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Centralized and Automatic Controls in Ships

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Centralized and Automatic Controls in Ships

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Contents

Foreword

This book is intended to provide a non-mathematical basic introduction to the subject of control engineering applied in the marine field. The aim is to assist students of marine engineering in the basic principles of the equipment they will be called upon to operate in modern ships.

Most of the subject matter has been published in papers which are widely scattered. In addition the author wishes to acknowledge the help he has received from information provided or published by the following firms:

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It is hoped that the collection and correlation of enough of the available information to give a basic understanding of the subject will have rendered some assistance to the student.

Editor's Preface

Centralized and Automatic Controls in Ships is the first book published on marine control engineering. It is specifically written in clear and concise language for seagoing engineers who will find the text a pleasure to read.

Although the approach is non-mathematical this work is far more than an introduction since it covers pneumatic, electrical and hydraulic methods of control including the various types of control action.

Sections on logic units and data processing equipment have been included. The later chapters illustrate how control techniques may be applied to the major areas of the modern ship's machinery.

The author treats the subject in breadth, embracing ship systems, ship construction and the commissioning routine for certain automated plant. This together with profuse detail should make selected chapters a suitable basis for course syllabuses at more than one level.

This book will be helpful to all marine engineers and essential to the younger generation.

A. J. S. B.

CHAPTER 1

Introduction

1.1. AUTOMATION

To the layman, largely guided by the popular press, "automation" appears as a startling modern invention which will lead to the wholesale establishment of automatic factories and the building of automatic ships. To the engineer automation is merely a contemporary phase in the process of technical evolution that has gone on continuously since the first crude machines. The engineer's aim has always been to make the best use of machines, materials and money. The answer, of course, does not lie in the mass installation of "black boxes", electronic or otherwise. It lies in the ingenuity and breadth of vision of the people involved in designing the control system.

Automation has been, and is still, a greatly misused word but its proper meaning and, therefore, its implications, is gradually becoming better understood. It is a concept through which a machine system is caused to operate with maximum efficiency by means of adequate measurement, observation and control. It involves a detailed and continuous knowledge of the functioning of the system so that the best corrective actions can be applied as soon as they become necessary. Thus automation should produce the optimum result. Unfortunately the word has gathered many wrong and half-wrong associations all of which imply mechanization, which in turn implies unthinking repetitive motion and this is the exact opposite of automation.

Instead of using the word automation it is better to talk of automatic control or to use the word cybernation, the theory of communications and control.

The primary aims of automatic control are to reduce the inefficiencies inevitably associated with human machine minding. A complete elimination of human judgement is quite impracticable. However highly developed an automatic system may become the skill and experience of the trained operator will still be essential.

Countless mechanical devices can be named which, to some extent, work themselves. For instance, a hoist can be made to stop at the end of its travel; an electric furnace or the domestic oven can be made to switch on when the interior temperature drops below a certain pre-set value. In certain conditions such devices possess varying degrees of "intelligence" in so far as they automatically do what is required. They do not, however, embody fully automatic control in that they cannot control the whole process from information derived from the end product. Very few control systems at present approach the ideal of being fully automatic.

1.2. AUTOMATIC CONTROL

An automatic control system is defined in the glossary of British Standard 1523 as one "in which the value of a controlled condition . . . is compared with a desired value and corrective action is taken dependent on the deviation, without the inclusion of a human element in the closed loop formed by the comparing and correcting chains of elements".

An automatic control system thus includes:

(a) the plant,
(b) the detecting or sensing element,
(c) the measuring or indicating element,
(d) the controller.

The difference between manual control (whether local or remote) and automatic control is shown in Fig. 1.1.

With hand control, or open-loop control, an instrument connected to the plant gives what is known as feedback of information, but this feedback initiates nothing on its own. Corrective action is left to the human operator.

Closed-loop control represents an automatic process. The information fed back from the sensing device via the indicator is made to energize the controller so bringing about the necessary corrective action. Such a closed loop is often referred to as a servo mechanism, i.e. an automatic closed-loop system controlled by feedback of information. In the same context it is as well to note that the term "servo motor" (derived from the French language and literally meaning "slave motor") is often used very loosely but it is really the final control element in a servo mechanism. It is the motor which receives the output from the amplifier and which drives the load. It

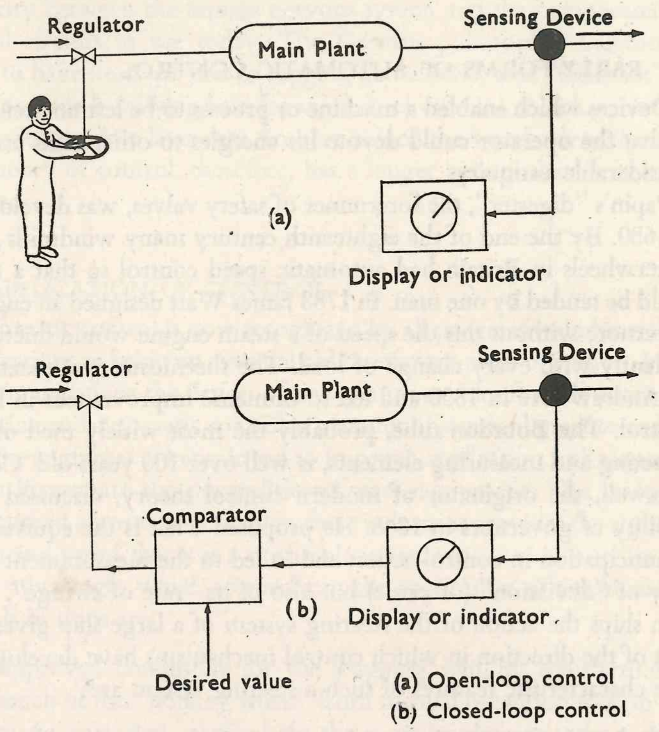


FIG. 1.1. Schematic diagram of open-loop and closed-loop controls.

must be emphasized that the term servo motor can describe a motor which produces linear motion as well as a motor which produces rotary motion. An example of a linear motor could be an ordinary hydraulic ram.

1.3. EARLY FORMS OF AUTOMATIC CONTROL

Devices which enabled a machine or process to be left unattended so that the operator could devote his energies to other tasks are of considerable antiquity.

Papin's "digester", the forerunner of safety valves, was developed in 1680. By the end of the eighteenth century many windmills and waterwheels in Britain had automatic speed control so that a mill could be tended by one man. In 1788 James Watt designed an engine governor; without this the speed of a steam engine would fluctuate violently with every change of load. The thermostat was patented by Andrew Ure in 1830 and led to immense improvement in heat control. The Bourdon tube, probably the most widely used of all detecting and measuring elements, is well over 100 years old. Clerk Maxwell, the originator of modern control theory, discussed the stability of governors in 1868. He proposed what is the equivalent of anticipation in control action and so led to the measurement not only of "deviation" (or error) but also of its "rate of change".

In ships the action of the steering system of a large ship gives an idea of the direction in which control mechanisms have developed. The characteristic features of such a steering system are:

(a) the considerable distance between helmsman and rudder;
(b) the amplification of a light touch at the wheel into the great torque (up to 1000 tons feet) required to move the rudder, which may weigh up to 30 tons, against the forces of the ship and sea;
(c) the position feedback which indicates on the bridge the exact position of the rudder;
(d) the final closing of the loop in the shape of the automatic pilot. This is a classic example of automatic control.

1.4. CYBERNETICS

The study of the theory of communications and control, or "cybernetics" (from a Greek word meaning steersman), has been greatly extended in recent years. It has illuminated many points of similarity between the human nervous system and the complicated control circuits in use today. The German philosopher Leibnitz seems to have been the first to suggest, about 1680, that "feedback" could provide a unifying base for work in economics, sociology and other sciences. At a later date Ampère coined the word *cybernétique*. The theory of control, therefore, has a longer history than is often assumed.

1.5. APPLICATION OF CONTROL

Automatic control is now recognized by all progressive industrial organizations as being an essential aid to efficient plant operation. In most organizations the design of new plant provides for full instrumentation and automatic control as a matter of standard practice and specialist engineers are employed to improve application techniques and to investigate the possibilities of new equipment. The widespread use of automatic control in these industries provides the most convincing proof that it is a profitable investment.

The advantages which accrue from the application of automatic controls in ships are:

(a) Improved conditions for the seagoing staff by transferring much of the "donkey work" from manual operation to automatic operation, particularly the more unpleasant tasks such as soot blowing, cleaning of oil purifiers, etc.
(b) Savings due to more efficient use of seagoing staff by transfer from watchkeeping to day work; routine maintenance can be carried out more efficiently by a day worker.
(c) Possible increase in the availability of the ship due to improved degree of operation and maintenance.
(d) Saving in maintenance costs due to improvement in efficiency of the machinery.

(e) Possible fuel cost saving due to improvement in efficiency of operation of the machinery.

However, before embarking on the design of control systems it is necessary to obtain a clear understanding of the nature of the process of executing control, and this applies whether control is exercised automatically or by men.

The basic task is, of course, measurement of the controlled variable followed by the interpretation of any departure from the "desired value". This leads to a decision whether a correction should be applied or not. If the decision is to make a correction then a computation must be made to determine the sense and degree of correction. In the process of restoring a specified operating condition the whole sequence is repeated until restoration of the controlled variable is complete.

With a man in control and taking over a strange job the one function that he cannot exercise accurately at first is the computation of the correction to be applied. This latter is usually a process of learning, often by trial and error. In fact the information which he has to collect is related entirely to the dynamic behaviour of the parts of the plant which he is trying to control and especially to the differences in dynamic behaviour of two or more associated units, e.g. fuel pump and F.D. blower.

In the case of automatic control the instrument settings and further settings which are required to achieve correct computation are not easily established since they depend on measurement of the actual dynamic characteristics of the function being controlled. These must be predicted or established experimentally if simple and accurate control is to be achieved.

This reveals a major point in design philosophy, namely, that skill in control engineering theory is of little value unless it is accompanied by a sufficient understanding of the plant itself both as regards its dynamic characteristics and the methods which are to be used in operating it. To achieve success it is essential to appreciate that the machinery and the controls cannot be considered as separate entities but that both are entirely interdependent.

In the following chapters it will be seen how necessary it is that the design philosophy should be based on systems rather than individual plant items. In the marine field the system to be considered is the complete ship as an integrated unit. From this it follows that no one man can assume responsibility for the system of controls in a ship. All the fields of activity involved in the operation and building of ships must co-operate and the most important of these are shipowning management, naval architecture, machinery design, control engineering and shipbuilding.

CHAPTER 2

Ship Construction

Considerations of hull design frequently result in the overhaul of marine machinery having to be carried out in more difficult conditions and so, at greater cost, than in an equivalent shore installation.

Engine room maintenance costs are influenced by the engine room layout in relation to layout of pipe runs, siting of spare parts, siting of crane rails, chain blocks, hoists, uptakes, platforms and fans. The naval architect naturally wishes to cut down engine room length so as to provide maximum cargo space in a given hull but increased earning capacity may be expensive if it results in a restricted and inaccessible engine room with resultant high maintenance costs. It is probable that in future ships more attention than hitherto will be given to designing engine rooms giving maximum accessibility even if this involves some loss of cargo space or, alternatively, a larger and more expensive hull.

Other areas which deserve attention are:

The elimination of all materials in the accommodation which require painting, polishing or hand cleaning.

Design of accommodation areas and furniture to facilitate the use of mechanized cleaning.

Air conditioning can result in reduced maintenance particularly in ships designed to operate in the tropics.

Improved manœuvrability during berthing and unberthing operations by the installation of a side thruster or active rudder.

Mechanized operation of the gangway.

Power assisted hatch closing and opening systems.

Automatic tensioning winches for mooring purposes.

CHAPTER 3

Main Machinery

Before considering the ship's main machinery it might be as well to consider the application of automation in the electricity generating stations ashore. It is now quite practicable for the small hydro-electric set or the diesel or gas turbine generator to be started up, synchronized and brought on load under automatic control from some remote point. The primary reason for so doing is that the station may be left unattended.

Automatic control of the large generating sets in a modern station is required for quite a different reason. The boiler, turbine and alternator, with their associated auxiliaries, form a self-contained unit of considerable complexity and complicated analogue or digital control systems are essential if operation is to be safe and efficient, especially under transient conditions. Improved safety can come from relieving the operator of routine supervisory duties. With suitable instrumentation and data processing equipment it is possible to provide a more comprehensive check on operating conditions, including not only the detection of abnormal readings but also the detection of abnormal rates of change. An alarm may thus be given if a dangerous condition is beginning to develop, such as could result from rupture of, or leakage in, high-pressure components.

The marine power plant lies somewhere between these two concepts, i.e. it is unlikely that a shipowner would be prepared to operate his ship unmanned and, at the present time, it is unlikely that any marine power plant requires computer control for safe and efficient operation.

The high cost of ships' repairs has already been mentioned and the necessity for holding these down to the minimum figure. For the machinery this involves both design and layout in relation to ease of access and the handling of items requiring regular overhaul or replacement; it also requires maximum reliability in the main plant plus all associated auxiliaries.

Standardization of main plant items to the greatest possible extent over a range of ratings can provide benefits to both the shipbuilder and the shipowner. Standardizing components and arrangements permits the shipbuilder to utilize duplicate design drawings and patterns for machinery arrangements and piping layout work. It also ensures that machinery arrangement drawings and piping details are available at the earliest possible date. The shipowner benefits in that it reduces the shore-based spares inventory and produces greater familiarization between ships by operating staffs.

It has been the practice with marine designers to arrange the machinery for the most efficient use of the space available, to functionally locate equipment to produce the shortest and simplest pipe and duct runs and to provide, at least, the minimum amount of space around each component necessary for operation and maintenance; always under the assumption that there is someone available nearby to perform the required operation at the required time. Little consideration appears to have been given to operating convenience or the distance a particular operating valve or switch might be from the watch station but this is entirely reasonable when it is assumed that the watch consists of a minimum of three men. This disability is now being removed by the provision of a centralized location from which all engine room functions can be monitored and controlled. Such a concept involves the provision of a monitoring system, a display system and a control system.

Monitoring is effected by sensors and/or transducers, fitted in the main plant, to monitor the variables such as temperature or pressure and produce a signal, proportional to the present state of the variable, the signal then being transmitted to the display system in the central control position. (A thermocouple is an example of a sensor producing an electrical signal from a temperature.)

The display unit may consist of conventional instrumentation, a date logger or a computer or a combination of all three. It may be supported by such items as mimic diagrams, alarm panels and various forms of print-out machinery and data display.

Finally, a control system is necessary so that the necessary movements of valves or switches on the main plant may be effected. Such systems may be electrical, pneumatic, hydraulic or combinations of these. The operation may be manual (open loop) or automatic (closed loop).

Figure 3.1 shows how the engineering plant may be broken down into its various systems and major components. Each must be studied and evaluated in detail to determine the extent of monitoring and control which is necessary. The flow lines show input information entering the central control console and then proceeding to conventional instrument and gauge boards or to data logging equipment or to a control computer.

It must be realized that such a system involves more than merely placing the equipment on board. The various systems and subsystems which are to be controlled must be studied with regard to modification in design so as to accomplish the following:

(i) Provide sensors and/or transducers to permit the monitoring of variables such as temperature, pressure, flow, position and speed.
(ii) Provide actuators to receive control signals to carry out the necessary operations.
(iii) Modification of design of the main machinery to accept the addition of (i) and (ii) above.
(iv) Simplification of existing systems to accommodate the control programme decided upon.

In addition other areas of the ship or plant may require modification, e.g.

(a) The voltage and frequency disturbances normally acceptable in ship's electrical power systems may be too great for the satisfactory operation of the type of control gear associated with centralized or automatic controls. The solution of this problem may be to either install special stabilized power supplies for the control equipment or

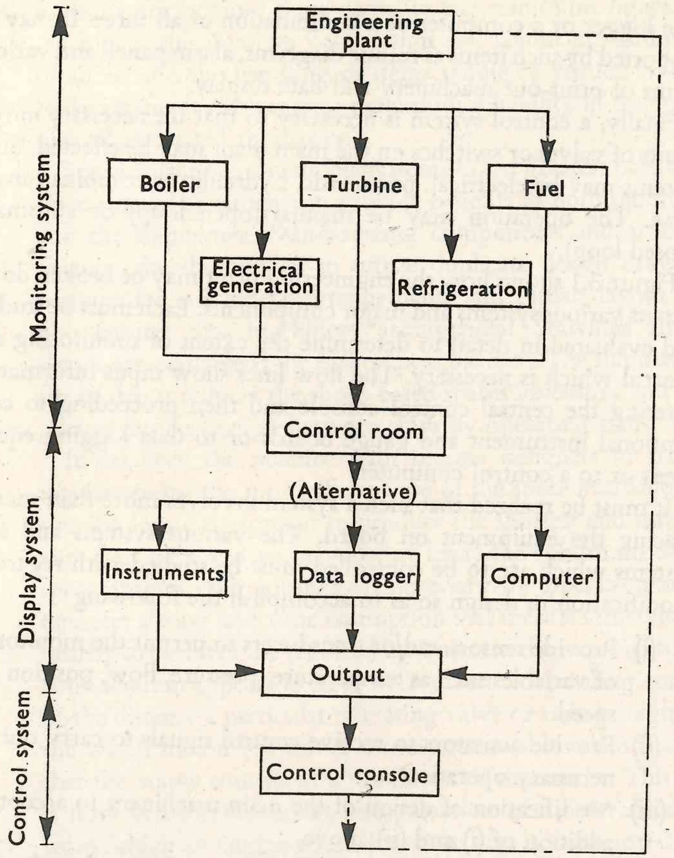


FIG. 3.1. Schematic arrangements of centralized machinery controls.

to tighten up on the tolerances for the ship's main electrical power system. The latter solution would probably only be applicable in warships where the electronic load represents a large proportion of the total electrical load.

(b) The introduction of control valves into main engine cooling systems can lead to increased pressure drops which require increased pumping powers and hence modification to the design.

Many variations of this concept have been produced and are in service, e.g.

(i) Many sub-loops or sub-systems of the machinery have a measure of automatic control applied to them. These include automatic sequential start up and loading of electric generating sets; automatic control of the steam-raising plant.

(ii) Whilst the majority of ships with centralized controls have such controls located in a special control room, some owners do not agree with the fitting of such a room, but install the control consoles in the open machinery space. This concept is based on the thought that the watchkeeper should be in intimate contact with the running machinery.

(iii) Bridge control of the main propulsion machinery is often fitted to relieve the man in the control room, or engine room, from the necessity of remaining at all times at the central control station. The arrangements are not basically altered by this addition since it usually involves merely the extension of the control system from control room to bridge. For bridge control to be completely practicable the operator on the bridge should not be burdened with the need to concern himself with plant operation, and it is usual to fit on the bridge console only those instruments to indicate to the bridge operator whether proper propulsion unit response is being obtained. Complete monitoring of the propulsion plant is reserved for the control room and it is normal for the control room to be able to take control at any time either on request from the bridge or without such request if this should ever be necessary.

CHAPTER 4

Central Control Room

THE normal practice in ships with centralized controls is to locate them in a control room fitted in a position which is of optimum convenience to the operator and giving as much surveillance as practicable of the main machinery, e.g. in the engine room/boiler room bulkhead area and projecting into both compartments.

Double-glazed windows permit visual observation of the machinery. Thermal and acoustic insulation is fitted to walls, deck and deckhead to prevent noise and heat transfer from the machinery spaces. The room is separately ventilated and air conditioned to maintain a control room temperature of between, say, 20°C and 25°C (68°F to 77°F) and a relative humidity of, say, 45 per cent. Air conditioning is essential both for the comfort of the operator and to establish steady ambient conditions for the efficient working of the monitoring and control equipment located in the room.

The console/consoles are usually divided into sections and are laid out for maximum operator convenience.

On the question of operator convenience it is difficult to be precise and the marine designer can learn much from the electrical utility industry, the petro-chemical industry and the steel-making industry where remote-control techniques have been in use for some years. Merely taking all the controls and instruments off each individual machine and transferring them to a panel will not necessarily make plant operation easier. The results of such a policy can be seen in some control rooms where knobs, dials and winking lights abound and where the staff have to be highly trained, dexterous and cool headed to operate the confusing number of controls.

With regard to panel design and display grouping there are some common-sense factors which, if considered in time, will lead to a "comfortable" and, therefore, an efficient layout resulting in fewer operating errors, greater confidence and speed.

(i) Controls should be visually separated from displays, e.g. visual displays in central areas and controls in peripheral areas, or displays on semi-vertical panels and controls on semi-horizontal panels.

(ii) Area or Group Identification. This is important in complex layouts. It can be achieved in many ways, e.g. adequate spacing between display and control groups (horizontal separation is usually better than vertical separation); or marked outlines around each group; or area colour patterns.

(iii) Identification labels should be placed consistently either above or below for a specific category, e.g. group title above and individual labels below. Labels should be in terms of what is measured, e.g. R P M, and not by the name of the instrument, e.g. tachometer.

(iv) Compatibility. There are certain "expected" relationships between control and display movements. Where possible control movements and location should be parallel to the axis of the display motion they affect.

(v) Panels should, as far as possible, be normal to the operator's eye, e.g. not fully vertical and not fully horizontal faces.

(vi) Panels should be of such dimensions that the operator does not have to stretch in order to operate a control or read a display, e.g. 2 ft (60 cm).

(vii) Displays:

(a) Adjacent dials should have similar numbering and scale breakdown.

(b) Scale values should have a logical sequence, e.g. increase from left to right or from bottom to top.

(c) Numbering and lettering should be designed with optimum height/width and stroke/width ratios for the viewing distance envisaged. There should be optimum contrast between figures and ground.

(d) Scales that are non-linear or those requiring elaborate interpolation should be avoided wherever possible.

(e) The colours chosen for differentiation of operating conditions should be readily distinguishable and identifiable. The use of too many colours should be avoided.

(viii) Controls:

(a) Control levers or handles should be easy to grasp and manipulate and extreme torque requirements should be avoided.

(b) Control movements should be in a logical direction, e.g. clockwise movements to produce an increase and anticlockwise movements to produce a decrease; with lever controls a forward motion for an increase and a backward motion for a decrease, or a similar logical sequence.

(c) Controls should be readily identifiable, e.g. by shape or by labels.

(d) The arrangement of controls should be such that a logical sequence of operations can be easily carried out.

(ix) Audible Signals:

(a) Audible signals should be easily distinguishable over the ambient noise level. Essential alarms should be easily distinguishable from non-essential alarms.

(b) The multiplicity of alarms should be avoided.

(c) A means of muting audible alarms should be fitted but operation of this should not extinguish visual alarms.

(x) General:

(a) Removable assemblies should be such that one man may handle and manœuvre them rapidly and safely.

(b) Equipment should be designed so that the maintenance technician may obtain easy access to the interior.

(c) Check points or connecting points should be accessible without the necessity for complete disassembly of equipment.

(d) Components requiring maintenance should be arranged to avoid high voltage, high temperature or other unsafe working areas.

(e) Hydraulic control systems should not be brought into the same panels (or, preferably, should not be brought into the same room) as pneumatic or electrical control systems.

(xi) Full-scale mock-ups, made from slotted angle and hardboard, are a distinct advantage at the design stage, and facilitate the location of instruments and controls for maximum operator convenience. These can be simulated from stick-on labels. Less than full-scale mock-ups are of very doubtful advantage.

In those ships where the control console is placed in the open machinery space it is current practice to fit a canopy, lined with thermal and acoustic insulation, over the console in an attempt to reduce noise and heat transfer; also to arrange a separate ventilating system for the console using a filtered air supply or to use local air-conditioning units for the consoles.

Some design studies have been carried out to consider placing the control room in the navigating bridge area and providing ready access to the machinery spaces, e.g. by lift or elevator, for regular tours of inspection. Whilst this is a distinct possibility for the future, and indeed may be practicable for certain short-haul vessels at the present time, it is probable that the reliability of control systems, in marine conditions, will need to be proved before this concept is applied to deep-sea vessels.

CHAPTER 5

The Monitoring System

5.1. SENSING DEVICES

In any integrated control system the sensing devices form the first link in a chain of control equipment—they observe what is happening—they take note of plant variables such as temperature, pressure, flow, etc.; they act as inspectors noting deviations from the specified value. Some of them are substitutes for the human senses—feeling, sight, hearing, taste and smell—while others have "extra sensory" characteristics beyond direct human perception, such as moisture measurement, chemical analysis and so on.

Before a variable in a process can be controlled it must first be measured. Measurement can be achieved in one of two ways; either some physical property of a sensing device can be utilized directly or, alternatively, comparison made with a known but adjustable quantity of the same nature, in which case the process of measurement involves the accurate assessment of equality between the two quantities.

Obvious examples of the first method are the thermometer, tachometer and barometer. Examples of the latter method are the measuring rule, micrometer, potentiometer and scale balance.

In the first type of instrument, change in the quantity being measured, for example temperature, speed or pressure, alters in some way a physical characteristic of the sensing device, such alteration being utilized to actuate directly an indicating or recording device.

In the second type of instrument, the sensing device is not called upon to provide direct indication of its condition; the work needed

to do this is provided either by manual adjustment or automatic adjustment of a comparison generator.

Figure 5.1 illustrates the essential components of this latter system; both the sensing device and the indicator provide signals to a sensitive balance detector; this detector, which can be arranged to provide negligible load on the sensing device, controls the magnitude of the comparison signal and, at the same time, the setting of the indicator.

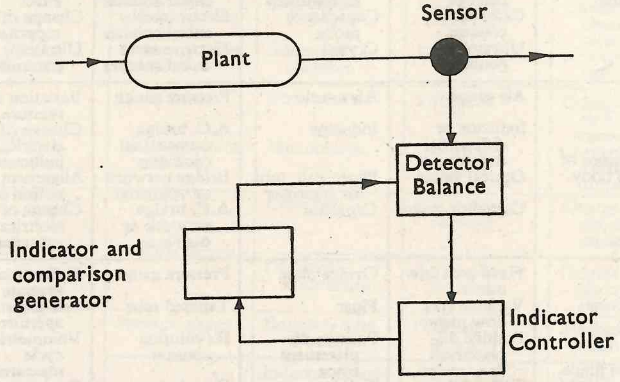


Fig. 5.1. Components of a measuring system.

The types of sensing devices in use today are legion—it would be quite impracticable even to list them all. Table 5.1 lists the more important quantities which can now be "sensed" with, in each case, a brief description of the type of instrument and sensing device, together with the measuring and/or indicating device normally used and the method of operation.

5.1(a). REQUIREMENTS OF SENSING DEVICES

All measuring devices aim at answering one of the following questions:

(i) Yes or No?

For example, is the particular variable less than a certain value? Is something present in its correct position?

TABLE 5.1. Some Types of Sensors.

Quantity sensed	Type of instrument	Sensing device	Measuring and/or indicating device	Method of operation
Acidity, Alkalinity	*p*H meter	Glass electrode	Electro-meter	Ionic diffusion
Counting	Mechanical counter	Lever or ratchet	Electro-mechanical counter	Mechanical movement
	Photo-electric counter	Photo-cell, tube or transistor	Electro-mechanical counter	Photo-electric effect
	Capacitance counter	Capacitance probe	Electro-mechanical counter	Change of capacitance
	Ultrasonic counter	Crystal	Electro-mechanical counter	Ultrasonic transmission
Dimensions of solid body	Air gauge	Air nozzle	Pressure gauge	Variation of air pressure
	Inductor or differential transformer	Inductor	A.C. bridge network or oscillator	Change of electrical inductance
	Optical gauge	Photo-cell, tube or transistor	Bridge network or voltmeter	Alignment of optical beam
	Capacitor gauge	Capacitor	A.C. bridge network or oscillator	Change of electrical capacitance
Flow of fluids	Fixed area flow meter	Orifice plate	Pressure gauge	Differential pressure
	Variable area flow meter	Float	Tapered tube	Self-adjusting aperture
	Positive displacement flow meter	Positive displacement rotor	Revolution counter	Volumetric cycle measurement
	Turbine flow meter	Turbine rotor	Revolution counter	Rotation of turbine rotor
	Magnetic flow meter	Electrodes in magnetic field	Voltmeter	Electro-magnetic induction
	Ultrasonic flow meter	Piezo electrical crystal	Phase meter	Doppler effect
Humidity of gases	Wet and dry bulb hygrometer	Wet and dry bulb thermometer	Differential temperature	Differential evaporation
	Hair hygrometer	Hair or "gold beaters" skin	Positional indicator	Dimensional changes of hygroscopic material
	Electrical hygrometer	Lithium chloride	Bridge network	Change in electrical conductivity
	Dew-point hygrometer	Polished metal surface	Device to indicate correlation between temperature measuring element and optical density	Relation between dew-point and humidity
Level of liquids	Sight gauge	Vertical tube	Meniscus	Gravity
	Level indicator	Float	Positional indicator	Buoyancy
	Bubbler tube meter	Tube	Differential pressure gauge	Hydrostatic pressure

Table 5.1 (*cont.*)

Quantity sensed	Type of instrument	Sensing device	Measuring and/or indicating device	Method of operation
Level of liquids	Differential pressure meter	Pressure diaphragm	Differential pressure gauge	Hydrostatic pressure
	Conductivity level indicator	Electrodes	Relay	Change of electrical conductivity
	Capacitance level indicator	Capacitance probe	A.C. bridge network	Change of electrical capacitance
	Nucleonic level indicator	Ionization chamber	Relay	Absorption of radiation
Noise	Noise meter	Microphone	Voltmeter	Change of electrical properties
	Noise spectrum analyser	Microphone	Spectrum analyser	Change of electrical properties
Position	Position detector	Capacitor	A.C. bridge network	Change of electrical capacitance
		Differential transformer	A.C. bridge network	Change of electrical capacitance
Pressure	Pressure gauge	Bourdon tube or bellows	Positional indicator	Mechanical strain
	Pressure sensor	Inductor capsule or differential transformer	A.C. bridge network	Change of electrical inductance
		Capacitor capsule	A.C. bridge network	Change of electrical capacitance
		Strain gauge	Bridge network	Change of electrical resistance
Salinity	Salinometer	Electrodes	A.C. bridge network	Change of electrical conductivity
Smoke density	Smoke density meter	Photo-cell, tube or transistor	Bridge, voltmeter or potentiometer	Photo-electric effect
Speed	Speedometer	Governor	Positional indicator	Centrifugal force
		Electric generator	Voltmeter	Electro-magnetic induction
		Impulse generator	Frequency meter	Pulse counting
		Drag cup	Torsion spring	Eddy current effect
		Pneumatic turbine	Pressure gauge	Turbine effect
	Stroboscope	Photo-cell, tube or transistor	Discharge tube	Optical comparison
Strain	Strain gauge	Strain gauge	Bridge network	Change of electrical resistance

Table 5.1 (*cont.*)

Quantity sensed	Type of instrument	Sensing device	Measuring and/or indicating device	Method of operation
Temperature	Filled system	Metal bulb	Bourdon tube or bellows	Liquid expansion or vapour pressure
	Bi-metallic thermometer	Bi-metallic strip	Positional indicator	Differential expansion
	Thermocouple	Junction of two dissimilar metals	Voltmeter or potentiometer	Seebeck effect
	Resistance thermometer	Platinum or nickel wire	Bridge network	Change of electrical resistance with temperature
	Thermistor	Temperature sensitive semi-conductor	Bridge network	Change of electrical conductivity with temperature
	Pyrometer	Thermopile	Potentiometer	Seebeck effect
Viscosity	Drag viscometer	Rotating cylinder	Spring deflected pointer	Variation of torque
	Vibrational viscometer	Vibrating reed	Voltmeter	Damping imposed on vibrating member
	Falling sphere viscometer	Falling sphere	Timing device	Time to fall fixed distance
	Restricted flow viscometer	Capillary	Differential pressure cell	Pressure drop at constant flow rate

(ii) HOW MANY?

For example, counting by mechanical, electromechanical or optical devices.

(iii) HOW MUCH?

If the question is interpreted as, "How much at some particular instant of time?", then most measuring instruments fall into this category.

If the question is interpreted as, "How much in a given time interval?", then integrating instruments must be included.

Whatever the nature of the sensing device, certain requirements are of fundamental importance.

Firstly, it is important to know what effect the presence of the

sensing device has on the quantity being measured. Ideally it should not change the conditions which existed before it was introduced. In practice this can rarely be achieved; for example the presence of a flowmeter affects the flow in a pipe; the presence of a comparatively low-resistance voltmeter affects the voltage across a high-resistance input. When the presence of a sensing device affects the system under consideration it is of prime importance that its modifying characteristics are thoroughly appreciated.

Secondly, some sensing devices respond to characteristics other than the one of primary interest. One voltmeter may, for example, respond to the average value of an alternating signal, another to the peak value, another to the r.m.s. value. It is important when choosing the sensing device to ensure that it responds only to the characteristic of interest. The signal provided by a flowmeter, for example, will be affected by other factors besides flow—temperature, pressure, density and viscosity. The effects of these secondary factors on the signal provided must be known and appreciated.

Thirdly, the speed of response to rapidly changing conditions is often of considerable importance. For example, a rapidly changing temperature cannot be indicated with a filled thermometer; a rapidly changing voltage cannot be indicated with a moving-coil voltmeter.

A sensing device can only provide an accurate indication of the quantity being measured if its calibration is repeatable. This necessarily requires that hysteresis shall be negligible, and that its behaviour shall be independent of ambient conditions such as temperature, pressure, humidity, magnetic fields and so on.

In addition, sensors often have to withstand very severe conditions such as corrosive or explosive atmospheres. In such cases special precautions have to be taken to ensure that the sensing devices function normally and that their presence is not hazardous.

Finally, installation is important. For good control the correct location of sensing devices is important and in some cases critical. Thus, to position a sensing device a few feet away from where it is required, for ease of manufacture or installation, may destroy the possibility of achieving satisfactory control. The fitting of a sensing device may involve penetration of a pressure vessel and it is both costly and time wasting to move it to its correct position if it has been incorrectly installed.

5.2. TRANSDUCERS

A primary requirement of any indicating or recording device is that it shall not subject the sensing device to any appreciable load or excessive friction. If, due to friction or "dead zone", the indicating system does not respond to a change in the parameter being measured, a still greater change must take place before it even starts to indicate the change. If, for example, a temperature-measuring system has a frictional or "dead zone" error due to its mechanical linkage of 2 per cent of the range of the instrument, then the actual temperature could vary by at least 2 per cent and the indicating system would not respond at all.

Furthermore, the measuring system should respond to variations as quickly as possible. In an automatic control system there must be a deviation in the measuring system before any corrective action can be taken by the control mechanism. If the measuring system is slow in response, there will be a delay in applying the correction by the controller, which means that a further deviation may take place before any corrective action is felt.

Examination of the devices in Table 5.1 shows that in the great majority of cases sensing devices provide either:

(i) movement of a mechanical member,
(ii) change in a force or pressure,
(iii) change in an electrical resistance,
(iv) change in an electric current or voltage,
(v) change in a light intensity.

In the following paragraphs the currently available methods of indicating such changes are described. The methods adopted must be chosen so that no appreciable load is imposed on the sensing device.

(a) *Indication of Mechanical Movement*

Pressure and temperature sensing devices of the Bourdon tube and diaphragm types can be connected directly to an indicator because they develop sufficient power to move the associated mechanical linkage without sacrificing accuracy of measurement. Motion-actuated elements such as floats are also readily adaptable since they too are designed to develop power.

In many systems, however, it is not practicable to derive adequate power to move a mechanical linkage. In such cases the problem of instrument design resolves itself into the development of suitable means of providing an easily observed indication of a small movement without imposing any appreciable load on the sensing device. This is nearly always done by converting the movement into a form which can readily be amplified, for example by conversion in a "transducer" to an electrical or pneumatic signal.

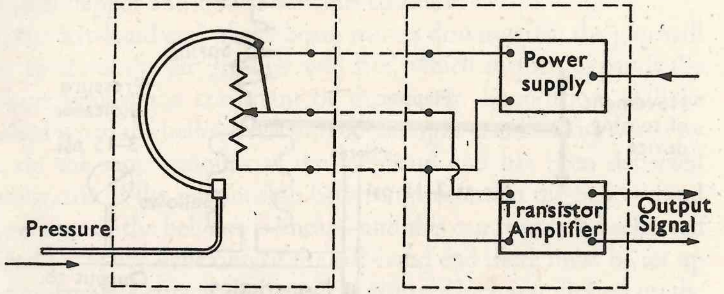


FIG. 5.2. Conversion of movement into electric current.

Possibly the simplest way is to attach to the moving member a slider which alters the value of a resistance arranged in a bridge or potentiometric network as shown in Fig. 5.2. The electrical change so produced can readily be utilized to provide indication of position. This simple system is not applicable where high accuracy is required because it necessarily introduces friction and backlash.

Another method often employed involves attachment to the moving member of a small metal armature of high magnetic permeability located near to an iron-cored inductor with an appropriate air gap. Movement of the armature produces a change of inductance.

An almost identical technique utilizes a capacitor instead of an inductor as the converting or transducing element.

Conversion of small mechanical movements into changes of capacitance or inductance enables accurate measuring instruments such as a.c. bridge networks or frequency meters to be used as the indicating or recording device, and very high sensitivity is possible without loading the sensing device in any way.

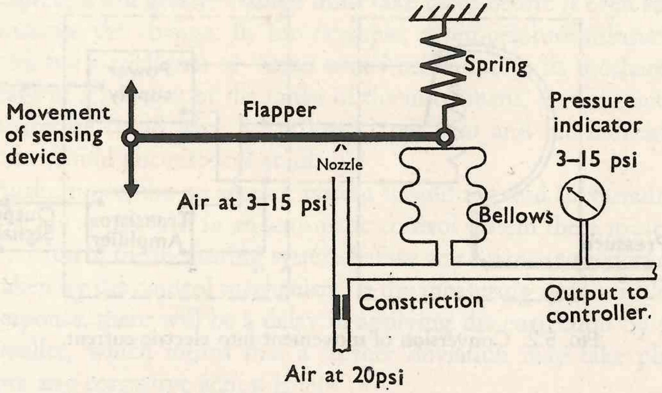


FIG. 5.3. Conversion of movement into air pressure.

Another well-known method of converting small mechanical movements into electrical change is the "load cell" or "strain gauge" in which use is made of the change in electrical resistance produced by strain in a fine wire attached to the deflecting member.

A further method involves conversion of the mechanical movement into a change in air pressure. This is illustrated in Fig. 5.3.

The moving member of the sensing device is linked with a lightweight beam or "flapper" the other end of which is attached to a bellows and spring arrangement. Midway between the two ends is a nozzle of small diameter which terminates a pipe system as shown, the constriction being designed to give an appreciable pressure drop. Suppose that initially the flapper is so far away from the nozzle that it does not impede the flow of air issuing from the 20 psi inlet line; the pressure drop across the constriction can readily be made 18 psi, e.g. the nozzle pressure indication will be 2 psi. Now assume that the flapper moves downwards until the nozzle is completely closed; the air pressure will rise to 20 psi. This change of pressure from 2 to 20 psi can be obtained for a flapper movement of less than one-thousandth of an inch. For practical purposes, therefore, the gap between flapper and nozzle remains constant.

If the left-hand end of the beam moves downwards, the gap will start to close, the air pressure will rise, which in turn expands the bellows against the constraint of the spring. Equilibrium will be reached when the bellows has moved the right-hand end upwards by exactly the same amount as the left-hand end has been deflected downwards. If the relationship between pressure in the bellows and movement of the bellows is linear—and this can readily be achieved—then for every deflexion of the left-hand end there must be set up at equilibrium a corresponding air pressure which is indicated on the pressure gauge.

It is usual to arrange that zero and full-scale deflexion of the sensing device correspond to 3 and 15 psi respectively. Thus a total change of 12 psi in air pressure can be obtained for quite small movements of the sensing device. Such a change can not only provide indication on a robust pressure gauge but can also provide air signals capable of directly providing adequate power to operate massive control valves. Furthermore, the system does not load the sensing device to any appreciable extent.

(b) *Indication of Change in a Force or Pressure*

There are many ways of converting a force into an electrical or pneumatic signal. The "strain gauge" is a force transducer. A piezo-electric crystal when compressed will provide a d.c. voltage proportional to pressure.

A method frequently used in industrial instruments utilizes the "force-balance" principle shown in Fig. 5.4.

The force is applied to a balanced beam which tends to deflect about a pivot. Any deflexion so produced changes the air gap of an inductor and the resultant change in inductance is utilized to vary the current output from a converter. This current is applied to an electro magnet which produces an opposing force. Balance is obtained only when the two forces are equal and the beam is practically undeflected—less than one-thousandth of an inch. This means that the output current is always exactly proportional to the input force.

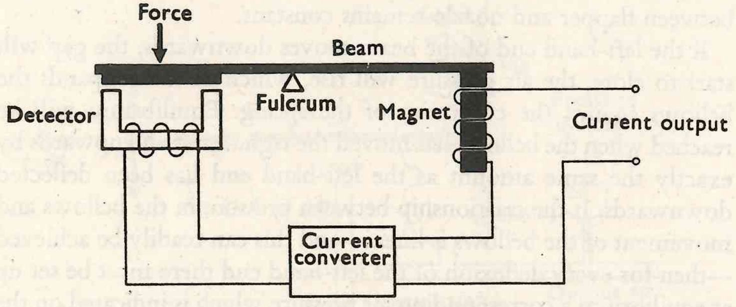


FIG. 5.4. Conversion of force into electric current.

If air or liquid is admitted to a bellows the pressure of the fluid can be applied to the beam and hence converted into an electric current. This technique is used to provide electrical signals over the range 4–20 mA from pneumatic sensing devices, such current signals being used in electronic controllers.

By substituting an air nozzle for the balance detector as shown in Fig. 5.3 and a bellows for the magnet, the applied force can readily be converted into a pneumatic instead of an electrical signal.

(c) *Indication of Change in Electrical Resistance*

Electrical resistance change can best be indicated and/or recorded by a self balancing Wheatstone bridge network in which the slider of the variable resistance arm is motorized. The out-of-balance signal, whether a.c. or d.c., is used, after amplification, to excite in the correct sense the motor windings. Equilibrium is achieved only when the motor is at rest, i.e. when balance is restored and no signals are applied. The position of the slider, which may move on a circular or linear track, indicates the value of the resistance and hence the quantity being measured. This is shown in Fig. 5.5.

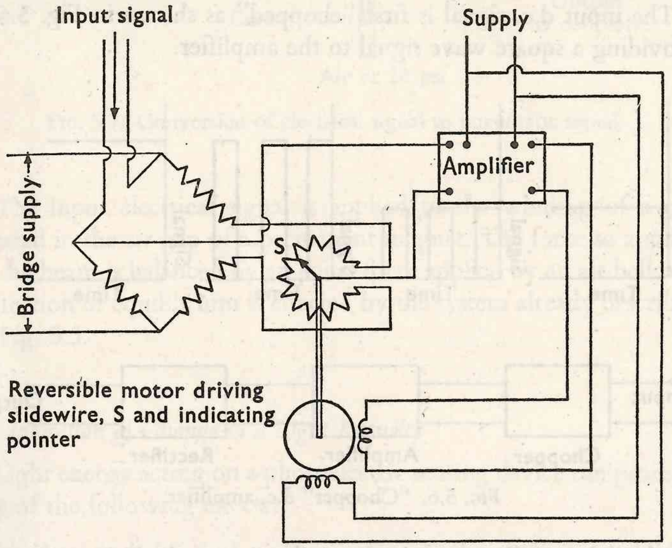


FIG. 5.5. Indication of charge in electrical resistance.

(d) *Indication of Change in an Electric Current or Voltage*

An alternating current or voltage can readily be indicated by conventional amplification. If adequate "feedback" is provided, the gain of the system can be made virtually independent of the characteristics of the valves or transistors employed. Calibration stability becomes dependent only on the long term stability of the resistors used in the network.

Low voltage d.c. signals, such as are derived from thermocouples, are often converted into a.c. prior to amplification, thus avoiding the difficulty of having to eliminate "drift" in a d.c. amplifier.

The input d.c. signal is first "chopped" as shown in Fig. 5.6 so providing a square wave signal to the amplifier.

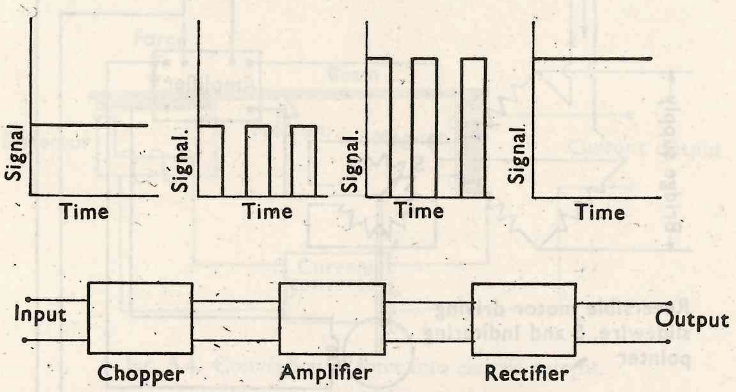


FIG. 5.6. "Chopper" d.c. amplifier.

The "chopper" may comprise a vibrating reed, closing and opening low-resistance contacts, a transistor multi-vibrator circuit which electronically opens and closes the input circuit or a capacitance modulator which produces a sinusoidal instead of a square wave signal. After conventional amplification the output is rectified and indicated in the normal manner.

In many control applications the electric current or voltage change derived from the sensing device is required to be applied to a conventional pneumatic controller. Conversion of the electrical signal into a corresponding pneumatic signal can be effected, as shown in Fig. 5.7 by a force-balance system very similar to that already shown in Fig. 5.4.

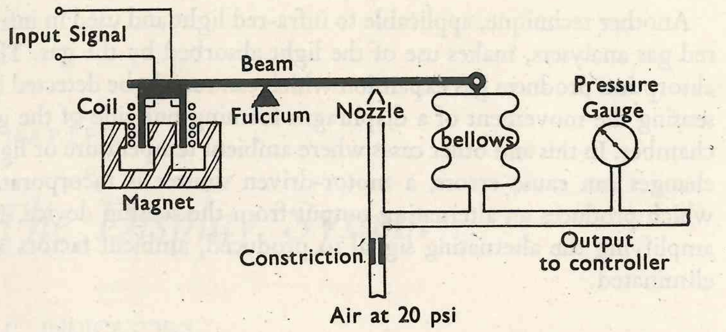


FIG. 5.7. Conversion of electrical signal to pneumatic signal.

The input electrical signal is applied to the winding of a coil located in the air gap of a permanent magnet. The force so applied to the beam is balanced by an equal force applied by an air bellows. Detection of equilibrium is effected by the system already described in Fig. 5.3.

(e) *Indication of Change in a Light Intensity*

Light energy acting on a photoelectric sensing device can produce one of the following effects:

(a) change of electrical resistance as in a lead or cadmium sulphide photoconductive cell;
(b) liberation of electrons as in a caesium phototube, or electric charge as in a photo transistor;
(c) development of voltage as in a selenium or silicon barrier-layer voltaic cell.

In all these cases, indication can be effected by conventional means of measuring small d.c. voltages. With very weak light sources, photomultiplier tubes can be used, in which an electron avalanche is produced, triggered directly by the light, and thus causing a comparatively large current to flow.

Another technique, applicable to infra-red light and used in infra-red gas analysers, makes use of the light absorbed by the gas. This absorption produces gas expansion which can readily be detected by sensing the movement of a diaphragm forming one side of the gas chamber. In this and other cases where ambient temperature or light changes can cause errors, a motor-driven shutter is incorporated which produces an alternating output from the sensing device. By amplifying the alternating signal so produced, ambient factors are eliminated.

CHAPTER 6

The Display System

6.1. INDICATORS

The various types of indicators and recorders in general use are:

(i) Signal flags, lights or annunciators.
(ii) Pointer type instruments.
(iii) Numerical display.
(iv) Counters.
(v) Cathode ray tubes.
(vi) Graphical charts—circular and rectilinear.
(vii) Paper or magnetic tape.

In addition, there are two forms of representing measured values—analogue and digital.

(a) *Analogue Representation*

A car speedometer is an example of analogue representation. The pointer of the speedometer may take up any position on the scale and sweeps through every value from zero to full scale as the car accelerates from rest to full speed. At any moment the amount by which the pointer has moved from zero is said to be an "analogue" of the speed of the car. With analogue representation the measured quantity (in this case, speed) is converted into another physical quantity (pointer position) in a continuous way; i.e. the value of the measured quantity is continuously represented by the value of the analogue and no minimum change or step is required in the measured quantity to cause a change in its analogue.

For example temperature may be measured by a thermocouple which gives a d.c. voltage which is the analogue of the temperature.

(b) *Digital Representation*

An example of digital representation is the indication of distance travelled as shown by a car milometer. The distance covered by the car is displayed as a number and this number increases in steps as the car proceeds; i.e. there is a minimum step of one-tenth of a mile required in the measured quantity before the milometer value changes. The milometer is, in fact, a mechanical counter which counts the number of revolutions of the car's wheels, through a suitable gear ratio.

Other examples are:

Liquid volume may be measured as integrated flow by counting the number of revolutions of a paddle wheel rotated by the liquid as it flows through a pipe.

The length of a steel billet may be measured by counting the number of rotations of the mill rollers (with corrections to allow for slip between the rollers and the billet).

Thus digital representation of a quantity is a number, often (although by no means necessarily) obtained by counting individual increments.

(c) *Choice of Analogue or Digital Representation*

For start-up and running-up to load (e.g. manœuvring) of machinery analogue presentation is usually preferred, since in this form, trends which take place rapidly, are more readily interpreted and understood by the watchkeeper.

Under steady load conditions, e.g. settled voyage conditions, digital displays are sufficient to indicate a healthy or unhealthy state of items of machinery. Alarm systems, which are digital in character, can meet this basic need.

To determine running efficiency or to assess where and when maintenance or replacement might be required to avoid breakdown,

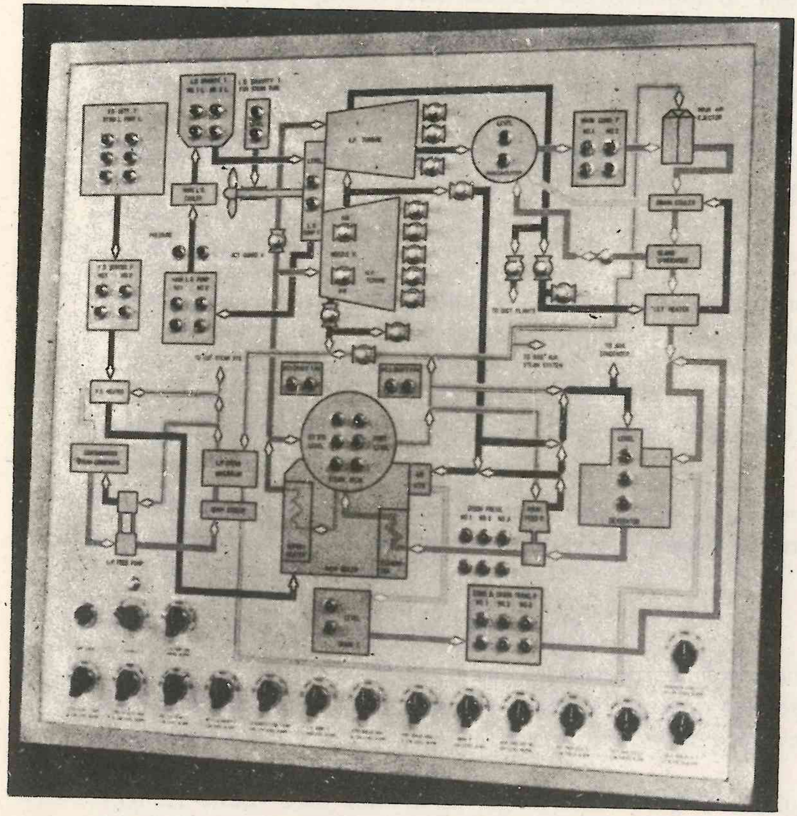


FIG. 6.1. Example of a mimic diagram.

the information can be displayed in either analogue or digital form. The time scale of performance deterioration is usually very long and, hence, analogue devices which record continuously offer perhaps too much information. Information once per watch or maybe once per day could be sufficient and digital devices may be more appropriate for this purpose.

6.2. INDICATION AND DISPLAY

In simple machinery installations in which only a few instruments are involved the individual indicators can be arranged for easy observation by the watchkeeper and manual logging adopted for records. Limitations in the design of direct reading instruments have tended to establish the large circular dial (8 to 9 in. diameter). These are easy to read but take up a lot of room on the control panel. Sector or edge-wise instruments are a distinct advance as far as space is concerned, as also are multi-point instruments whereby several sensing points can be read in turn on one meter. Improvements in the properties of steels for permanent magnets, largely as a result of demands from the aircraft industry, have produced the miniature instrument, with dials of about 2 in. diameter.

(a) *Mimic Diagrams*

When the number of panel-mounted instruments becomes large, however, the task of assimilating the information may be very great. This is of paramount importance when the amount of machinery to be controlled from the central control room becomes large. In addition the withdrawal of the watchkeeping staff to a central point usually requires that the instrumentation be increased somewhat over that provided in the older ships. One method of easing this problem is to make use of "simple to understand" graphic panels or mimic diagrams as shown in Fig. 6.1.

The purpose of a mimic diagram is to show the state of the machinery in the central control position. In the older ships where separate operators control independent areas of the machinery there is little justification for a remote indication of their state. As the operation of individual machines become interdependent and the use of automatic starting and stopping increases so it becomes necessary to indicate at a central point the state of the machinery. This can be achieved by indicator lights and, where necessary, push buttons and switches for control and meters for indication. Such an arrangement still fulfils the needs of a large number of ships.

However, the reduction in numbers of watchkeepers proposed for certain modern ships, made possible by the increase in automatic and sequential controls, has led to a further requirement, viz. not only should the state of the various items of machinery be transmitted to the central operating point but also the inter-relationship and sequence of operation of those items. In such a situation the mimic diagram becomes an essential tool of control and economically justifiable. It should show pictorially the nature of the plant, its function and preferably its geographical layout. This latter is, however, a counsel of perfection and often difficult to achieve. An additional advantage of a well-thought-out and carefully executed mimic diagram is the ease with which a new, strange watchkeeper can be introduced quickly to the functioning of the machinery. This point is particularly relevant in ships where there are often quite frequent staff changes.

Each separate system in the mimic layout is normally traced in a distinctive colour for that system. Status lights show the position and state of vital valves, controls or tank levels. Since it is not normal practice to have the engine room alarm panel associated directly with the mimic diagram it is usual to fit additional warning lights in the system mimic, in appropriate locations, which are energized simultaneously with the associated alarm circuits.

The process of devising a good layout of a mimic diagram is far from straightforward, especially where complex plant involving many interconnected units is concerned. This is mainly because it is not always possible to project a three-dimensional system on to a plane surface without introducing overlaps in the connections. Overlaps should be avoided wherever possible since they tend to introduce confusion into the indication.

It should be decided at the outset whether plant items are to be shown as a series of symbols and single straight lines, or whether an attempt should be made at realism with plant items represented by their typical elevation and pipelines by their shape. If space permits the latter is usually preferable because it permits the direction of flow to be indicated by illuminated coloured arrows set within the pipe.

Probably the most controversial factor in mimic diagrams is that of illumination. The indicating light sources for the various devices have to be bright enough to be clearly visible to the watchkeeper under normal lighting conditions. When red or green lenses or filters are used the difficulties are considerably less than with blue, orange or clear lenses. This is because most lamps emit yellow light which, for example, will mix with blue to give a greenish rendering.

(b) *Data Logging*

Even with all the above "information assimilating" aids the watchkeeper's task of digesting all the information presented by a large number of instruments may be very great. Moreover, and what is often more important, human operators make mistakes. Mistakes are made every day but, usually being of a minor nature, do little damage. The effects of some mistakes, however, can be very serious and can cause, say, a change from a stable state to an unstable state in a very short space of time. An attempt to solve this problem is the introduction of data logging equipment, and the purpose of such equipment is:

(i) To continuously monitor all the important quantities which are being sensed.
(ii) To give audible and visual warning if any variable moves outside specified, pre-set limits.
(iii) To provide a time-identified printed record of all "off limit" conditions.
(iv) To provide a printed log of all, or pre-selected groups of variables both at pre-determined intervals and on demand.
(v) To display the value of any selected variables in illuminated decimal digits.

(vi) To provide a reduction in the number of conventional indicating and recording instruments.

The advantages of data logging equipment may be summarized as:

(vii) Early warning of potential breakdown.
(viii) Factual records of performance.
(ix) Watchkeeping staff is relieved of routine logging and recording duties.
(x) Increased operating efficiency due to the close tolerance supervision of the machinery.
(xi) Determination of trends and undesirable characteristics of main machinery under varying conditions.
(xii) The acquisition of accurate operational data permits better performance analysis for current and future maintenance and provides a firm basis for studying future machinery design.

A diagram of a typical data logging system is shown in Fig. 6.2. The sensing/transducing devices, which must provide an electrical output, are connected to a scanning system whose function is to switch each line in turn to a common channel for transmission to the next sub unit. The rate of scanning could be as high as 50 points/second but for marine systems scanning speeds of about 1 point/second are commonly used. A digital clock provides timing pulses to initiate periodic logging and a visual display of time on numerical or printed indicators.

The signal then passes through an amplifier so that whatever the form of the electrical input, the output will conform to a standard d.c. signal for all points.

The next sub-stage is the analogue to digital converter which converts each signal in turn into a digital number, the value of which is proportional to the magnitude of the signal and therefore to that of the variable.

Following the analogue to digital converter the signal is routed into two channels, one for logging and display and the other for alarm announcement and print-out.

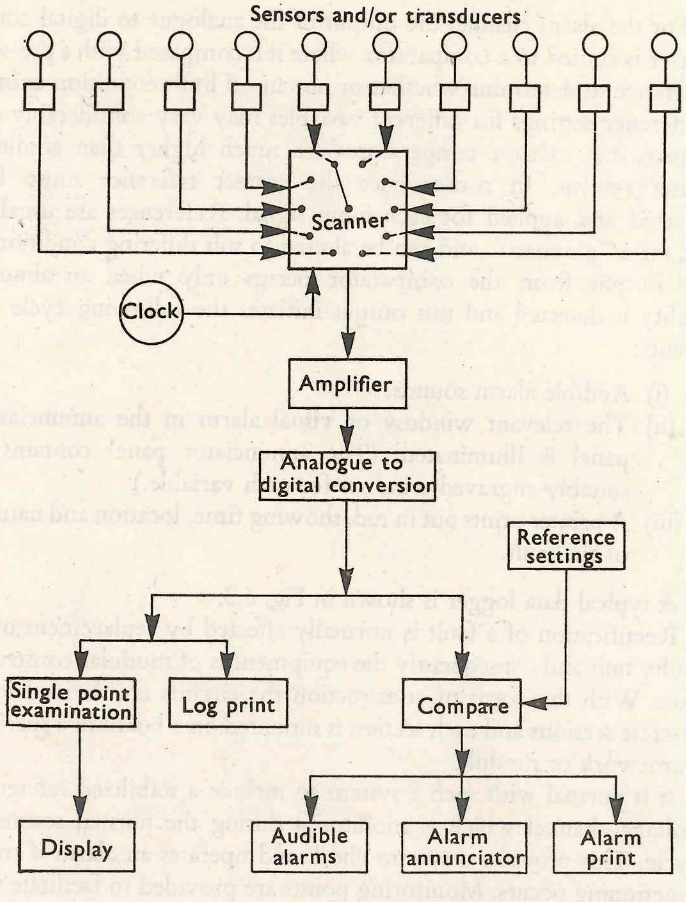


FIG. 6.2. Diagram of a typical data logger.

The logging channel provides an automatic print-out of all variables at any required time interval. It will also provide a full print-out on demand. Any point which is outside limits will be printed in, say, red. Logging can be on the same printer as for alarms, or on a separate printer, or on an electric typewriter or teleprinter type instrument.

For the alarm channel the output of the analogue to digital converter is routed to a comparator where it is compared with a pre-set reference to determine whether or not an off limit condition exists. Reference settings for different variables may vary considerably of course, e.g. exhaust temperatures are much higher than cooling water returns. In consequence the correct reference must be selected and applied for each input signal. References are usually set on a "pinboard" and can be altered to suit differing conditions. An output from the comparator occurs only when an abnormality is detected and this output initiates the following cycle of events:

(i) Audible alarm sounds.
(ii) The relevant window or visual alarm in the annunciator panel is illuminated. (The annunciator panel contains a suitably engraved window for each variable.)
(iii) A printer prints out in red, showing time, location and nature of the fault.

A typical data logger is shown in Fig. 6.3.

Rectification of a fault is normally effected by replacement of a faulty unit and consequently the equipment is of modular construction. With this form of construction the circuits are divided into discrete sections and each section is mounted on a board in a specific framework or module.

It is normal with such a system to include a stabilized reference voltage channel which is monitored during the normal scanning cycle. This provides a system check and operates an alarm if malfunctioning occurs. Monitoring points are provided to facilitate the location of the defective module.

Solid state devices (see Chapters 8 and 11) are used wherever practicable to ensure reliability and the modules are encapsulated to give protection from the normal marine conditions of vibration, salt, moisture and/or oil-laden atmospheres. This encapsulation does not normally involve "potting" but rather the coating of the module complete with components with a layer of epoxy resin material, polyurethane or equally effective material.

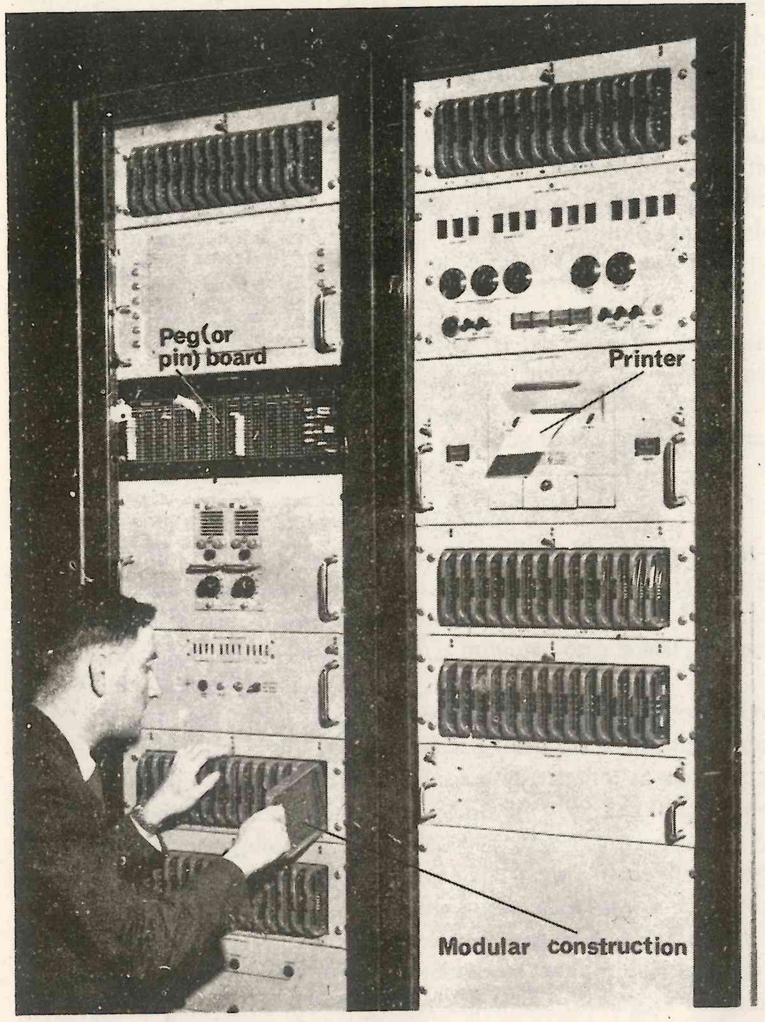


FIG. 6.3. A typical data logger.

Silicon solid state devices are used as far as is technically practicable since the alternative germanium devices have an upper temperature limit of about 55°C. Where germanium devices must be included for technical reasons, air conditioning must be provided either in the unit or for the control room as a whole. It must be appreciated that for service in the tropics 45°C will represent the minimum ambient air temperature. Indeed, temperatures in excess of 60°C have been recorded in the engine rooms of ships and, for this reason, a test temperature of, say, 75°C inside cubicles is recommended for the works testing of such equipment if it is intended for shipboard use.

The normal voltage and frequency tolerances in the marine electrical system are greater than those normally encountered ashore, e.g. in a cargo ship with a.c. pole-changing deck machinery transient voltage dips of minus 20 per cent may occur. In addition marine electrical installations are of the insulated neutral type and hence there is the likelihood that transient overvoltages will be higher than those occurring ashore where systems are normally of the earthed neutral type. Positive evidence on the incidence of overvoltages is difficult to obtain but indications are that overvoltages in excess of 2500 volts (peak) are not uncommon. Solid state devices are particularly susceptible to voltage transients and may be completely destroyed by high overvoltages. This raises problems for the designer of such equipment and, indeed, equipment which has proved its reliability ashore may not necessarily be satisfactory in the marine environment. Separate stabilized power supplies may be the only satisfactory solution.

Practical experience of the failure rate of such equipment is not widespread and literature on the subject is relatively limited but the reports that have been published indicate a good level of reliability. The main design features which would appear to be necessary for reliability are:

(i) Solid state components throughout and no electro-mechanical components except outside the main loop, e.g. printers.

(ii) Large design margins and all components to be under run.

(iii) Minimum number of plugs and sockets.

(iv) Complete testing at three stages: components, sub-assemblies and overall system.

(v) A "soak" test for the complete equipment before delivery. Such a test involves running the equipment continuously for, say, 500 hours minimum, at full rated load and at the ambient temperature to be expected in service. This allows for premature failure and consequent replacement for all failed components. Components which survive such a test are then likely to last their full life expectancy.

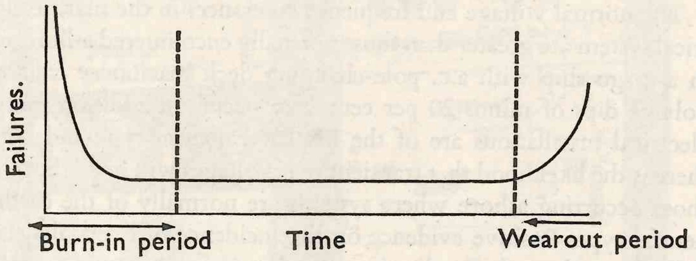


FIG. 6.4. Pattern of failure rate of electronic components.

This latter requirement is based on what is sometimes called the "bathtub" curve for the reliability of electronic components and is illustrated in Fig. 6.4.

This curve shows that the failure rate of electronic components is fairly high during the early portion of the life of the equipment. Any components which successfully survive these early hours can then be expected to run their full life expectancy before the failure rate increases again.

Electro-mechanical devices such as printers and typewriters should be run for about 500 hours before commissioning. Such a test helps to remove burrs from the mechanical components. In addition it should be arranged that the motor of such devices should be energized only when printing is taking place. Failure to observe this precaution has sometimes resulted in loss of lubricating oil due to oxidation with subsequent mechanical trouble.

The size of data loggers which have been fitted in ships at the present time varies enormously. One proposal has been for a logger of about 1000 inputs and in another ship 200 inputs have been fitted for the propulsion machinery alone. Such data processing equipment is expensive. Basically a data logger performs two functions—it takes over laborious donkey work, i.e. information storage and data logging, and it improves operational communications throughout the shipowners' organization, and here "operational" is used in its widest sense. Whilst it is not possible to say that one purpose is right and the other wrong it is probable that a shipowner who installs data processing equipment merely to replace donkey work is not getting the best value from such equipment. Equipment of this type provides a great deal of accurate data and this data must be used if the installation is to be economically justified. This means that sufficient technical effort must be available in the owners' headquarters to assess and analyse the results provided. Failure to make use of the information for current and future maintenance and for future design makes the installation of such equipment economically suspect.

In several ships instead of full print-out, about 30 per cent to 50 per cent of the total inputs are printed out, although all inputs may be connected to the alarm and display channels. These printed outputs are restricted to those which the shipowner requires.

CHAPTER 7

Actuators

Having sensed the required variables by means of sensors and/or transducers and measured them by means of the display system, it may be necessary to take some corrective action. This is achieved by means of an actuator which may be considered as a device that converts some form of energy into a mechanical motion, the motion being either linear or rotary. This definition can include power cylinders, electric motors, bellows, Bourdon tubes, etc.

As well as providing motion the actuator must be capable of providing sufficient power and speed to drive the device to which it is connected under all operating conditions. For example, an actuator may be required to operate a load from one extreme position to the other in a very short space of time or to accelerate the load and to change from one velocity to another in a particular time interval.

One of the aims with actuators is to obtain linearity of operation and with this end in view the designer tries to ensure that minimum friction is obtained, that the diaphragm area remains constant throughout the stroke and that springs with a linear rate are selected. If these cannot be wholly achieved then external forces such as friction or valve body unbalance transmitted through the valve stem, can cause an off-positioning of the valve stem or non-linearity of operation. Known static unbalanced forces, provided that these are constant throughout the stroke, can be overcome by, say, increasing or reducing the rate of the spring or the initial compression thereon. It is rare, however, for the forces to be static throughout the stroke of the actuator and may cause considerable lack of linearity in control. To overcome this, feedback devices known as "positioners" may be required. Such a device measures actuator position, refers it to the signal received and makes the necessary correction. Positioners are often used where the control valve is located some distance from the controller and process time lags must be kept to a minimum (see also Chapter 12).

Types of actuators can be conveniently divided into three categories dependent upon the medium used for operating the device, these being hydraulic, pneumatic and electric.

7.1. HYDRAULIC ACTUATORS

Hydraulic actuators are perhaps the most versatile of the actuators. They may be used for very low-power applications or for high-power applications involving thousands of horse power. They respond smoothly to the controlled flow of fluid from a pilot valve and can be designed to deliver the required operating torque without the use of mechanical gearing. Smooth stepless motion is obtainable with these direct drives.

The linear actuator is the type most commonly used and consists of a power cylinder. There are three types of linear actuator as shown in Fig. 7.1.

The single-acting actuator comprises a piston that moves inside a cylinder, the piston being connected to a push rod which transmits the piston force and motion. The connecting rod passes through a guide boss at one end of the cylinder. The operating medium is applied through port *A* to the under side of the piston only. On release of the pressure the movement of the piston in the opposite direction is obtained by an out-of-balance load or spring.

In the double acting type with single push rod, the operating medium can be applied to ports *A* or *B* thus providing both forward or reverse motion. The force developed by the actuator is the product of the differential pressure and the active areas. The velocity is the flow rate delivered by the control valve divided by the displaced volume per unit volume per unit motion of the piston.

The third type with double push rod has the advantage of having a piston which has equal effective areas on both sides and hence

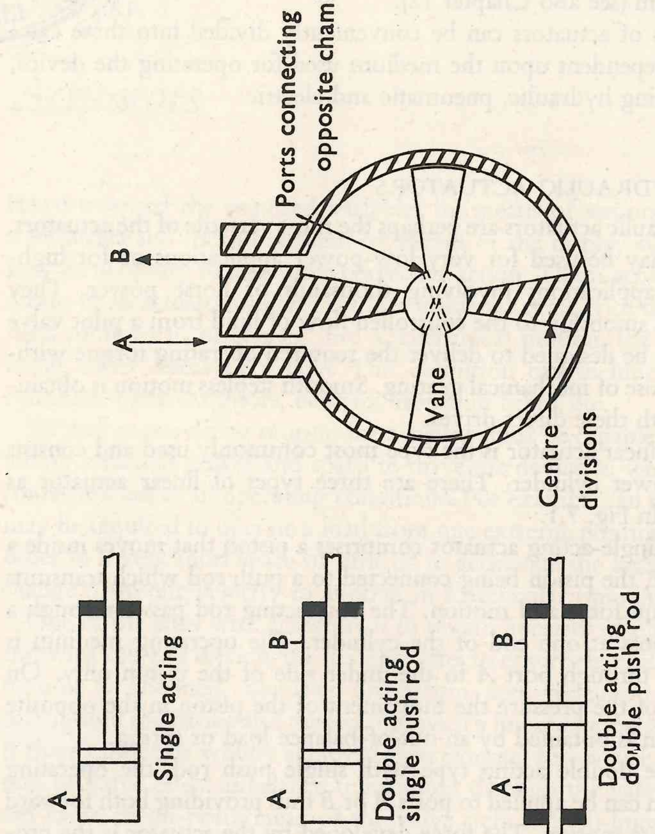


Fig. 7.1. Hydraulic actuators.

produces equal thrust in both directions and loads can be connected to each end of the push rod. Against these advantages is the increased overall length of the unit.

Figure 7.1 also shows a rotary single vane type actuator. It consists of a vane that rotates in a chamber, the chamber being divided into two by a partition. The partition restricts the movement of the vane to approximately 140°. A drive shaft is connected to the centre of the vane to transmit the torque and motion. The operating medium is applied to ports *A* or *B*. By applying pressure to port *A* and exhausting port *B* the vane moves in an anticlockwise direction. By reversing the procedure, reverse motion is obtained. As the vane area in each chamber of the actuator is identical, the force developed in either direction is equal.

Advantages of Hydraulic Actuators

High efficiency at full power and speed.
Smooth, stepless, positive motion over a great velocity range.
Extremely high output power and velocity for a given size and weight.
Usually self lubricating because of the hydraulic fluid used.
Inherently fast in action.
Can be arranged with integral hydraulic supply.
Can be held in position on failure of operating medium by means of a trapping valve in the supply line.

Disadvantages of Hydraulic Actuators

Need for hydraulic fluid at high pressures.
Need for high-pressure piping to conduct the fluid.
Possibility of entrapped air affecting the positive action.
Possibility of leaks occurring and damaging adjacent plant or material.
Possible fire hazard if mineral oil is used as an operating medium.
Viscosity change of fluid caused by changes in temperature which causes variation in performance.

7.2. PNEUMATIC ACTUATORS

Probably the most widely used operating medium for automatic control equipment used in industry is compressed air. Air is used to provide both the power for operating the controllers and for the transmission of the control signal.

Pneumatic control systems operating from air supply sources at pressures of up to 100 psi are widely used for control loops where the speed of response is not of prime importance. The compressibility of air when used as an operating medium provides a cushioning effect which prevents possible breakage due to abrupt motion as can occur with other systems. This same effect, however, is a disadvantage with regard to positioning accuracy and stability when used in automatic systems.

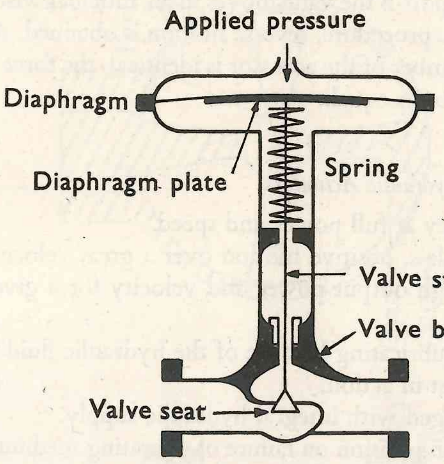


Fig. 7.2. Diaphragm actuator.

Pneumatic actuators are similar in design and action to the hydraulic types already described, but in addition to these a further linear type is commonly used. This is the diaphragm actuator as shown in Fig. 7.2.

The diaphragm actuator is suitable for operating valves used on low-pressure drop applications. It is suitable for use in automatic control schemes or for remote manual operation of valves. In automatic schemes it is normally operated on a 3–15 psi pressure signal, although pressures of up to 60 psi can be employed if required.

The device consists of a diaphragm opposed by a spring, the diaphragm being mechanically coupled to the push rod of the valve.

The downward diaphragm force is opposed by a large coil spring; this pushes upwards and has a force range equal to the thrust developed by the diaphragm. For the standard range of 3–15 psi the diaphragm starts to move downwards when the applied diaphragm pressure exceeds 3 psi. The movement continues until a position is reached where the diaphragm force and the spring force are in equilibrium. As the relation between spring thrust and movement is linear, the valve travel is related linearly to the controller output. The extreme bottom position is reached when 15 psi is applied to the diaphragm.

The size of the unit is determined according to:

(i) valve stroke,
(ii) operating force required.

Fortunately, both functions are usually tied to the nominal size of the valve so that the variation is generally compatible.

The diaphragm valve actuator gives good accuracy unless

(i) there is high friction on the valve stem,
(ii) the reactions at the end of the valve stem are large and variable,

in which case a positioner is required. As this device supplies additional power to the actuator a supplementary source of power is often used and the positioner is fed with a constant air supply, normally 20–30 psi. This supplementary air supply enables greater speed of operation to be obtained by the actuator as well as greater power output.

As mentioned previously a positioner is often used where the control valve is located some distance from the controller and process time lags must be minimized. Positioners are also used on large-sized diaphragm actuators where the amount of bleed through a conventional instrument would take a considerable time to pressurize the large volume of the diaphragm chamber.

If the valve stroke is long in proportion to the forces required a power cylinder is used in place of the diaphragm actuator. This obviates the waste of power in the diaphragm actuator, which is absorbed in the compression of the spring. No spring is normally fitted with these designs, hence they are not provided with the inherent "fail safe" properties of the diaphragm actuator. However, where the control valve must positively open or close upon loss of operating medium they may be fitted with a spring or (by the introduction of trip valves and a reserve air supply) one side or the other of the piston may be loaded with high-pressure air to move the stem in the required direction in the unlikely event of air supply failure.

Advantages of Pneumatic Actuators

Air is free, is light in weight and does not constitute a fire risk.

No possibility of damage to adjacent plant due to leakage of operating medium.

Temperature changes have little effect on viscosity of the medium.

Most pneumatic actuators are relatively cheap.

Maintenance is easy and infrequent.

Possible to provide storage of air to enable equipment to be operated for some time after failure of supply to the compressor.

Disadvantages of Pneumatic Actuators

Compressor plant must be kept running continuously.

Large reservoirs are necessary to maintain a constant pressure to take care of rapid and frequent changes in demand. These vessels are a potential hazard as a rupture can cause an explosion.

At least two compressors are necessary to ensure continuity of air supply.

Need for piping.

Time is required for the actuator to develop its thrust due to air being compressible.

Power transmission is relatively slow and makes fast response difficult especially over long runs.

Low efficiency.

Requires complicated locking devices if required to be held in position on loss of air supply.

7.3. ELECTRIC ACTUATORS

Electric actuators have been used for many years and they are now used for all aspects of remote manual control and for use on some automatic control loops in conjunction with electronic control equipment.

When used with electronic controllers they eliminate the use of the electrical/hydraulic or electrical/pneumatic converter which is required if either of the other two types of actuator is used.

The electric actuator consists essentially of three units:

(i) motor unit,
(ii) gear unit,
(iii) drive unit.

The output motion can be linear or rotary just as for pneumatic or hydraulic units.

Although d.c. and different types of a.c. motors can be, and are, used for operating small valves, the three-phase a.c. motor is most commonly used for the larger type of actuator. However, the three-phase motor has a linear speed of response characteristic and this puts it at some disadvantage for certain applications. By using a two-phase controlled motor in place of the three-phase type it is possible to vary the speed of the motor for automatic control application. The control equipment varies the speed of the motor as the controller output signal varies. This type of motor, however, is limited to sizes of up to approximately 3 h.p. and has the disadvantage of a low efficiency when operating at the lower speeds.

The gear unit contains the gear ratios which are determined in conjunction with the motor size, both of which are dependent upon the load and the speed of response required.

The drive unit in the case of the rotary actuator consists of an output nut which is driven via a worm and worm wheel from the gear unit.

The linear type consists of a ram which is connected to a nut which extends and retracts the ram as the lead screw, which passes through the nut, is revolved in either direction via the gear unit.

Electric actuators are available as a simple assembly consisting of the bare minimum necessary to drive the regulating unit, or a more sophisticated assembly incorporating many refinements.

The simple assembly is suitable for use on applications where they are manually operated at infrequent intervals. It is not suitable for use on automatic control loops where frequent operating is required and where backlash in the drive must be kept to a minimum.

For remote manual control applications, the standard type of contactor starter control equipment is quite satisfactory. For automatic control applications, however, this is not acceptable due to the high degree of wear which occurs on the contacts due to the frequent making and breaking which takes place.

Solid state switching devices are preferred for initiation of electric actuators when used in automatic control loops. Such devices are constructed in a similar manner to that previously described for data logging equipment, i.e. modular construction, and are subject to the same risk of breakdown in a marine system, e.g. high transient overvoltages, etc. (see also Chapters 6, 8 and 11).

Advantages of Electric Actuators

No compressor or pumping equipment required.

Clean and no possibility of damage to adjacent plant by leakage.

On failure of supply the actuator is held in the last controlled position.

The rotary actuator can be connected direct to valve and damper spindles.

Efficiency is high if three-phase motors are used.

Positive action.

Disadvantages of Electric Actuators

Not suitable for use in explosive atmospheres, e.g. dangerous spaces in tankers.

Lower power/weight ratio.

If three-phase motor is used additional equipment is required for accurate positioning when used on automatic control loops.

Maintenance is more complicated than for pneumatic or hydraulic devices.

Expensive electronic control equipment is required when used on automatic control loops.

7.4. SELECTION OF ACTUATORS

The choice of actuator for a specific application must clearly be governed by technical or economic requirements or both.

In addition to rotary and linear motions and the speed of response characteristics, there are other factors which must be taken into consideration. These involve actuator size and weight, cost, environment, reliability and life. The relative importance of these varies with each application. Some of the factors influencing the choice of actuators are shown in Table 7.1 (see page 54).

TABLE 7.1. Selection of Actuators.

Selection			
Technical	*Environmental*	*Life*	*Cost*
Use: Remote manual or auto control	Explosive atmosphere	Short	Limited budget
Rotary or linear motion	Fire hazard	Medium	No limit
Max. speed of response	Contamination hazard	Long	
Linear or non-linear			
Speed characteristics	Shock		
Load to be handled	Vibration		
Operating medium available or desirable	Ambient temperatures		
Positioning accuracy			
Distance of actuator from control position			
Integral manual operating gear			
Size/power ratio			
Weight			
Efficiency			

CHAPTER 8

Non-automatic Control Elements

IN CONTROL systems of the open-loop variety the decision to operate the actuator and to carry out the necessary corrective action on the plant is taken by the human operator. This is quite different from the closed-loop type of control where a "desired value" is fed into an automatic controller, this latter device then carrying out the corrective functions as and when necessary.

In this chapter some of the devices provided to enable the operator to operate the actuator in a satisfactory manner will be described.

8.1. PNEUMATIC CONTROL ELEMENTS

(a) ON/OFF *Valves*

There are many types of ON/OFF valves but the basic operation is identical. An air supply is admitted to one port of the body and movement of the valve spindle to the appropriate position allows the supply air to be directed to the required delivery port, at the same time uncovering the passage for the exhaust air. Valves can also be arranged with a neutral position when all ports are closed. Various types of return springs can be fitted which ensure that the valve returns to neutral or to either of the full stroke positions.

Figure 8.1 shows a typical knob operated ON/OFF valve.

Supply air is fed via the port marked IN and to the chamber surrounding the supply valve and its seat. With the push button in the release position the supply valve is closed and the port marked OUT is connected to atmosphere through the hollow plunger. When the knob is depressed the plunger moves down so that its lower end contacts the supply valve and closes the exhaust passage to atmosphere. Further downwards movement unseats the supply valve and allows air pressure to pass around the plunger to the delivery line.

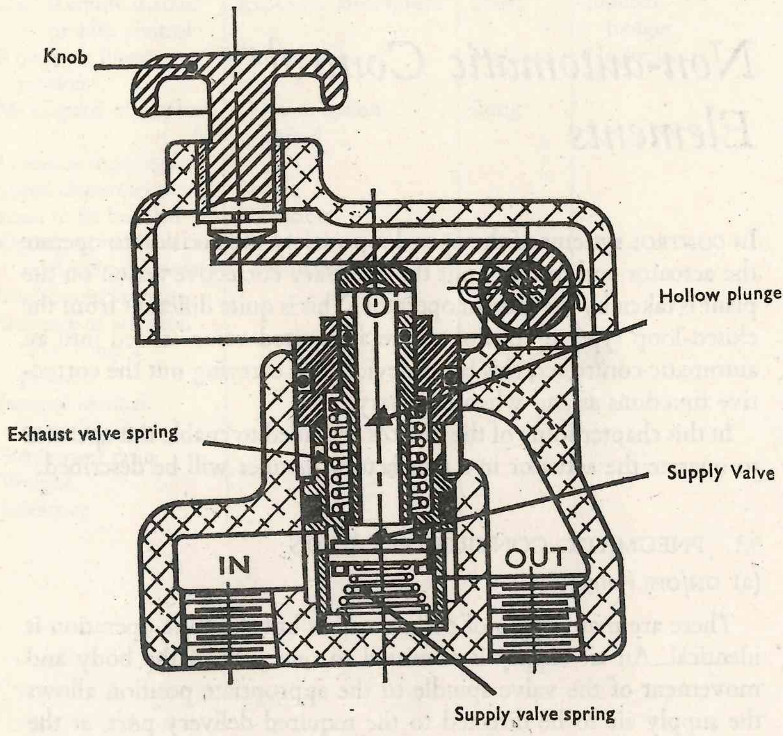


Fig. 8.1. Pneumatic ON/OFF valve.

When the knob is released the exhaust valve spring lifts the plunger towards the release position and, at the same time, the supply valve spring moves the supply valve up against its seat. Thus the flow of supply air is stopped and the delivery line is vented to atmosphere.

(b) *Rotary Valves*

These are for use where it is desired to connect the air supply to one or other of alternative control positions. An example is shown in Fig. 8.2.

The supply air from port 1 is always in communication with the upper surface of the rotary valve plate. Thus supply air pressure ensures that the rotary valve plate always maintains firm contact with the valve seat.

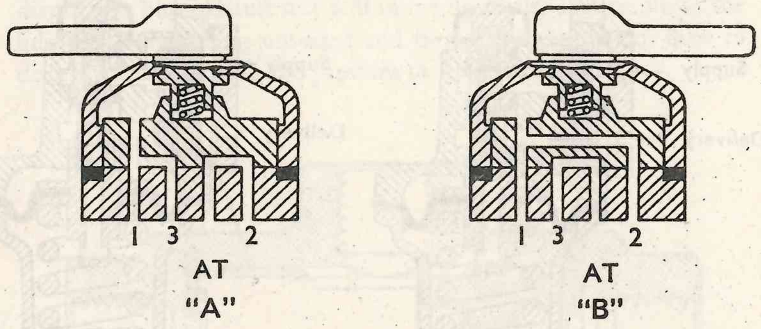


Fig. 8.2. Pneumatic rotary valve.

In position *A*, supply air pressure from port 1 is taken to the top of the valve plate and also to port 3 where it is connected with the operative control position. At the same time port 2 is connected to atmosphere, thus rendering the other control position inoperative.

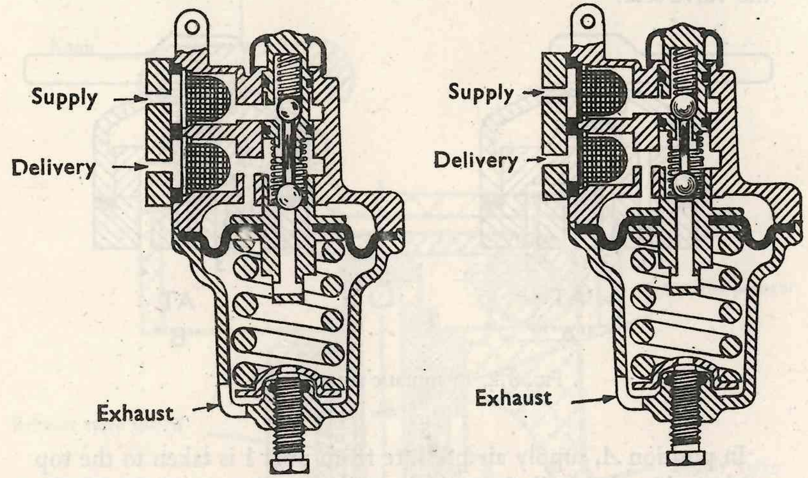
In position *B*, supply air pressure from port 1 is taken to the top of the valve plate and also to port 2, while port 3 is connected to atmosphere. Thus the supply reaches the alternative control position and the original position is inoperative.

(c) *Reducing Valves*

The reducing valve is a regulating device which serves to reduce the air pressure supply to the required delivery pressure. A typical example is shown in Fig. 8.3.

This particular design is constructed in two main sections; the upper portion which consists of a combined inlet and exhaust valve assembly and the lower portion which houses a diaphragm, the diaphragm spring and the spring adjuster.

With the valve in the inoperative position the upper (inlet) ball is held off its seat by the effort of the diaphragm control spring upon the lower (exhaust) ball seat, which in turn closes the exhaust valve.



Application

Release

FIG. 8.3. Pneumatic reducing valve.

When air is applied to the supply connection it flows past the inlet ball valve to the chamber surrounding the valve unit and thence to the delivery line. At the same time supply pressure is felt on top of the diaphragm.

As the pressure increases so the diaphragm moves downwards, allowing the inlet spring to close the inlet ball valve, when balance is achieved between diaphragm spring force and delivery air pressure. Should the supply air pressure increase above that called for by the valve setting, the diaphragm will be forced downwards against the control spring, taking with it the exhaust valve seat. Thus the excess supply pressure is vented to atmosphere through the slot in the control spring casing.

If the delivery line pressure decreases the control spring will overcome the force of the air pressure on top of the diaphragm and the diaphragm plus exhaust seat will move upwards. This results in the inlet ball valve being unseated and further air supply can flow to delivery thus restoring the pressure to the desired value.

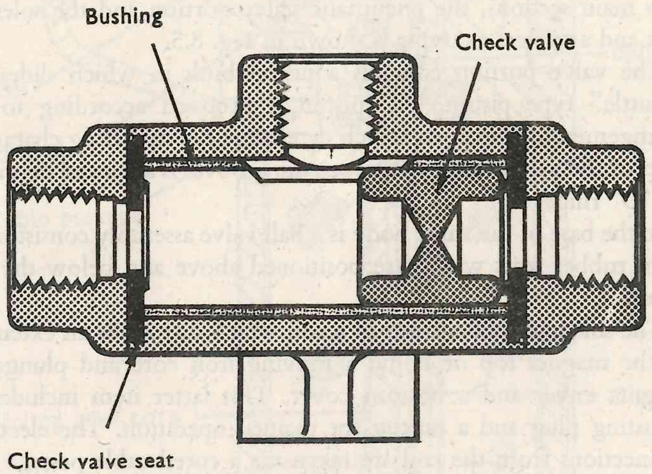


FIG. 8.4. Pneumatic check valve.

(d) *Check Valves*

These are used where it is desired to provide control of a device from either one or other of two sources of air supply. A typical example is shown in Fig. 8.4.

In the figure shown air is free to enter the left-hand end of the valve and into the annular chamber which is connected to the delivery port via the radial holes in the bushing.

When air is applied to the right-hand end of the valve, the disc valve is unseated against the pressure of its spring. Further pressure forces the valve cage assembly to the other end of the valve, seating the valve disc, thus blanking off the air supply from the left. Air from the right-hand end is now free to pass through the holes in the valve bush, into the annular chamber and so to the delivery line.

(e) *Solenoid Valves*

These provide a means of relaying an air supply by remote electrical control to operate a pneumatic device. The valve consists of two main sections, the pneumatic valve portion and the solenoid unit and a typical example is shown in Fig. 8.5.

The valve portion contains a piston bush in which slides the "shuttle" type piston. The piston is grooved according to the arrangement of the ports which determine the operating characteristics of the valve. Sealing between the grooves is achieved by means of "O" rings.

In the base of the valve body is a ball valve assembly consisting of twin rubber seats which are positioned above and below the ball valve.

The solenoid unit consists of a coil which surrounds an extension of the magnet top or body, a moving iron core and plunger, a magnet cover and a bottom cover. This latter item includes an adjusting plug and a button for manual operation. The electrical connections from the coil are taken via a cored cable passage to a terminal chamber.

Figure 8.5 is shown in the de-energized position. In this condition the ball valve is held on its lower seat by action of the supply pressure which is introduced on the underside of the piston, thus the way to exhaust past the stem of the plunger is closed. In the figure *S* is main air supply, *X* is exhaust and *U* is the supply being operated.

Supply pressure communicates with the top of the piston via a cored passage and, due to the larger effective area of this surface, the piston is held down in the position shown. When the solenoid valve is energized the solenoid unit lifts the ball valve off the lower seat and on to the upper seat. This action isolates the supply from the top of the piston and allows the air already in this chamber to vent down

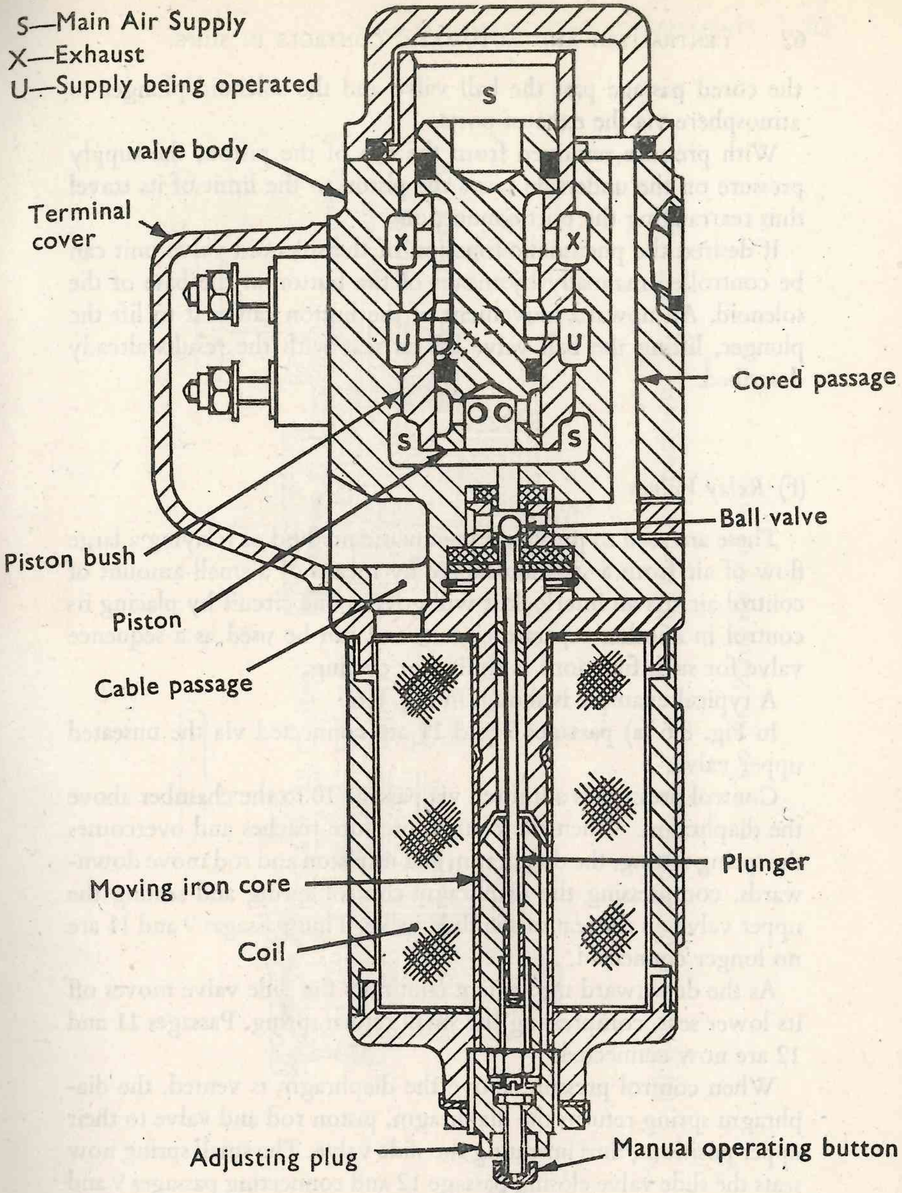


FIG. 8.5. Pneumatic solenoid valve.

the cored passage past the ball valve and the solenoid plunger to atmosphere via the exhaust ports.

With pressure removed from the top of the piston, the supply pressure on the underside raises the piston to the limit of its travel thus rearranging the port connections.

If desired the pneumatic function of the solenoid valve unit can be controlled manually by means of the button at the base of the solenoid. An upward movement of the button causes it to lift the plunger, lifting the ball valve off its seat with the results already described.

(f) *Relay Valves*

These are used to provide a pneumatic method of relaying a large flow of air from a separate source by means of a small amount of control air. As an interlock it will govern one circuit by placing its control in another separate circuit, and can be used as a sequence valve for such functions as timing or cycling.

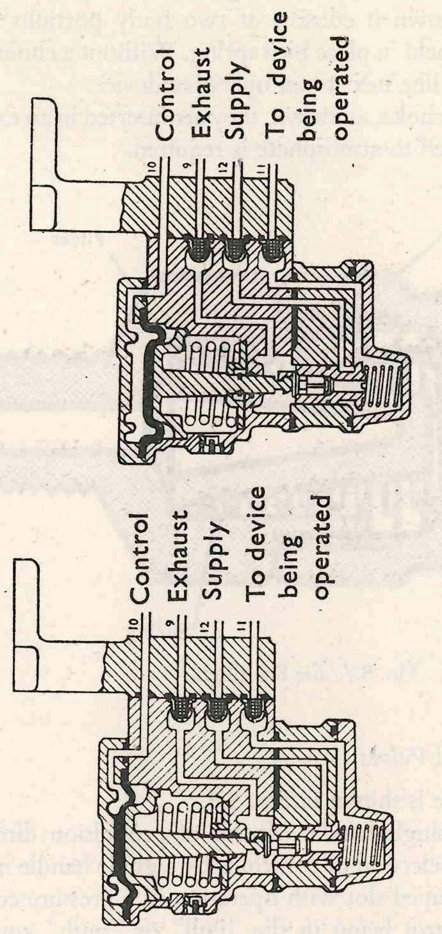
A typical example is shown in Fig. 8.6.

In Fig. 8.6 (a) passages 9 and 11 are connected via the unseated upper valve.

Control pressure is admitted via passage 10 to the chamber above the diaphragm. When the control pressure reaches and overcomes the spring setting, the diaphragm and its piston and rod move downwards, compressing the diaphragm control spring and seating the upper valve on the seat of the slide valve. Thus passages 9 and 11 are no longer connected.

As the downward movement continues the slide valve moves off its lower seat, compressing the small return spring. Passages 11 and 12 are now connected.

When control pressure above the diaphragm is vented, the diaphragm spring returns the diaphragm, piston rod and valve to their upper positions, thus unseating the slide valve. The small spring now seats the slide valve closing passage 12 and connecting passages 9 and 11 via the unseated upper valve.



(a) Released position

(b) Applied position

Fig. 8.6. Pneumatic relay valve.

(g) *Air Line Filters*

A typical air line filter is shown in Fig. 8.7.

In the example shown it consists of two body portions and a conical porous filter held in place by a spring. Without a choke they are inserted in an air line next to an operative device.

When used with a choke, as shown, they are inserted in an exhaust line when a slow bleed to atmosphere is required.

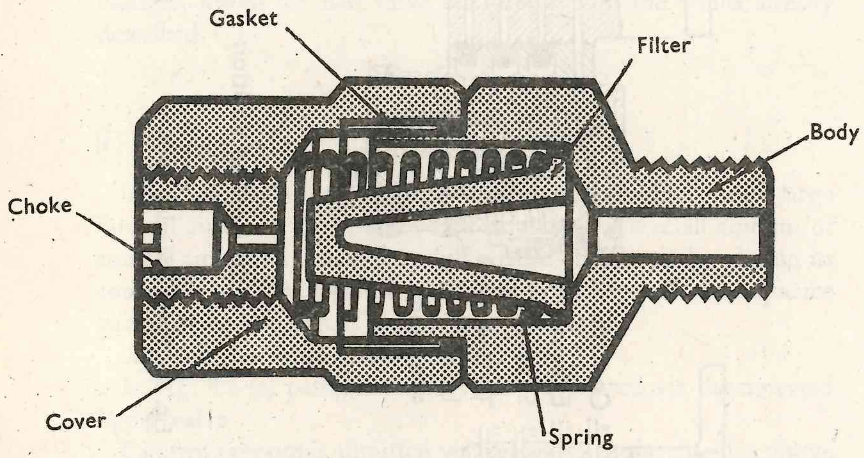


FIG. 8.7. Air line filter.

(h) *Multi-way Control Valves*

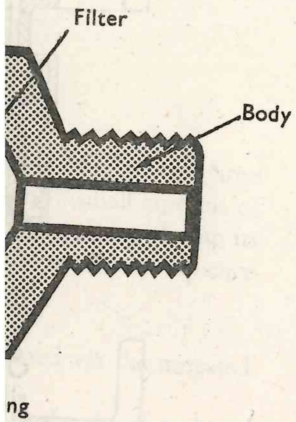
A well-known type is shown in Fig. 8.8.

This can provide single-handle control of propulsion direction and engine throttle. Selection of control is by a guide handle movement through a Z-shaped slot with operation of a pressure control unit for throttle control being in the "pull" or "push" zones of movement. Two ON/OFF valves are fitted, operation of which is by the handle control. A heart-shaped cam, which is rotated by movement of the handle in the push and pull sections of the guide slot, bears on the roller-type cam follower of the graduating valve.

7.

body portions and a Without a choke they e device.

e inserted in an exhaust ired.



opulsion direction uide handle move- a pressure control "push" zones of on of which is by rotated by move- of the guide slot, raduating valve.

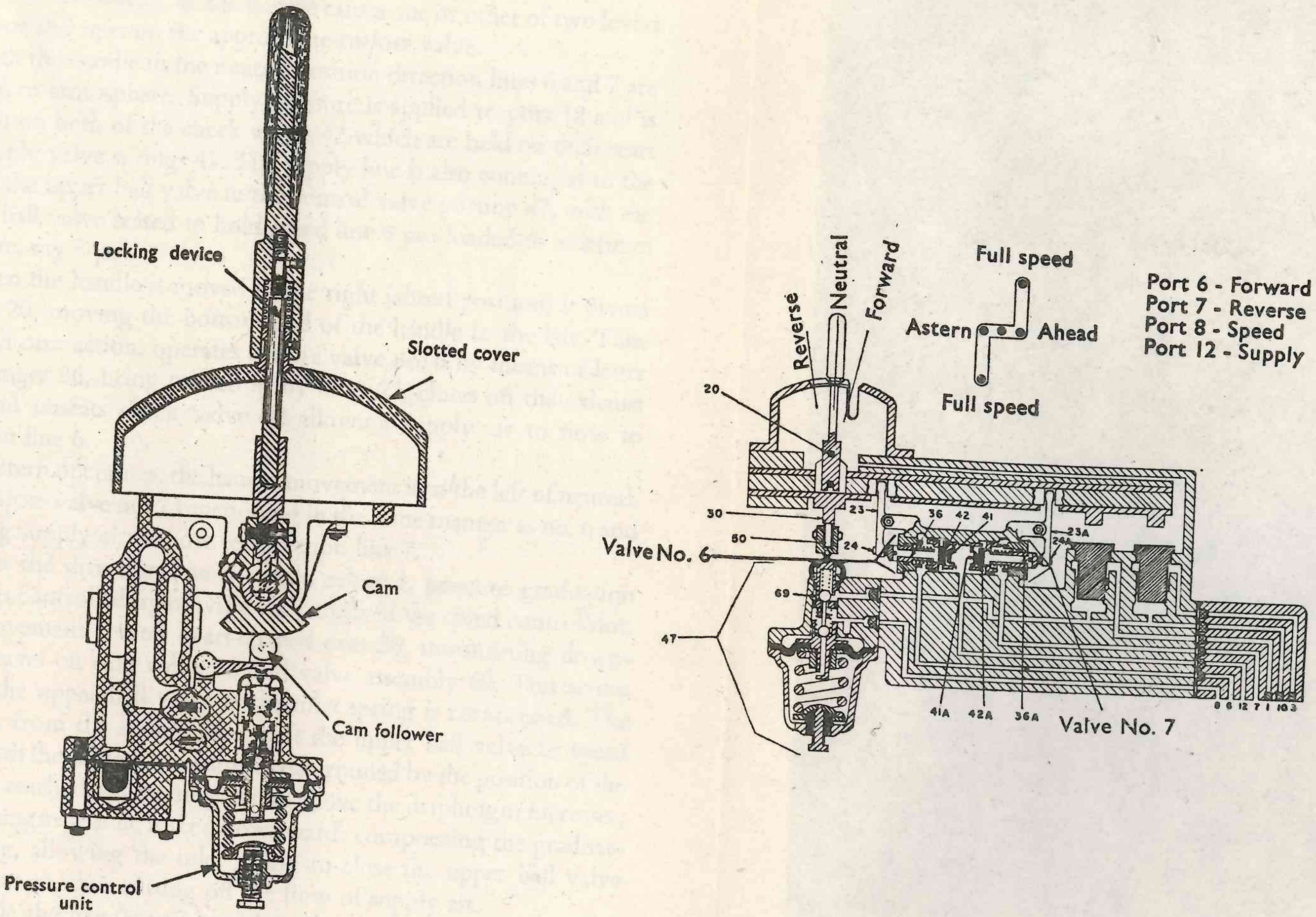


FIG. 8.8. Multi-way control valve (pneumatic).

Sideways movement of the handle causes one or other of two levers to pivot and operate the appropriate ON/OFF valve.

With the handle in the neutral position direction lines 6 and 7 are vented to atmosphere. Supply pressure is applied to port 12 and is present on both of the check valves 42 which are held on their seats by supply valve springs 41. The supply line is also connected to the top of the upper ball valve in the control valve portion 47, with the lower ball valve seated to hold speed line 8 pre-loaded to a definite pressure, say 8 psi.

When the handle is moved to the right (ahead position) it pivots on pin 20, moving the bottom end of the handle to the left. This, through cam action, operates ON/OFF valve no. 6 by means of lever 23. Plunger 36, being moved in by lever 23, closes off the exhaust port and unseats check valve 42 allowing supply air to flow to direction line 6.

For astern operation, the handle movement is to the left of neutral, with ON/OFF valve no. 7 functioning in the same manner as no. 6 and allowing supply air to flow to direction line 7.

When the direction line has been selected, pressure graduation (speed) is controlled by moving the handle in the speed control slot. This movement rotates heart-shaped cam 30, transmitting downwards travel on cam roller 50 and valve assembly 69. This action unseats the upper ball valve as the inlet spring is compressed. The air flows from the supply pipe, past the upper ball valve to speed line 8, until the delivery pressure, as determined by the position of the handle is reached. As the air pressure above the diaphragm increases, the diaphragm will be forced downwards compressing the graduating spring, allowing the inlet spring to close the upper ball valve against its seat, thus cutting off the flow of supply air.

If, while the handle is in position, the pressure in the speed line should decrease due to leakage, or temperature change, the pressure on the diaphragm will be reduced. The valve assembly will move upwards and open the inlet valve to restore the proper delivery air pressure. When this pressure is reached, the valve assembly will lower, permitting the inlet valve to reseat itself. Excess pressure in the speed line will cause the diaphragm and the exhaust valve seat to move downward, away from the lower ball valve and allow excess pressure to vent to atmosphere. When the pressure has been decreased to the desired delivery pressure, the diaphragm spring will be able to raise the diaphragm and the exhaust valve seat against the lower ball valve thus cutting off any further venting of excess pressure to atmosphere.

If the handle is moved to decrease the pressure the valve assembly moves upward, with the upper ball valve held on its seat by the inlet valve spring, and lifts the lower ball valve from the exhaust valve seat, thus venting the excess pressure in the speed line to atmosphere through the spring chamber. As the pressure decreases, the force on the diaphragm decreases permitting the diaphragm spring to move the exhaust seat towards the exhaust ball valve. When the pressure, as determined by handle position, has been reached the exhaust valve closes.

8.2. ELECTRIC CONTROL ELEMENTS

The requirements of electric control equipment vary according to the application but, in general, the control equipment includes units for all or most of the following operations:

(i) Starting.
(ii) Speed control.
(iii) Reversing.
(iv) Stopping.
(v) Switching off the supply automatically if operating conditions become abnormal, e.g. overload, short circuit, phase failure, and under voltage.
(vi) Isolation of motor and control equipment from the supply.

All these operations can be effected by well-known conventional items of equipment such as circuit breakers, switches, fuses, contactors and relays. The reader will be familiar with the use of such conventional items from basic electrical engineering courses or, if not, information on the application of such items can be obtained from any standard textbook on electrical engineering.

With open-loop control it is advantageous to control the final motor element (or actuator) by means of a low power signal. With closed-loop control, the signal which is delivered from the sensing element is inherently a low power signal. Consequently a suitable means of amplification must be employed before the main power element and the methods available at the present time are:

(i) Standard d.c. exciters.
(ii) Two-stage, cross-flux excited d.c. machines, e.g. amplidynes.
(iii) Valve amplifiers.
(iv) Magnetic amplifiers (or transductors).
(v) Transistor amplifiers.
(vi) Thyristors (or silicon controlled rectifiers).

(a) *Rotary Amplifiers*

An ordinary d.c. exciter may be regarded as a power amplifier since the power required to excite its field fully is considerably less (by a factor of, say, 100) than the power delivered by the armature. An example of this application is the Ward–Leonard control used in deck machinery and in some steering systems.

One of the best examples of the two-stage cross-flux excited exciter is the amplidyne. Thousands of such machines are in service and the normal working power amplification of the amplidyne is about 2500 to 1 and it has a very good rate of response.

The drawback of such rotating amplifiers is, of course, that they contain rotating parts which necessitate bearings and commutators together with associated brush gear, all of which require maintenance.

(b) *Valve Amplifiers*

In spite of a marked reluctance to admit thermionic valves into control systems certain applications have demanded such a high degree of accuracy that in the past there has been no other solution, e.g. control of the gyro compass. However, for any control system reliability is of paramount importance and maintenance must not be a lengthy and complicated procedure. The standard of electronic circuit components has been dictated largely by the radio industry, which is by far the largest user. Under marine working conditions the reliability of these components has often proved inadequate.

(c) *Magnetic Amplifiers*

Sometimes referred to as "transductors" magnetic amplifiers came into use because of the limitations of thermionic valves and the rotary amplifier. A schematic diagram of the circuit is shown in Fig. 8.9.

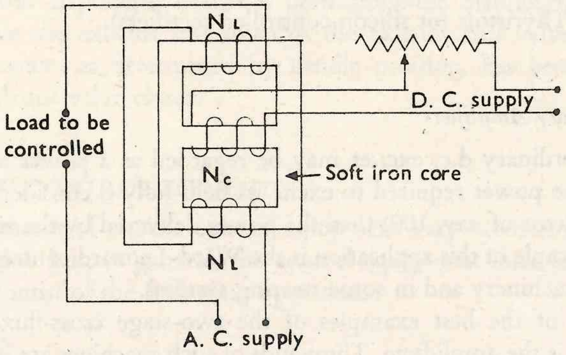


FIG. 8.9. Magnetic amplifier (transductor).

By applying a controlled d.c. current to coil *Nc* the flux density can be increased until the core is saturated. At this point the device is highly sensitive and a small change in the d.c. current, say a signal from a sensor/transducer, will immediately vary a relatively large load in the winding N_L.

Such amplifiers are robust, have no moving parts and require no routine attention. The power amplification per cycle of a single stage magnetic amplifier is in the region of 100 to 1.

A reduction in weight and size and an improved rate of response may be obtained by increasing the frequency of supply but a fairly delicate design compromise is necessary; the optimum would appear to be about 400 c/s. The additional expense of a special 400 c/s alternator could be justified only where many magnetic amplifiers are required, however.

The magnetic amplifier shares with the amplidyne comparative freedom from electrical interference. On the other hand, the magnetic amplifier is not inherently reversible, and if required for a reversing operation it usually has to be duplicated in a push–pull arrangement of some kind. This requires that each amplifier is at least double the rating of the field winding constituting the load. This tends to make the magnetic amplifier expensive for such applications.

(d) *Transistor Amplifiers*

While magnetic amplifiers can be designed for ratings from a fraction of a watt up to 100 kW or more they are now facing increasing competition from the transistor and the silicon-controlled rectifier (or thyristor). The former rivals the magnetic amplifier at the lower end of the power range and the latter at the higher end.

Transistor amplifiers are suitable for outputs up to about 100 watts and can be relatively inexpensive. The response is fast (a few milliseconds) and a typical amplifier has a power amplification of 10^8. The need for duplication in the event of a reversible output being required is relatively unimportant at the power level used.

The power level of transistor amplifiers may be extended by the use of a technique in which the transistor is rapidly switched between the fully-conducting state and the non-conducting state. The relative times spent in these two states is varied in order to achieve the desired control of mean output from the amplifier. Such an amplifier is often called a "mark-space" amplifier. This operation at a higher power level is permissible because internal energy dissipation of the transistor is kept low compared with the state in the conventional amplifier.

(For further details on transistor theory and for the use of transistors as "on-off" devices the reader is referred to Chapter 11.)

(e) *Thyristors and their Applications*

The Thyristor, widely referred to as the silicon-controlled rectifier, is the most important recent solid-state development, certainly in the power field, since the introduction in the mid 1950's of the semiconductor power diode.

It is a solid-state device with door-like characteristics, i.e. it can be opened or closed at will, permitting or preventing the flow of current in one direction, or in neither when shut.

Its electrical characteristics can be loosely represented by the contactor analogy in Fig. 8.10 (a).

When switch *G* is closed the main contactor *C* is actuated by coil *M* and a current flows from the supply to the load and, at the same time, energizes the holding coil *H*. Further operation of switch *G* makes no difference to the flow of current and contactor *C* cannot be opened except by breaking the circuit current, say, by opening *D*. The rectifier *R* is inserted to signify that under no conditions can reverse current be made to flow. Below a specified value of load current there is the possibility of contactor *C* dropping out—this represents the minimum holding current of the thyristor.

Fig. 8.10 (b) shows a thyristor performing the same basic function. In this case forward conduction can only occur when the supply is of the correct polarity, due to the rectifier action, and is initiated by the application of a small pulse of current into the gate *G* supplied by the trigger circuit *T*. Alternatively a bias voltage may be applied to the gate with respect to cathode, and conduction will occur when the forward voltage across the device reaches a pre-determined value. As in the analogy, conduction can only be stopped when the current is interrupted by some other means such as opening switch *D* or, in the case of an a.c. supply, when the current passes through zero. Without the application of a trigger pulse no conduction can occur and, once flowing, the current is in no way influenced by the gate.

The electrical characteristics are as shown in Fig. 8.10 (c). This shows that forward conduction can be initiated at any forward voltage, by the application of the gate signal, or by forward breakover when the supply voltage exceeds Vbo. The control of conduction refers only to the point in time when it is initiated and in no way does the device control the value of the current flowing, this being determined by the circuit constants and the applied voltage.

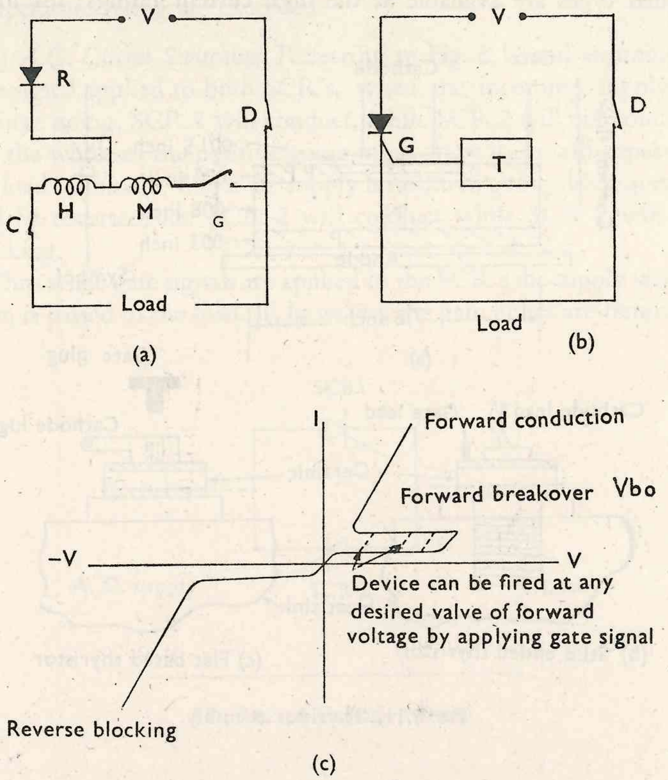
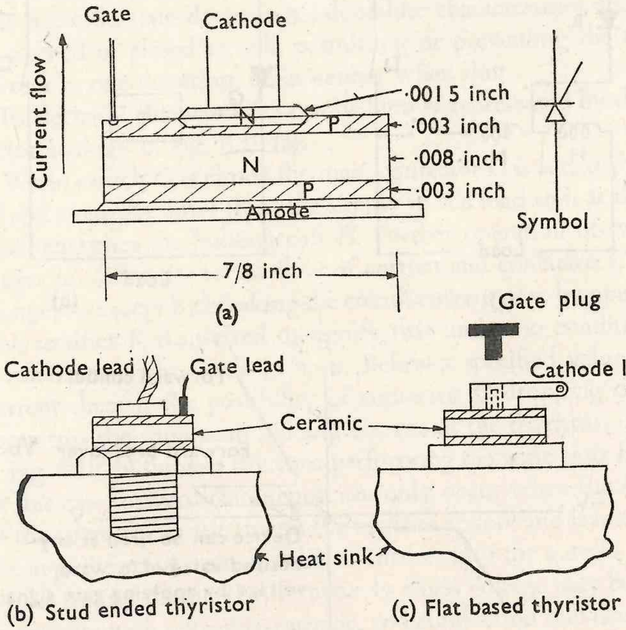


Fig. 8.10. Thyristor operation and characteristics.

In practice a thyristor has a cross section as shown in Fig. 8.11 (a). The approximate dimensions are given to show the order of precision required, particularly in the 0·0015 in. base region which controls the firing characteristics. (For details of N and P materials the reader is referred to Chapter 11.) The semiconductor unit is housed in a case or capsule. This provides connection to the device for heat dissipation and for electrical purposes and also provides mechanical protection. This is shown diagramatically in Fig. 8.11 (b) and (c). In Britain and on the Continent both flat-based and stud-ended types are available at the high current ratings; for lower



(b) Stud ended thyristor

(c) Flat based thyristor

FIG. 8.11. Thyristor assembly.

ratings stud-ended types are used. In the U.S.A. all sizes are generally stud-ended. Most thyristors today are filled with dry inert gas to ensure the best possible conditions for the junction region.

The most important points in favour of thyristors are small size, long life, low auxiliary power requirements, not affected by vibration and shock, can operate in any position, very high efficiency and fast response time. Against this is the fact that permanent damage

will result if the rated voltage, forward current capacity or maximum temperature rating are exceeded.

(i) *A.C. Circuit Switching*. Referring to Fig. 8.12 and assuming a gate signal applied to both SCR's, when the incoming supply is positive going, SCR 1 will conduct, while SCR 2 will not conduct and the whole of the positive going input wave form will appear at the load terminals. When the supply is negative going this sequence will be reversed, i.e. SCR 2 will conduct while SCR 1 will be blocking.

Thus while gate signals are applied to the SCR's the supply waveform is passed to the load. If, however, the gate pulses are removed

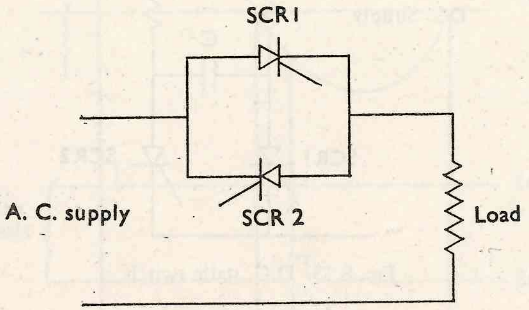


FIG. 8.12. A.C. static switch.

both devices will always block the current. Removal of the gate pulses will not instantaneously switch the rectifiers to the non-conducting state but switch-off occurs as the supply passes through a voltage (or current) zero. In the worst case, therefore, switching occurs at something less than one-half cycle after removal of the gate signal.

(ii) *D.C. Circuit Switching*. This is illustrated in Fig. 8.13.

Application of a gate signal to SCR 1 causes it to switch into the conducting state and voltage is applied to the load. At the same time the right-hand plate of capacitor *C* is positively charged with respect to the left-hand plate through resistor R.

If SCR 2 is now "turned on" by a signal to its gate, capacitor *C* becomes connected across SCR 1 via the low resistance of SCR 2 which is in the "on" state. This reverse biases SCR 1 (positive connected to cathode). Providing that at this time the gate signal is removed from SCR 1, this reverse voltage causes SCR 1 to "turn off" thus interrupting the current in the load.

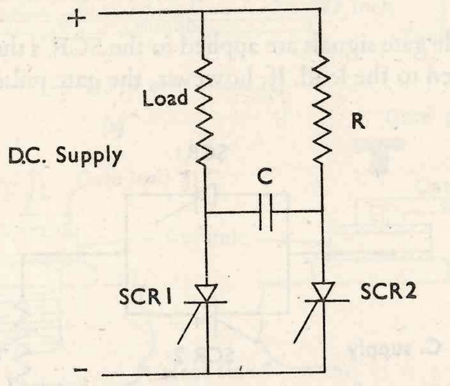


FIG. 8.13. D.C. static switch.

Although SCR 1 must handle the full load current, SCR 2 only conducts for a short period (the turn-off time of SCR 1). Consequently SCR 2 can be of lower current rating. A mechanical switch could be substituted for SCR 2 if desired.

(iii) *Provision of Variable d.c. Voltage from a.c. Supply.*

Figure 8.14 shows a single phase bridge rectifier with two arms containing controlled rectifiers, the other two arms having ordinary rectifiers.

With no gate signals applied to the SCR's no output is obtained. To obtain full wave rectification, two separate gate signals are required displaced one from the other by 180 electrical degrees.

These are shown in the diagram which also shows the input waveform and the output waveform for a resistive load.

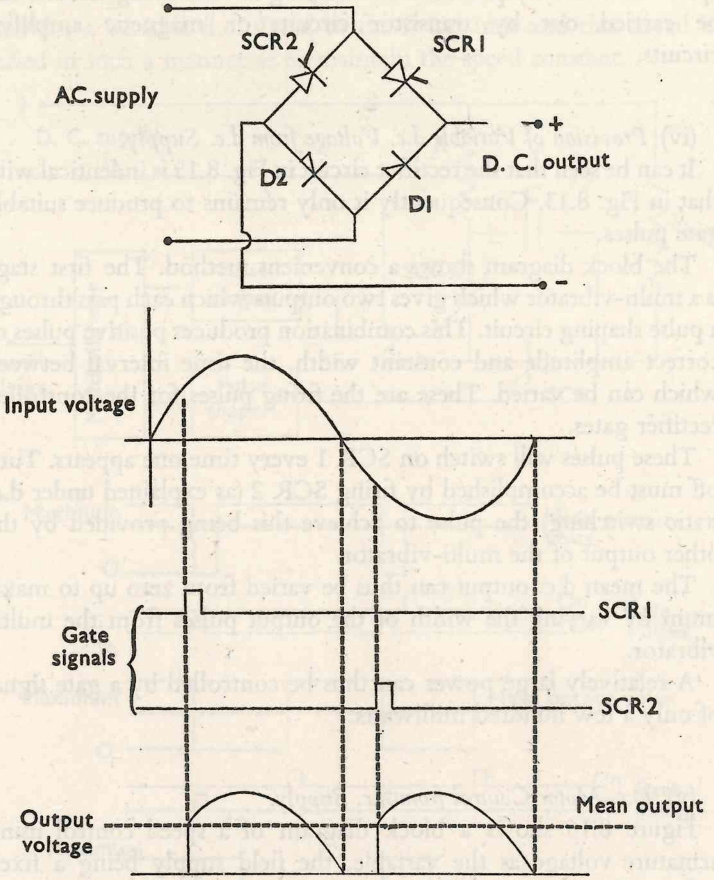


FIG. 8.14. Variable voltage d.c. from a.c. supply.

In the diagram the gate signals appear at approximately 60° but can be varied between zero and 180°. Thus an output voltage is available which is infinitely variable from zero (no conduction) to a complete replica of the supply waveform.

The pulses applied to the gates are normally obtained from the positive and negative half cycles of the supply and consequently 180° apart and correctly phased. Pulse shaping for the firing circuits can be carried out by transistor circuits or magnetic amplifier circuits.

(iv) *Provision of Variable d.c. Voltage from d.c. Supply.*

It can be seen that the rectifier circuit in Fig. 8.15 is indentical with that in Fig. 8.13. Consequently it only remains to produce suitable gate pulses.

The block diagram shows a convenient method. The first stage is a multi-vibrator which gives two outputs which each pass through a pulse shaping circuit. This combination produces positive pulses of correct amplitude and constant width, the time interval between which can be varied. These are the firing pulses for the controlled rectifier gates.

These pulses will switch on SCR 1 every time one appears. Turn off must be accomplished by firing SCR 2 (as explained under d.c. static switching) the pulse to achieve this being provided by the other output of the multi-vibrator.

The mean d.c. output can thus be varied from zero up to maximum by varying the width of the output pulses from the multi-vibrator.

A relatively large power can thus be controlled by a gate signal of only a few hundred milliwatts.

(v) *D.c. Motor Control from a.c. Supply.*

Figure 8.16 shows a block diagram of a speed control using armature voltage as the variable, the field supply being a fixed voltage.

The full lines indicate the components necessary for open-loop control while the additions necessary to provide a closed-loop control are shown by dotted lines.

In the diagram, a tacho generator provides a signal proportional to motor speed, which is fed back into the controller. The controller provides a variable d.c. signal to the firing unit and this signal is varied in such a manner as to maintain the speed constant.

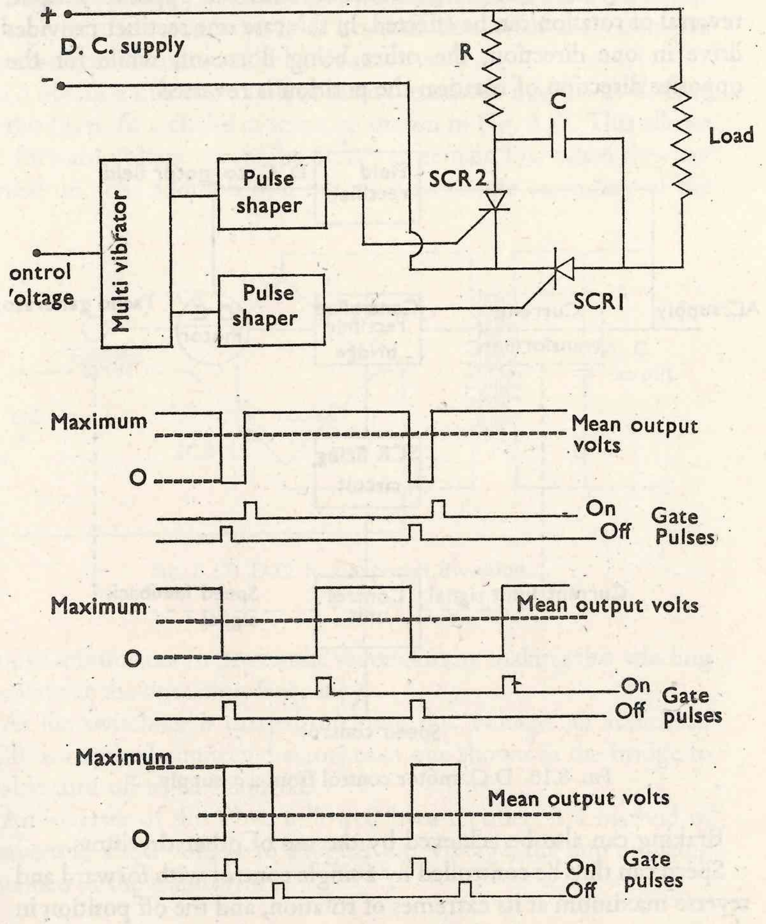


FIG. 8.15. Variable voltage d.c. from d.c. supply.

In addition, a current transformer in the a.c. input lines provides a small current at its secondary terminals, which is fed into the controller and used to limit the input current by reducing the firing point of the controlled rectifiers when it exceeds a pre-set value.

By fitting another bridge rectifier with an opposite output, reversal of rotation can be effected. In this case one rectifier provides drive in one direction, the other being dormant, while for the opposite direction of rotation the position is reversed.

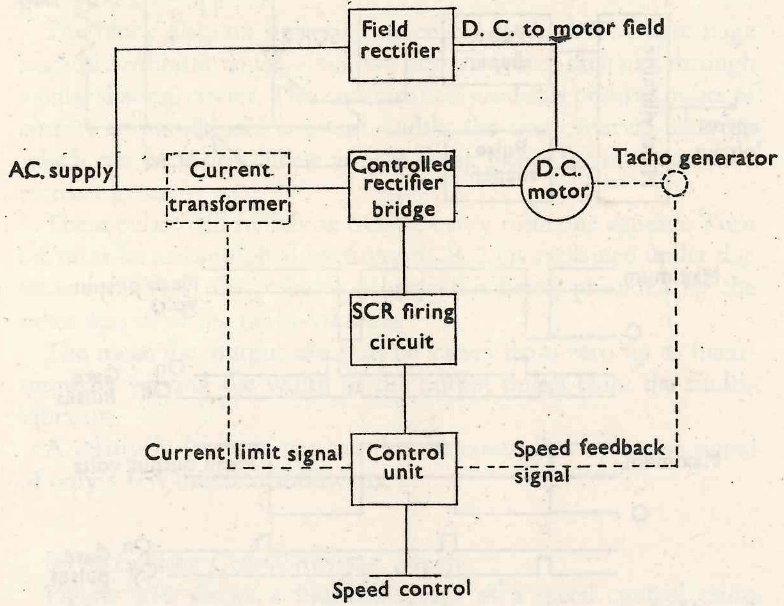


FIG. 8.16. D.C. motor control from a.c. supply.

Braking can also be achieved by the use of other thyristors.

Speed can thus be controlled by a single control with forward and reverse maximum at its extremes of rotation, and the off position in the centre, regenerative braking being effective in either direction whenever the speed setting is reduced or reversed.

(vi) *D.C. to a.c. Power Inversion.* The inverter is the inverse of a power rectifier.

In Fig. 8.17 SCR 1 and SCR 2, and SCR 3 and SCR 4 are turned on alternately, current being switched in alternate directions through the primary of the output transformer, and inducing an a.c. voltage in the secondary. It is obvious that with the circuit as described the output would be a square wave.

To obtain a sine wave output several methods may be used. One method is to fit a choke in series, as shown in Fig. 8.17. This allows the forward voltage across the SCR's to remain low when they are turned on. The addition of a capacitor across the secondary of the output transformer improves the waveform by making this winding resonate at the operating frequency.

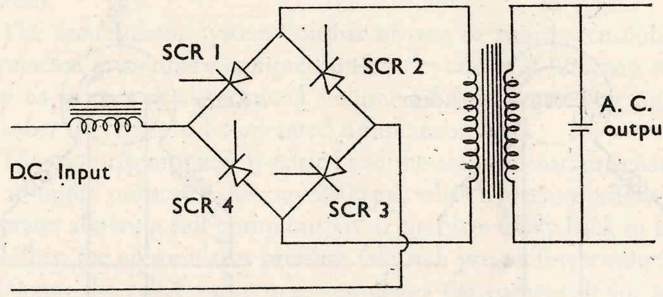


FIG. 8.17. D.C. to a.c. power inversion.

As the switching is carried out on a d.c. voltage, an additional SCR is required connected across each one shown in the bridge to enable turn off to be achieved.

An inverter of this type, followed by a rectifier, is a method of converting a d.c. voltage to a higher d.c. voltage, the step up being obtained in the transformer.

(g) *Synchros (Self-synchronous machines)*

This group of devices bears trade names such as Dessyn motors, Magslips and Selsyn motors. The machines are a special type of a.c. motor. The transmitting and indicating units are connected electrically as shown in Fig. 8.18.

In some designs the rotors are energized by 50 or 110 volts a.c. and in others by 12 or 24 volts d.c.

The transmitter and indicator work as though they were coupled by a flexible shaft. If the rotor of one synchro is displaced current will flow to react with the magnetic fields and will produce torques tending to restore the rotors to coincident positions. If one rotor is displaced the rotor of the other motor will immediately be displaced to take up the same position.

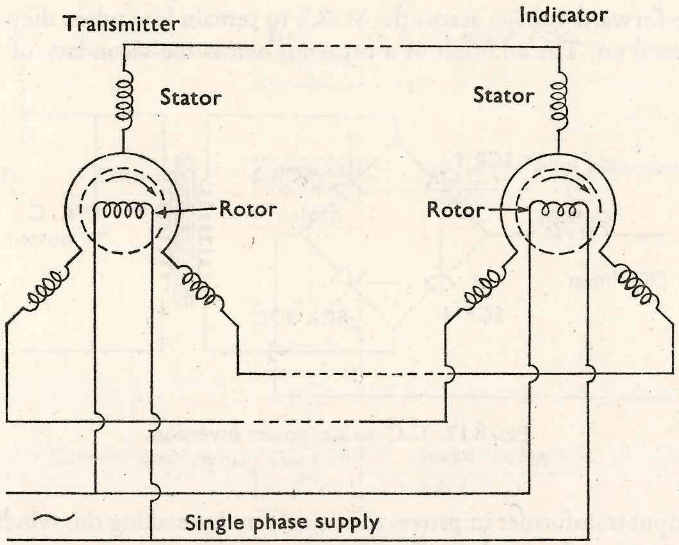


Fig. 8.18. Diagram of synchro transmission.

They are widely used but particularly in steering-control systems and in ship stabilizing units.

8.3. HYDRAULIC CONTROL ELEMENTS

A hydraulic system normally consists of a self-contained power pack, control and indication system and the requisite number and types of actuators. The power pack is installed in some convenient location, e.g. the engine room, and a pair of pressure lines run the length of the ship with branch lines to each control point.

(a) *Power Equipment*

This consists of an electric motor driving a hydraulic pump. The pump draws fluid via a filter from a supply tank and the pump outlet is connected to a pressure relief valve. This is set to a suitable value (e.g. 3000 psi) to safeguard the pump unit from excessive operating pressures, the relief port being connected back to the tank via a non-return valve. Downstream of the pressure relief valve the pump output passes through a non-return valve to the accumulator system.

The accumulator system consists of one or more accumulators connected to auxiliary compression bottles and is of sufficient capacity to store a predetermined volume of fluid depending on the number of valves to be operated simultaneously.

The motor/pump unit is started and the accumulators are charged to an upper pressure value, say 2800 psi, when a pressure relief valve operates allowing full pump output to circulate freely back to tank.

When the accumulator pressure falls to a pre-set lower value, say 2600 psi, the relief valve operates, closes the path to drain, automatically bringing the pump back on load to recharge the accumulator to cut-out pressure when the cycle is repeated.

(b) *Control Valves*

Control valves are available in a wide variety of types and can be operated by hand lever, by mechanical means or by hydraulic pressure. The valve contains a centralized spool with tapered lands and the action is shown in Fig. 8.19.

It can also incorporate a pilot switch (for wiring into a contactor starter). This switch is closed when the operating lever is moved in either direction from the neutral position. With this arrangement the system pump motor can be switched on or off