. Sketch such a system and describe its operation in detail, from change in level to change in indication of measured level

24. Make a clearly labelled circuit diagram of a 'bridge' thermometer which has ambient temperature compensation, and also has provision for 'zero or standardising' selection.

Explain the operating sequence followed to make the zero/standardising test before using the thermometer. Describe how the ambient temperature compensation functions.

HNC (BTEC and SCOTVEC)

1. Describe, with the aid of a suitable diagram, the constructional details and operational working principle of one of the following devices:
   (a) oil mist detector,
   (b) torsionmeter,
   (c) oxygen analyser.
2. Draw a diagram of a system for fully automatic main engine jacket temperature control, incorporating steam preheating of the coolant, utilising split range control.

   Comment on the type of control action to be used and the 'fail safe' arrangement adopted.
3. (a) Construct a 'truth table' for a two input NOR logic gate.
   (b) Sketch the circuit symbols for a *pnp* and *npn* transistor and clearly label the leads.
   (c) Draw a block diagram for part of a marine data logger and describe in detail the function of one particular block unit.
4. Automatic control valves are available with the following features:
   (a) linear or equal percentage characteristic,
   (b) power to open or power to close,
   (c) single or double seated.

   Discuss the factors that determine the choice of each of the above features.
5. Make a diagrammatic sketch of a three-term controller suitable for use in a feed water control system. The sketch should include measure and regulating units.

   Briefly explain why it is necessary to incorporate: (i) a negative feedback arrangement, (ii) a relay (amplifier).
6. (a) State three advantages which solid state devices have compared to thermionic valves.

   (b) State the function of the gate in a transistor. Sketch waveforms of ac supply voltage, load voltage and gate pulse for a thyristor when the trigger angle is 90°.
7. Make a diagrammatic sketch of a steam flow plant incorporating a flowmeter utilising an orifice plate and a differential pressure transmitter.

   Explain the operating principle of the transmitter.

   Sketch the output signal graph with and without square root extraction.
8. Explain the meaning of the following terms used in control terminology:
   (a) offset,
   (b) fail safe,
   (c) proportional band,
   (d) derivative action time,
   (e) cascade control.
9. Explain, with the aid of a diagram, a controller utilising proportional plus integral action.

   Describe how such a controller is 'tuned' within a system.
10. A boiler pressure is to be maintained at 5 bar by a pneumatic proportional controller. The pressure element has a range from 3 bar to 6 bar and the proportional band is set at 20%.
    (a) Calculate maximum and minimum pressures corresponding to no load and to full load (5.3 bar, 4.7 bar).
    (b) If the controller output pressure range is from 1.2 bar to 2.0 bar, draw a graph of boiler pressure and controller output pressure, and from the graph determine the boiler pressure at a controller output pressure of 1·44 bar. (5·16 bar).
11. (a) Sketch typical forward and reverse characteristics for a zener diode and briefly explain the action of this device when a reverse voltage is applied to it.
    (b) State one application of the zener diode in marine equipment.
    (c) A 10V, 500 mW zener diode used as a voltage stabiliser is supplied at 40 V through a series resistor of 500 Ω. If the load voltage is stable for diode currents greater than 5 mA, draw the circuit diagram and calculate: (i) the maximum and minimum load current for stable operations (55 mA, 10 mA); (ii) the minimum power rating of the series resistor (1800 mW).
12. Describe, with the aid of sketches, the construction and operational features of one of the following devices:
    (a) a buoyancy tube liquid level transmitter,
    (b) a pneumatic differential pressure transmitter

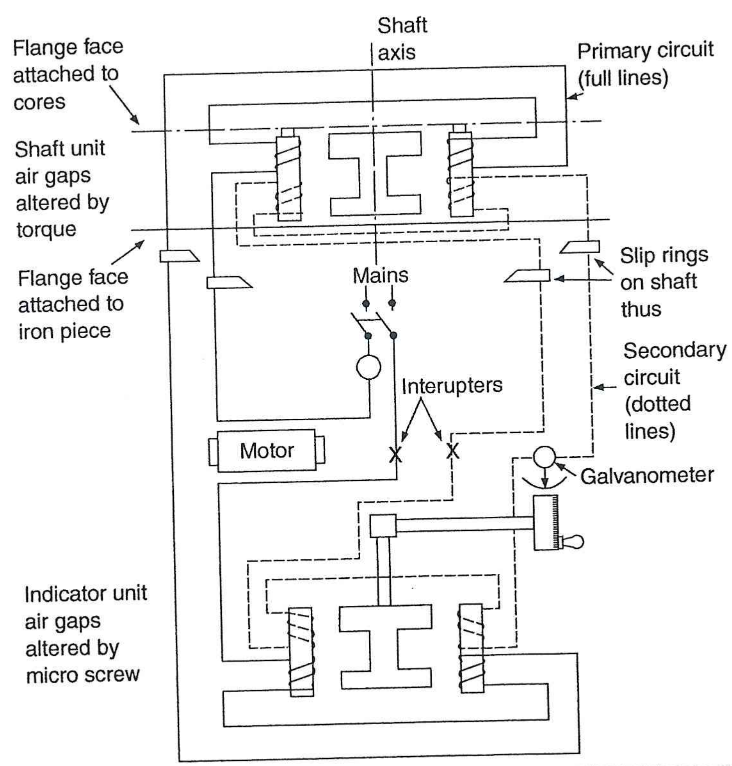
13. With the aid of simple diagrams illustrate the response of a proportional controller, when the system is subject to a load change if:

(i) the proportional band is too narrow, (ii) the proportional band is too wide, (iii) the proportional band is at the optimum setting. Briefly describe why a relay valve is used with such a controller and state what secondary function relay valves usually perform.

14. An electric torsionmeter, shown in Figure G is fitted to the output shaft of a marine engine.

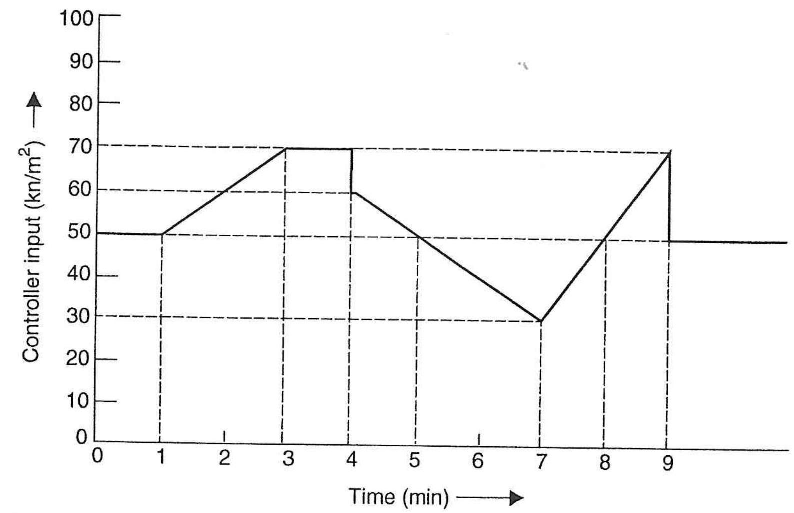
(a) With the aid of this diagram explain in detail the principle of operation.

(b) Explain how the instrument would be used to determine the output power using the appropriate formula. Detail carefully how shaft constants are obtained.



▲ **Figure G**

15. Sketch a thyristor speed control system for a dc motor. Discuss briefly how the system will respond to an increase in the speed set point potentiometer and explain the motor protection features included in the system.



▲ **Figure H**

(a) Construct a diagram showing the variation in controller output due to:

(i) proportional action,

(ii) integral action,

(iii) combined (total output).

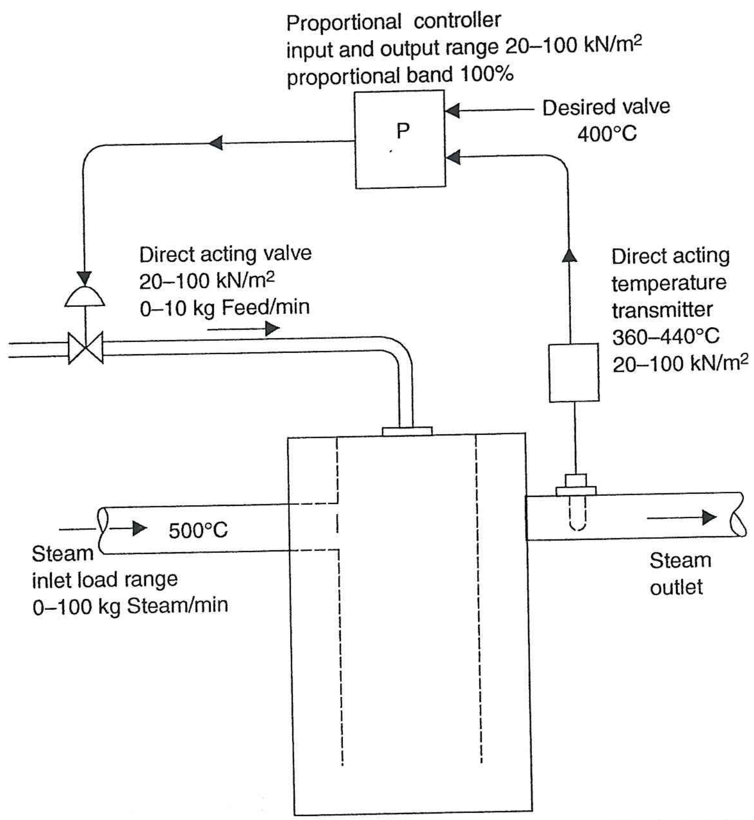
(b) State whether the diagram constructed indicates that the load on the plant has been restored to the original value after the disturbance and give a brief reason for your answer. Proportional band 80%, integral action time 120 s, controller output before disturbance 70 kN/m² ($K = 1.25$ then use a tabular method; at 3 min, for example, using $V = K_1(\theta + K_2/K_1 \int \theta\, dt)$ the total change in controller output is -37.5, that is, $-37.5 = -1.25\left(20 + \frac{1}{2}\times 20\right)$. Controller output is not restored to its original value so neither is the load).

17. Figure I shows the arrangement of a spray-type of attemperator in which the outlet steam temperature is controlled by varying the amount of feed water injected (1 kg feed is required to attemperate 10 kg of steam).

Assuming that the system has been adjusted so that the measured variable (outlet steam temperature) is at the desired value when the load is 40 kg of steam per minute determine:

(i) the offset if the load changes to 20 kg/min (–16°C),

(ii) the limits of load that can be accommodated, assuming that the offset shall not



▲ **Figure I**

18. (a) Sketch, and state, the type of logic gate which obeys the following:

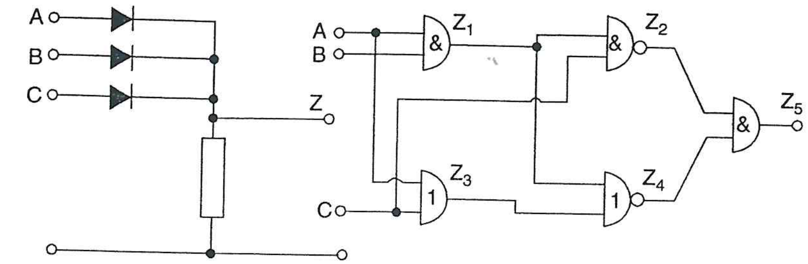
'If all inputs are one the output is zero; for all other combinations the output is one.' (NAND).

(b) Figure J (left-hand sketch) shows the circuit of an electrical logic gate. By inspection or otherwise, state what type of gate the circuit represents and write down the equation for the output at Z (OR, A + B + C).

(c) Construct a truth table for the logic circuit shown in Figure J (right-hand sketch) and give the outputs at Z from each logic unit (e.g. ABC conditions 011, outputs 01100).

19. (a) Draw a fully labelled diagram of a pneumatic temperature transmitter operated by a liquid or gas filled sensor.

(b) Describe the operation of the transmitter in response to a temperature increase, making particular reference to the need for, and operation of, negative



▲ **Figure J**

20. (a) Define, and illustrate with simple diagrams, the following:

(i) distance–velocity lag, (ii) transfer lag, (iii) potential correction.

(b) Define, and state the mathematical representation of the following modes of control: (i) proportional, (ii) integral.

21. (a) Draw a system for the automatic control of main turbine engine gland steam pressure. The system is to use two control valves, one make up and one rejection operating on an equal split range with 4 kN/m² underlap in the signal.

(b) State or show on the system drawing:

(i) the control valve actions and fail safes, (ii) the operating signal range for each valve, (iii) the reason for underlap in the signal.

(c) Describe clearly the actions throughout the control loop as the gland steam pressure rises.

22. An oil–water separator is fitted with two Teflon-coated capacitance probes, each with separate measuring bridge and output:

(i) an oil depth probe vertically, to operate the oil discharge valve, (ii) an interface probe horizontally, to operate an alarm and oil bilge pump trip.

(a) Sketch the arrangement and explain clearly in terms of capacitance change the operation of each probe as oil level varies.

(b) If the separator is completely empty all alarm conditions will operate when starting up. Explain the reason for this.

23. In a calibration check on a *P* + *D* controller the ramp input is increased linearly at 1% per minute. This produces an immediate 4% step change in output, after which the output changes linearly at 2% per minute.

(a) Sketch input and output characteristics and determine: (i) derivative action time (2 min), (ii) proportional band. (50%).

A step change of 6% is applied to the input of a $P + I$ controller and the output undergoes a sudden step change of 4% and after a time interval of 2 min the total output change is 10%.

(b) Sketch input and output characteristics for this calibration test and determine:

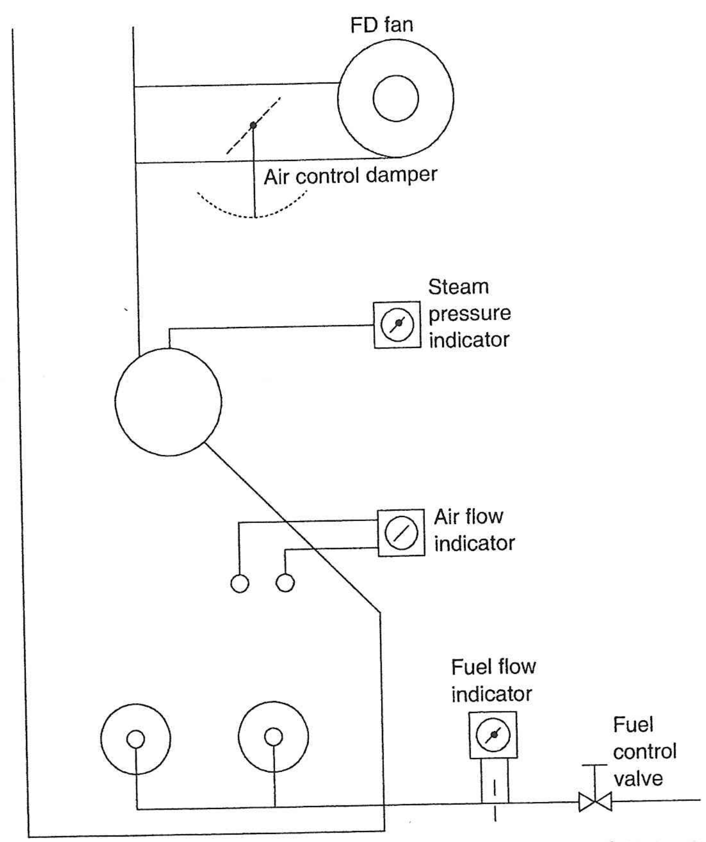
(i) proportional band, (150%), (ii) integral action time (1.333 min).

(c) Define the terms distance–velocity lag and exponential lag.

24. Figure K shows a boiler arranged for manual control of the drum steam pressure.

(a) Complete the diagram by adding the necessary components and connections to convert to an automatic closed-loop combustion control system.

(b) Describe the operation of the automatic system.



▲ Figure K

HND (BTEC and SCOTVEC)

1. With the aid of a sketch describe a type of controller which incorporates proportional, integral and derivative actions. Explain clearly how each action is generated and comment briefly on possible interaction that may occur.

2. Sketch circuit diagrams of resistance–capacitance networks which will provide an output signal that approximates to:

(a) proportional plus derivative of input signal,

(b) proportional plus integral of input signal.

Show, in each case, how these networks could be incorporated into a closed-loop control system so as to improve the operating performance of the system.

3. For a closed-loop position control system:

(a) make a sketch to illustrate how the components are connected,

(b) describe the sequence of events following movement of the input shaft,

(c) explain the term 'overshoot' in relation to such a system,

(d) describe how damping feedback could be incorporated.

4. (a) Define the terms proportional and integral action.

(b) Sketch the open-loop characteristic response for proportional and integral action when a step input change is applied in each case.

(c) Calculate the integral action time if a step input change of 0.04 bar applied to a pneumatic controller set with a 100% proportional bandwidth gives a response change of 0.2 bar in 3 s (0.75 s).

5. (a) Explain, by means of a block diagram or otherwise, the fundamental principle of a dc chopper amplifier.

(b) Sketch a circuit/block diagram to show how a chopper amplifier is used in an instrument servo-mechanism which records dc potentials by means of a self-balancing potentiometer. Briefly describe the operating principles utilised.

6. (a) Explain by means of a two transistor analogy, or otherwise, how a gate input pulse will cause a transistor to conduct.

(b) A thyristor stack is used to regulate the heating power to a cargo hold in order to provide automatic temperature control. Draw a block diagram to show the basic components for such a control system.

(c) Using switches and a lamp as an example, explain with the aid of simple diagrams what is meant by the following logic terms:

7. With the aid of a diagram describe the construction and operating principle of a valve positioner.

Give three reasons why such a device may be utilised in a control system.

Explain how a positioner may be adjusted to alter the valve stroke from 1.2–1.8 bar to 1.3–2.0 bar and state why gain should be as high as possible.

8. Explain the principles of viscosity measurement and detail the type of instrumentation used.

Sketch an oil viscosity control system and describe the operating principle.

Give reasons for which control actions you would incorporate in the controller.

9. Describe with a block diagram the operational construction of a data logger suitable for marine use.

Clearly indicate the functions of alarm annunciation recording of input signal information, and analogue to digital conversion.

10. (a) Describe the effect of:

(i) positive feedback, (ii) negative feedback, on a closed-loop speed control system.

(b) For voltage at input e_1 output e_0 and error actuating input e to a negative feedback electronic amplifier of forward gain G and negative feedback fraction F, derive the following:

$$\frac{e_0}{e_1} = \frac{G}{1+FG}$$

$$\frac{e}{e_1} = \frac{1}{1+FG}$$

If the 'open loop' gain is infinite, determine F if the overall gain is 25 (0·04).

11. (a) Draw a block diagram of a remote position control servo-mechanism suitable for controlling the angular position of the ship's rudder. Clearly label the inputs and outputs for each block and use them to explain what is meant by proportional control.

(b) Explain with the aid of diagrams why damping needs to be introduced into the system, when a step change of input is applied, and state one method of introducing damping into such a system.

12. (a) Explain the meaning of the following terms, using suitable diagrams where appropriate:

(i) distance–velocity lag,

(iii) time constant,

(iv) thermal capacity.

(b) A thermometer bulb is housed in a pocket. Show by means of a response curve an estimation of the effect of the pocket and state what factors influence the design of the pocket to minimise this effect.

13. (a) Briefly describe why it is desirable to employ a multi-element system in the control of boiler water level.

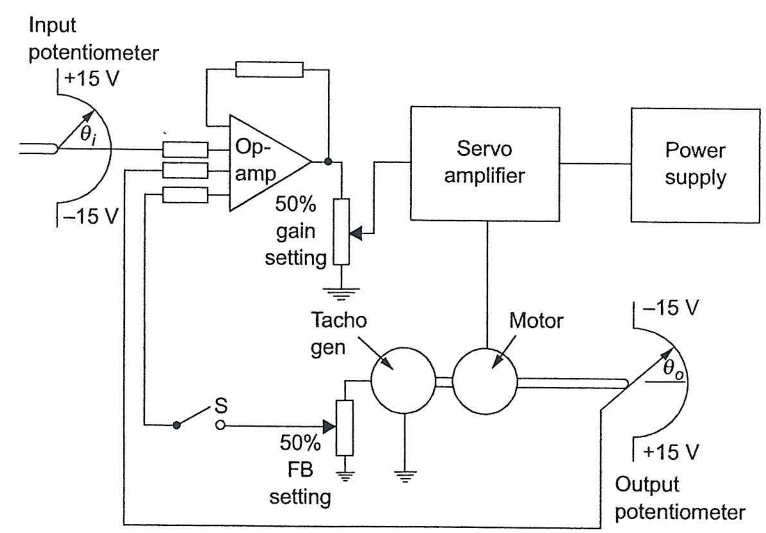
(b) Make a diagrammatic sketch of a three-element boiler water level control system, naming all the parts and giving a brief description of its operation.

(c) Sketch a diagram showing the variations in boiler water level and feed pump load that might be expected if a water tube boiler is subject to a step increase in load, with:

(i) single-element control, (ii) three-element control.

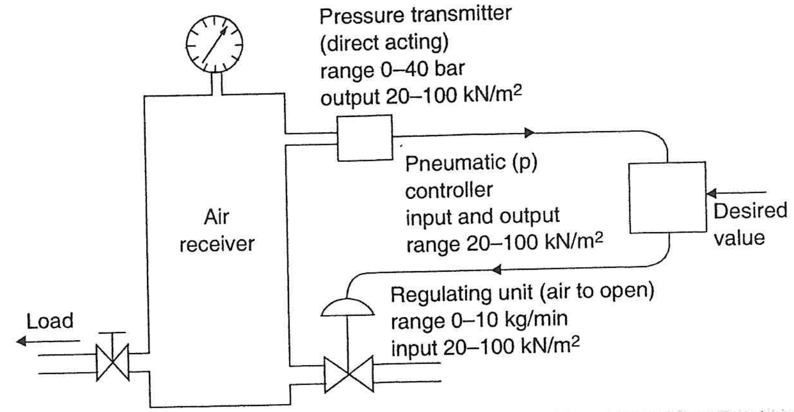
14. (a) Figure L shows the block diagram of a low power remote position control servo system with velocity feedback damping. State the function of each component in the system.

(b) Explain briefly how the system will respond to a step input and sketch the corresponding response curve for: (i) switch S open, (ii) switch S closed.



▲ Figure L

15. The air pressure control system shown in Figure M has been adjusted such that at a load of 6 kg/min the equilibrium value of the controlled condition is at the desired



▲ Figure M

(i) the proportional control factor (μ) of the system if the proportional band of the controller is 50% (0.5),

(ii) the offset if the load changes to 8 kg/min (–4 bar),

(iii) the proportional band setting required such that for a load change from 6 to 2 kg/min the offset is limited to 2 bar (12.5%),

(iv) the smallest load that the system can deal with if the proportional band of the controller is set to 100% (3.5 kg/min),

(v) the proportional band of the controller such that the system can deal with any load within the range 0–10 kg/min (41.7%).

16. (a) Sketch the forward characteristic for a thyristor and indicate clearly:

(i) the hold current level,

(ii) the effect of increasing the gate trigger pulse upon the forward break-over voltage.

(b) State three advantages of a thyristor compared to other types of controlled rectifier.

(c) Figure N shows the circuit of an ac controller:

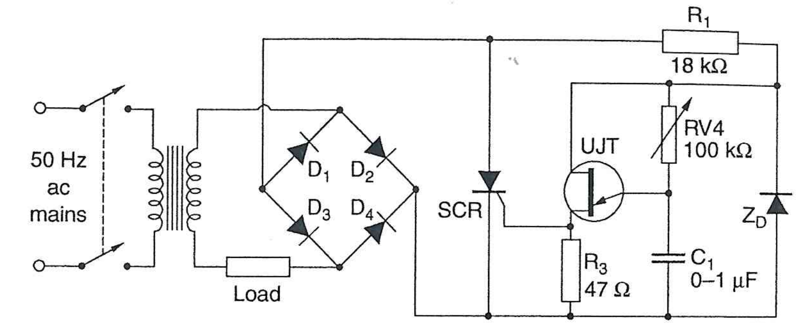
(i) explain briefly how the power in the load is controlled,

(ii) sketch the waveforms of load voltage and gate pulse for half maximum load power.

17. (a) Define the following terms: (i) integral action, (ii) derivative action.

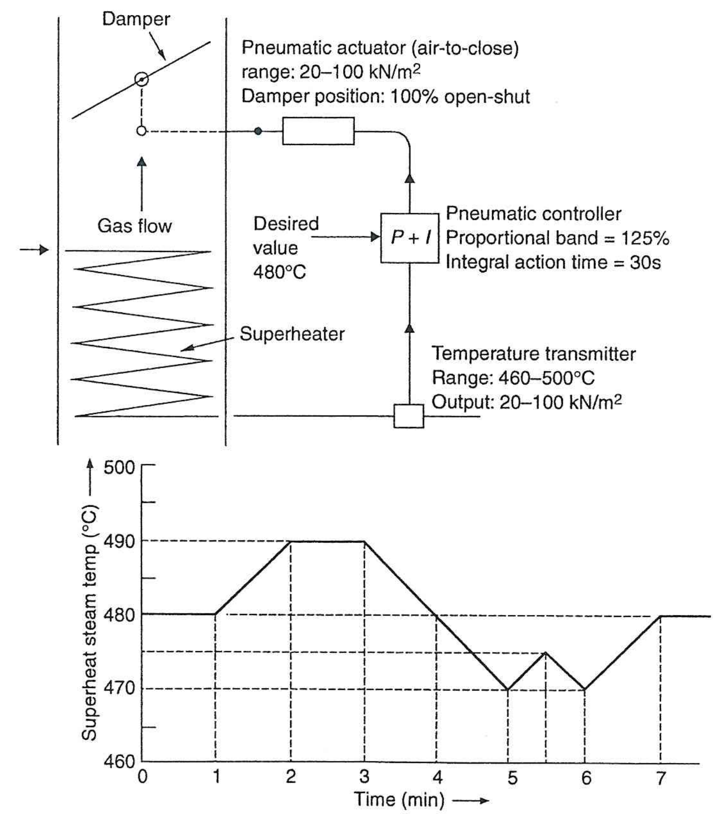
(b) With the aid of suitable diagrams derive expressions for:

(i) integral action in terms of controller gain and integral action time,



▲ Figure N

18. Figure O shows the arrangement of a damper position control system for a boiler employing damper control of the final steam temperature, and the variation in steam temperature, during a transient condition. Draw an accurate diagram showing the damper position during the same transient period. The damper may be assumed to be in the 60% open position immediately before the transient condition



commences. (System proportional control factor μ = multiple of proportionality characteristics, coefficients, that is, $2 = 2 \times 0.8 \times 1.25$ then use a tabular method; at 2 min, for example, using $\Phi = -\mu(\theta + I/S \int \theta \, dt)$ the damper is 20% open, that is, $-40 = -2(10 + 1/0.5 \times 5)$. Damper is closed between 2.5 and 5 min).

19. (a) Draw a detailed diagram of an instrument suitable for converting electrical control signals into pneumatic signals.

(b) Explain clearly the operation throughout the instrument in response to an increased input signal.

(c) Discuss briefly the relative advantages of electro-pneumatic control.

20. (a) Draw the circuit for a two input diode-transistor logic OR gate suitable for operating an alarm system. Construct the truth table and describe the operation of the gate.

(b) Construct a logic flow diagram for a soot-blowing system which incorporates:

(i) a warming through period,

(ii) retractable blowers which blow in each direction,

(iii) provision to bypass selected blowers,

(iv) suitable operation checks.

Show the details for one blower only and draw a block diagram for the others.

21. (a) Sketch a fully labelled diagram of a two-element superheated steam temperature control system which uses a three-term controller and two control valves, a steam to attemperator and an attemperator bypass valve.

(b) Explain the reason for using two-element control in this system and describe the actions throughout the loop following a load increase.

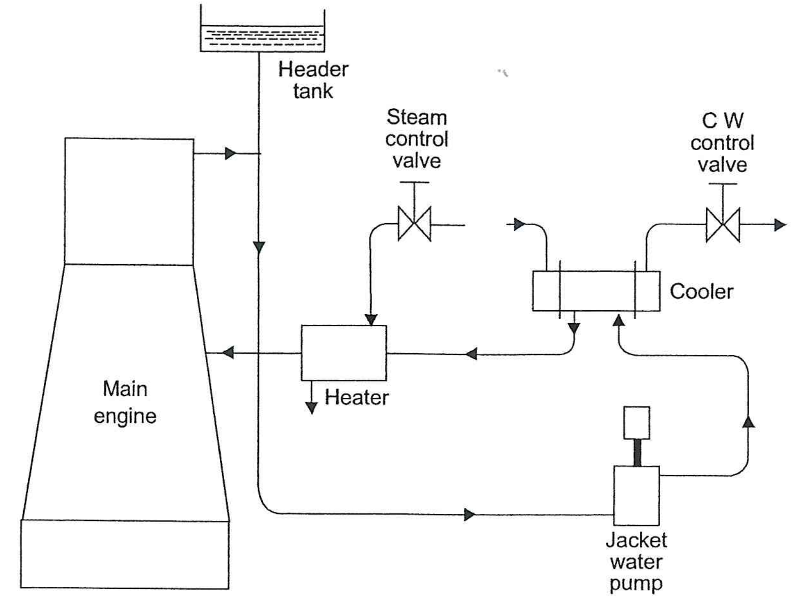
(c) State the reasons for using integral and derivative terms in the controller.

22. Show in block diagram form the basic requirement for a bridge control system for a main diesel engine. The control programme unit may be shown as a block.

Briefly describe the sequence of events throughout the system following movement of the bridge telegraph from stop to full ahead. What emergency arrangements must be incorporated in the system and fitted on the bridge?

23. Figure P shows the main components of a jacket cooling water system for a marine diesel engine, outlet temperature is controlled condition.

(a) Assuming that it has been decided to modify the system to provide a split level, two element, cascade closed-loop pneumatic control system, complete the diagram naming clearly all the additional components required.



▲ **Figure P**

(b) Describe the operation of the modified system giving typical operating ranges and stating clearly the modes of action employed, for example, direct acting proportional.

(c) Describe the effects on the system of:

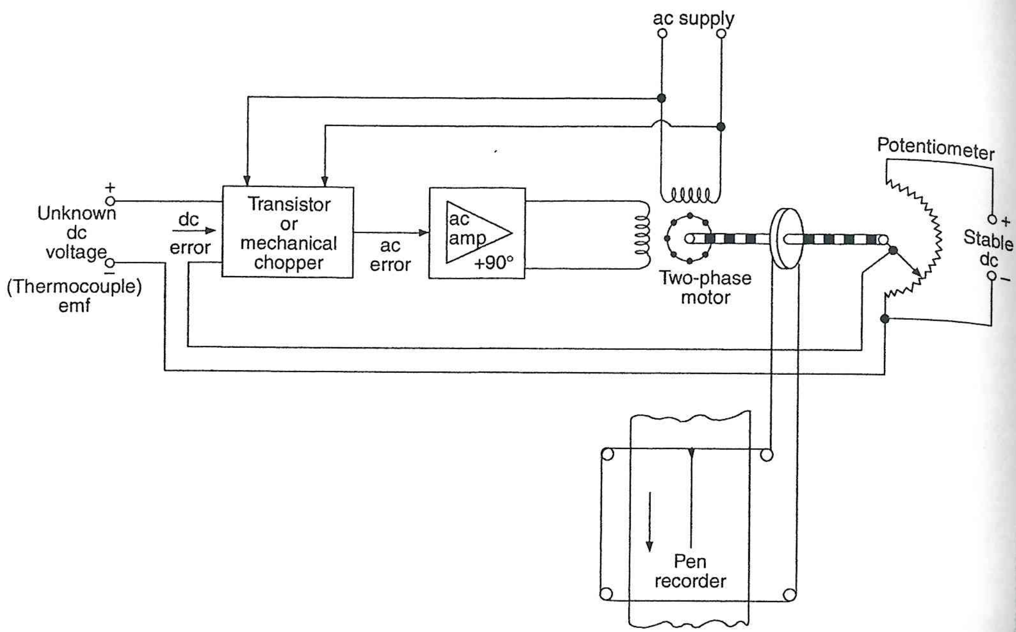
(i) an increase in sea water temperature,

(ii) a decrease in engine load.

24. (a) Figure Q shows the elements of an instrument servo–self balancing potentiometer – used to record the temperature of a thermocouple by means of a self balancing potentiometer. Discuss briefly how the instrument will respond to an increase in the thermocouple temperature.

(b) Give two reasons why transistors may be preferred to an electro-mechanical chopper for the input stage.

(c) Sketch the circuit for a simple transistor chopper and briefly describe its operation.



▲ **Figure Q**

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