The Application of Modern Instrumentation and Distance Control of Machinery

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It is intended to limit the scope of this paper to the instrumentation and distance control of the type of mechanical machinery fitted in ships.

The necessity for instrumentation has always been accepted but the same cannot be said of distance control. In modern processes dealing with fine limits of operation and substances dangerous to human life, instruments and distance control by either manual or automatic means has become of vital importance.

The paper sets out to describe various types of instruments used for measuring and indicating the more common quantities such as pressure and temperature, etc., and discusses their grouping and location. Distance and automatic control instruments are similarly treated and the scope of such equipment discussed with particular reference to the operating medium and its suitability for use in ships at sea.

The problem of control at sea compared with established practice on land installations is discussed with examples illustrating good and bad practice, and conclusions are drawn indicating the future rôle of this particular branch of engineering.

INTRODUCTION

The title of this paper covers such a wide field that it is necessary to define and limit its scope in order to restrict the information to that considered generally of interest to the readers. Accordingly, it was thought that a discussion on general principles, together with particular examples of instrumentation and distance controls as applied to marine mechanical machinery (as opposed to radio work), would be most suitable.

Instruments are used to enable physical and chemical changes to be indicated and recorded so that the condition of equipment or state of a process is readily apparent. Plant conditions having been displayed, the next step is to provide the operator with controls to adjust the variables for correct functioning of the machinery. If controls are locally mounted it is difficult to observe the result of any corrective action and the logical solution is to group both controls and instruments together. It is usual to mount the instruments and controls either on one common panel or on separate panels adjacent to each other, thus enabling the operator to observe the effects of his actions without excessive movement.

Man is an instrument, as he can be used for detecting certain physical changes. His sensitivity is very low generally and he suffers from a lack of objectiveness which makes him an expensive and inefficient instrument. Similarly, his reactions to the changes he detects may be slow and the adjustments he makes as a result of such changes may be ill-judged. Where rapid response and accurate adjustments are required, therefore, it is nearly always preferable to use an automatic controller in place of man.

There is available a wide range of instruments and controls and the choice in each instance should represent a balance between cost, accuracy required and reliability. In some cases it becomes necessary to design a special instrument or control system to suit particular requirements but before this is attempted the possibility of using standard equipment slightly modified should be thoroughly investigated. It is essential for a close study of each problem by engineers familiar with the range of available equipment to precede the fitting of instruments and controls, if an economic and suitable arrangement is to be achieved.

In the past there has been, unfortunately, rather a tendency to treat instrumentation as a necessary evil, to be engineered after everything else and installed as cheaply as possible without thought for its particular requirements. Operators took the attitude that instruments were fitted specifically to check their activities instead of to assist them in their work. They therefore took every opportunity to assist materially the normal vibration and shock forces to which apparatus is subjected at sea with the result that it was an easy matter to demonstrate the gross inaccuracy of an instrument after, perhaps, only twenty-four hours of operation. It is, therefore, extremely important that operators should be made aware of the reasons for and the rôle of instruments in the day-to-day operation of a plant. With the increasing complexity of machinery and danger to life, the rôle of instruments and distance controls is becoming of vital importance and takes its place with major items of the process machinery.

It is not always realized how important it is for operators to be accurate and there must be very many cases of first class

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instrument arrangements being absolutely wasted by slovenly recording and setting of charts.

Some instruments perform the dual function of indicating (and/or recording) some quantity or characteristic while, at the same time, controlling it. It will be apparent, therefore, that instrumentation and distance control are very closely connected and in studying a system arrangement they should be treated together. However, it is intended initially to deal with these two aspects separately in order to give a clear picture of these functions.

It is the author's opinion that the overall value of an instrument and control arrangement must be based on an assessment of the following points.

(1) Instrument accuracy and sensitivity.
(2) Position of both detecting element and indicator.
(3) Maintenance and checking.
(4) Operator/observer accuracy.

Until recently there has been a lack of standardization in the terminology and graphical representation of instruments and distance controls and this had led to some confusion. It is the author's hope that in future more general use will be made of the terminology and symbols contained in British Standards 1523 and 1646.

For convenience this paper has been divided into the following main sections: —

(1) Instrumentation.
(2) Distance Controls.
(3) Arrangement and Application.
(4) Conclusions.

INSTRUMENTATION

The vast majority of instruments in use within the scope of this paper may be divided and grouped under the following general headings: —

Temperature
Pressure
Level and quantity
Power
Speed and movement
Flow
Gas and water analysis.

Temperature

Vapour or liquid filled thermometers may be employed for measuring temperatures up to 1,000 deg. F., but the recommended upper limit is approximately 850 deg. F. as the error may become unacceptable above this figure, even though all known precautions are taken.

For accurate temperature measurement over the range 850 deg. F. to 2,500 deg. F. the thermocouple or the resistance thermometer is normally used. The former depends on the phenomenon that an electric potential is set up at the junction of two dissimilar metals when this is heated to a temperature above the remote ends which form the cold junction. The dissimilar metals used in thermocouples are chosen according to the temperature to be measured and a good guide for accurate measurement is: —

Up to 700 deg. F. ...	iron/Constantin
700 deg. F. to 1,800 deg. F.	chromel/alumel
1,800 deg. F. to 2,500 deg. F.	platinum/platinum-rhodium

Resistance thermometers operate on the principle that the electrical resistance of particular materials varies with temperature and it is considered good practice to use platinum wound on mica, or quartz for the higher temperatures.

It is now fairly general practice to use a temperature transmitter which measures and converts the temperature into a fluid or electric impulse. The conversion is carried out locally to the measuring point and then transmitted with the minimum of lag to the indicating and/or recording instrument, which may be situated far away. Fig. 1 shows the fluid type employing a fluid-filled temperature-sensitive measuring system while Fig. 2 indicates the electric type which is actuated by a thermocouple element.

The visual method depends on the variation in wavelength

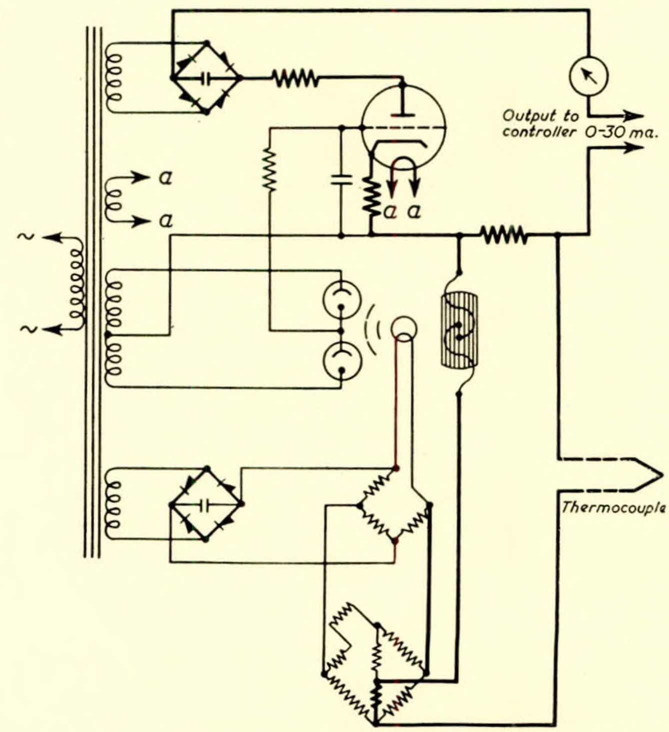

FIG. 2—*Diagrammatic arrangement of temperature transmitter —electric impulse*

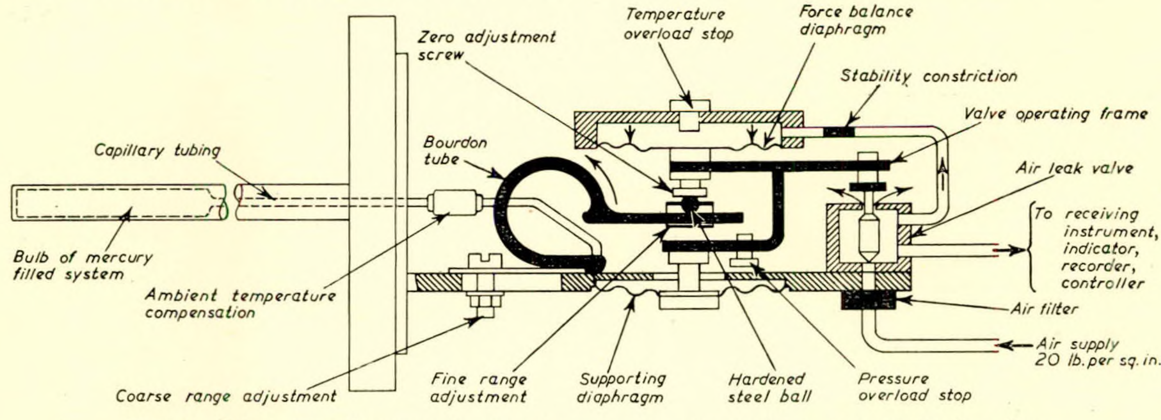

FIG. 1—*Diagrammatic arrangement of temperature transmitter—pneumatic impulse*

of the energy emitted from the heated object, the level being measured in terms of colour (e.g. the old method of tempering chisels, etc.).

Pressure

This is a fairly easy problem and the only real difficulties are those arising in the measurement of high vacua and small differentials at high pressure. For medium and high pressure it is usual to use the well known bourdon tube, which is a robust and well-tried instrument. For low and medium gauge pressures a bellows is often employed, while for low gauge pressures a diaphragm is often the better choice and the robust and easily maintained "U" gauge with mercury, water or an oil filling is simple and effective. The position of pressure gauges very often leads to the application of a static liquid head, and where this is large care should be taken to make the necessary compensation.

The measurement of vacua presents a special problem as the difference between, say, 28in. Hg and 27·5in. Hg vacuum may mean the failure of a plant to operate and it is obvious that when measuring an absolute pressure of 50 mm. of mercury, a normal barometric variation could amount to an error of 50 per cent. A well known absolute gauge used extensively for condenser work is the Kenotometer. For more sensitive measurement the capsule instrument and absolute gauge are useful, the latter being mainly used for test readings. Fig. 3 shows an absolute gauge called a "Vacustat".

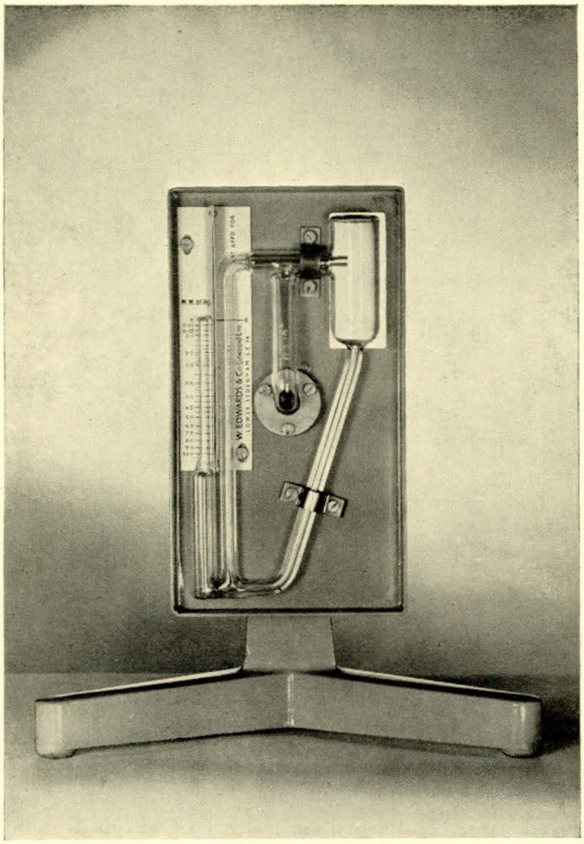

FIG. 3—*"Vacustat" absolute pressure gauge*

Differential pressures may be measured conveniently by means of "U" gauges employing suitable liquids. This method is satisfactory even for high pressures when the differential is not too large but the apparatus becomes rather unwieldy for differentials in excess of 50lb. per sq. in.

In boiler work, where draught gauges are employed to measure the comparatively small pressures in flues and air ducts, it is essential to take great care with the connecting pipework. This should have a bore of at least ¾ inch and be run in a manner to avoid pockets where moisture can accumulate and suitable removable plugs should be provided to facilitate the cleaning of lines periodically.

For accurate measurement of small differentials such as velocity head measurement, the inclined tube gauge filled with a suitable fluid is simple, cheap and effective. Direct reading gauges for measuring differential pressures of the order of 10 per cent of the maximum pressure are based on common gauge practice. For greater accuracy a diaphragm system driving the pointer through a magnetic coupling is used, but the maximum pressure is restricted to 850lb. per sq. in. gauge at present although undoubtedly this figure will be raised in the course of time. For differentials at higher pressures it is possible to obtain accurate readings by means of an indirect system, utilizing either fluid or electric means for transposing extremely small diaphragm or bellows movements into proportional pressures or current. The principles of instruments utilizing pneumatic and electric means for transmitting are shown in Figs. 4 and 5 respectively. These types of instruments are also in wide use for measuring pressures and are termed pressure transmitters. The main principle employed in accurate instruments of this type is the "force balance" system. This system is designed to compensate while in service for the effects of slight wear and changes in material properties of bellows, springs, etc., and operates on the principle that the disturbing force is exactly balanced by a force produced by the change in transmitted pressure or current.

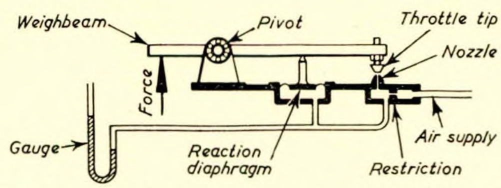

FIG. 4—*Diagrammatic arrangement of differential pressure transmitter—pneumatic impulse*

Level and Quantity

These two properties have been grouped together as level measurement is nearly always an indication of quantity or quantity variation depending on the observer's knowledge about the containing boundaries.

There are many suitable instruments on the market for indicating and recording either the level or contents of tanks and these may be of the self-actuating type for distances up to some 50 feet between gauge and tank. Those utilizing an external source of fluid or electric power may be used for indicating at much greater distances.

The fluid type utilizes air, either from a constant supply source or a hand pump, to balance a diaphragm against the tank fluid head. The electrical type requires a continuous power supply and operates on the force balance principle. The transmitted current, which may vary from 0 to 30 m.a. can be used for indicating and/or recording. The use of electrical transmission enables changes to be transmitted over very large distances with an extremely short lag and the transmitting equipment is made intrinsically safe so that it is suitable for use with many inflammable fluids.

The most simple form of level indicator is, of course, the gauge glass, its only real disadvantage being the necessity for local mounting. There are several ways of obtaining remote indication, the two most familiar being by mirrors and the use of a second similar gauge filled with a non-miscible fluid. Both these methods are used extensively in indicating the all-important water level in steam boilers. The mirror system is very reliable but suffers from the disadvantage that definition is poor over distances of above 80 feet and the image is difficult

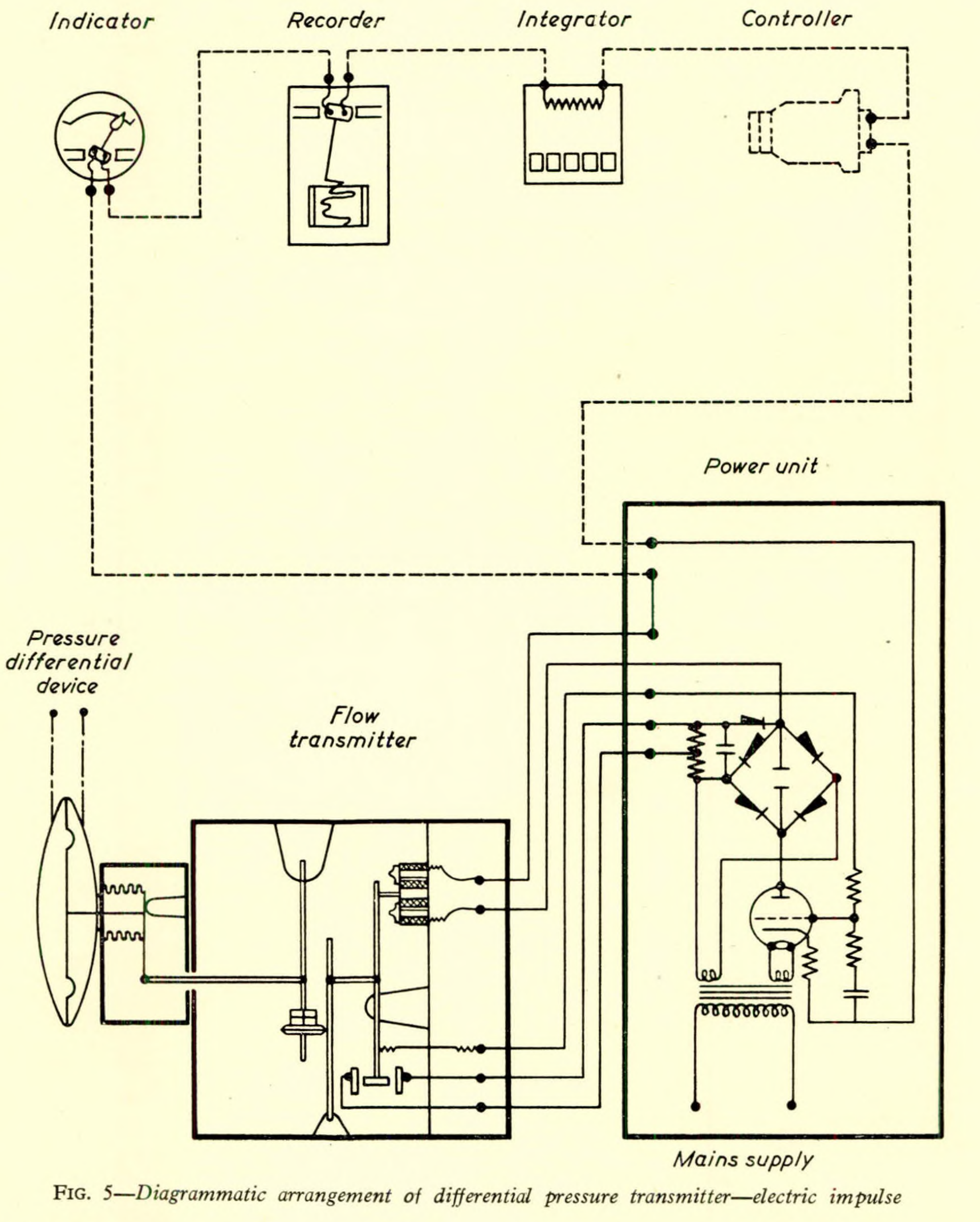

FIG. 5—*Diagrammatic arrangement of differential pressure transmitter—electric impulse*

to see except from a limited area. The second method is also reliable and is more easily observed but suffers from the disadvantage that it must be fitted either below or at the level of the fluid interface to be indicated. As processes become more complicated and the size of plant units increase, the distance between the measuring source and indicating point may be hundreds of feet and as it is not desirable to have long instrument pipes carrying high pressures, the modern trend is to transmit boiler water level by fluid or electric means. In the two types of instruments the principles involved are very similar and the systems provide for a great degree of flexibility. Here again the electrical system is faster in overall response but the difference is small enough to be neglected for boiler water level indication and recording under all normal plant arrangements. The transmitters are designed on the force balance principle and produce an electrical or fluid pressure signal proportional to the deviation of the level from the desired value. The electrical type produces a constant current at each output value if the external circuit does not exceed the recommended resistance and it is thus possible within this limit to add additional indicators or recorders by simply wiring them in series.

A method of remote level indication which is comparatively expensive but is gaining popularity with large boiler installations is the so-called "closed circuit" television equipment. A typical diagrammatic arrangement is shown in Fig. 6 and consists of a camera connected by cable to a receiver. The camera operates on the "Flying Spot" principle and is positioned approximately 3 feet from the gauge glass on which it is focused. The circuit adopted is simple, very reliable and produces a clear and well defined image as long as the gauge glasses are not too thick. This system cannot indicate a false

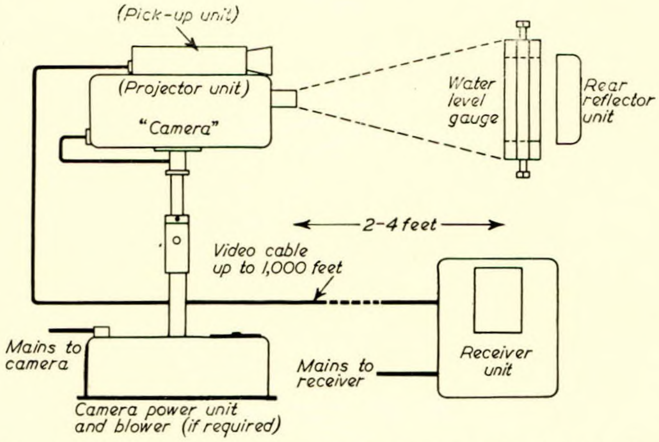

FIG. 6—*Diagrammatic arrangement of water level indication by television*

water level (unless, of course, the water gauge becomes choked) and is, therefore, a very valuable addition from the safety point of view. A rather similar system employing a camera of the television broadcasting type can be used for the observation of boiler furnace conditions and remarkably good pictures have been obtained. Furnace observation is used to indicate partial or complete loss of ignition as this can produce a highly dangerous condition resulting in an explosion. Another method for indicating excessively low furnace flame conditions without using television is the use of a photo-electric cell employing a special circuit and actuating an audible and visible alarm.

Power

It is a fairly simple matter to measure electrical power by the use of watt meters, power factor meters, etc., but the indication of shaft horse power is more difficult.

High horse power turbine machinery is usually fitted with an instrument called the torsionmeter, which can be calibrated to read directly the torque transmitted. The measurement is carried out electrically and transmitted to the instrument panel. Another type employed measures the actual shaft thrust by means of special pistons which are loaded to balance the thrust of the propeller shaft. This system has the advantage that fouled or bent propellers are apparent from the readings. It is not intended to describe these instruments as the field is very wide and could form the subject of a separate paper.

Speed and Movement

The instruments used for indicating and measuring speed are very well known and it is not intended to describe the large variety available.

It has become necessary to measure the transverse and axial movement of rotating shafts and while the latter measurement may be carried out fairly simply, the former is rather difficult. During the initial warming and running up of large turbine machinery, it is necessary to know the axial clearance and also whether any shaft distortion has occurred. Equipment for indicating these features is called supervisory gear and is fitted to many power station turbines.

Flow

The measurement of rate of flow of fluids such as water is comparatively simple when the system is under atmospheric pressure. The usual method of employing a "V" notch weir is suitable for many applications but where accuracy is required the fluid must be weighed. For viscous fluids and where temperature variations are very wide the only really accurate means is by weighing although it is now claimed that fluids which are electrically conductive may be measured by electro-magnetic means, giving an indication which is proportional to the weight passing in a given time.

In order to measure the flow of gases or fluids under pressure the most usual methods used are the venturi and orifice plates. The orifice method takes up less space, is cheaper and produces a larger permanent pressure loss than a correctly designed venturi but it is used quite extensively where the required accuracy of measurement does not involve a large pressure loss. These types of instruments have to be very carefully calibrated and allowances must be made if the operating conditions vary from those for which they have been calibrated.

There are many industrial flow meters available which are reasonably accurate and work on the principle of a vaned rotor immersed in the fluid to be measured. This type is rather susceptible to wear. Another type employs a vaned or grooved float mounted in a vertical tube up which the fluid flows. The float takes up a position in accordance with the velocity of flow and suitable calibration enables a direct reading to be made from the float position. Where several flows are related to each other it is possible to mount an equivalent number of these flow indicators alongside each other and arrange a particular relationship between them for correct operating conditions, e.g., all floats in line.

Gas and Water Analysis

The two most well known instruments in the marine field are the CO_2 meter and the salinometer.

There are three types of CO_2 meters, all utilizing electricity as the motive power but differing in principle of operation and falling into the following groups:—

(1) Chemical absorption.
(2) Electrical conductivity.
(3) Gas density.

The first two methods are used extensively in this country, but the third, which employs two similar fans, one pumping air and the other the gas to be measured, is not known quite so well. The application of all three methods is rather similar and the result of analyses may be electrically transmitted to a distant point if required.

If long lines connect the instrument to the measuring point, it is necessary to use some type of aspirating equipment in order to reduce the time lag in measurement, which may be considerable.

These instruments are reasonably reliable but should be checked periodically by an Orsat. In many cases faulty operation of these instruments can be traced to badly run interconnecting piping, which should be erected carefully to eliminate pockets which collect moisture formed by the condensation of water vapour in the flue gas.

Salinometers are electrical conductivity instruments and are used to indicate the quantity of sodium chloride or chlorine in water, usually condensate returned from a steam condenser or evaporated make-up water. Instruments are usually graduated to indicate either parts per million (or hundred thousand) or grains per gallon. They must be supplied with a continuous flow and it is very important to realize that as they are electrical conductivity meters, any ionized substance will produce a reading. Therefore, it is possible for the instrument to indicate an extremely high chloride reading when the only solute is, say, calcium hydroxide.

Two instruments which have been developed considerably lately and are now used more extensively are the oxygen indicator and recorder and the *p*H meter. The former has been developed along two parallel lines, one employing a system in which the oxygen is used for combustion while the other employs what is known as the para-magnetic principle. An oxygen recording instrument is now fitted in some power stations to give a continuous record of the dissolved oxygen content of the feed water. This is superior to the old method of taking intermittent samples and analysing them chemically. The oxygen meter is very useful for indicating combustion efficiency due to the fact that most of the fuels employed for steam boilers, when burned efficiently, produce a gas with the percentage of excess oxygen lying within a fairly narrow band. It may also be used as a controller to regulate the ratio of air to fuel directly or as a final trimming device to obtain correct combustion.

The two methods used for *p*H measurement are calorimetric and electrical, the former being only suitable for intermittent indication. The electrical method depends on measuring the potential of a solution which is dependent on the number of hydrogen ions. The potential is very small and it is therefore necessary to amplify it considerably in order to operate any indicating or recording instruments. The instrument is extremely useful in industry and may be used in conjunction with automatic control equipment where processes require the maintenance of a constant *p*H value in a solution.

DISTANCE CONTROLS

There are really two types of distance controls, one being carried out by manual and the other by automatic means. Th latter is a refinement of the former in so far as the sensing and corrective measures required are carried out by an instrument instead of an operator but the final regulating unit, which is commonly called a "slave", may be exactly the same for both types. Automatic controls nearly always incorporate a switching mechanism to allow the system to be operated manually. However, as there are some very slight differences in the possible layout of the two systems and a very definite difference in approach to the problem the two types will be treated separately. In designing a system of distance manual control it is not necessary generally to concentrate on any great accuracy in the movement of the "slave" following the operator's adjustment at the remote position. The reason for this is the inherent lack of sensitivity of both movement and perception of the average human being. An operator cannot assess accurately subtle rates of change but, on the other hand, he can judge with reasonable success overall changes and, in addition, experience enables a particular change to be made at the control end for a given set of conditions. This means that, so long as the "slave" position always bears a fixed relationship to the position of the remote control device, satisfactory operation can be obtained.

Manual Control

The following are three distinctive methods of operation but it is very common practice to use a combination of two or even three of these.

(1) Mechanical
(2) Electrical
(3) Fluid.

The very first distance control applications were all mechanical as this method is very simple and quite effective so long as the distance involved is not great. The system employed is an arrangement of levers, wires or even rope to transmit movement from the control to the controlled point. The obvious disadvantages are the lost motion and frictional resistance in addition to the lack of power at the controlled point. For long distances and awkward runs this system becomes complicated and cumbersome and requires a comparatively large amount of space. A system of wires or chains with proper provision for tensioning is more satisfactory because of its smaller weight and greater flexibility. On board ship it is very necessary to enclose the linking system when it runs through several compartments as it is quite usual for the uninitiated to assume that wires, chains or rods have been placed there for their special convenience and proceed to use them as clothes hangers and for the storage of oddments. Modern developments consist of various systems using sheathed wire or flexible cable arranged to transmit power both in compression and tension. These operate very satisfactorily over medium distances so long as reasonable bends are maintained for negotiating corners. It is difficult to design a system for fine adjustment due to the lost motion which is always present and increases with use but for on/off operations such as shutting and opening dampers and valves, the mechanical type of distance control is satisfactory for small force requirements.

The mechanical connexion is usually termed a positive system and does not require a separate means for transmitting back to the operator the position of the controlled element. If the system has become jammed or disconnected the operator is immediately aware of the fact by the "feel" unless the frictional force of the operating mechanism is a very large percentage of the total force required for movement. In a system employing rods it is preferable to design for the rods

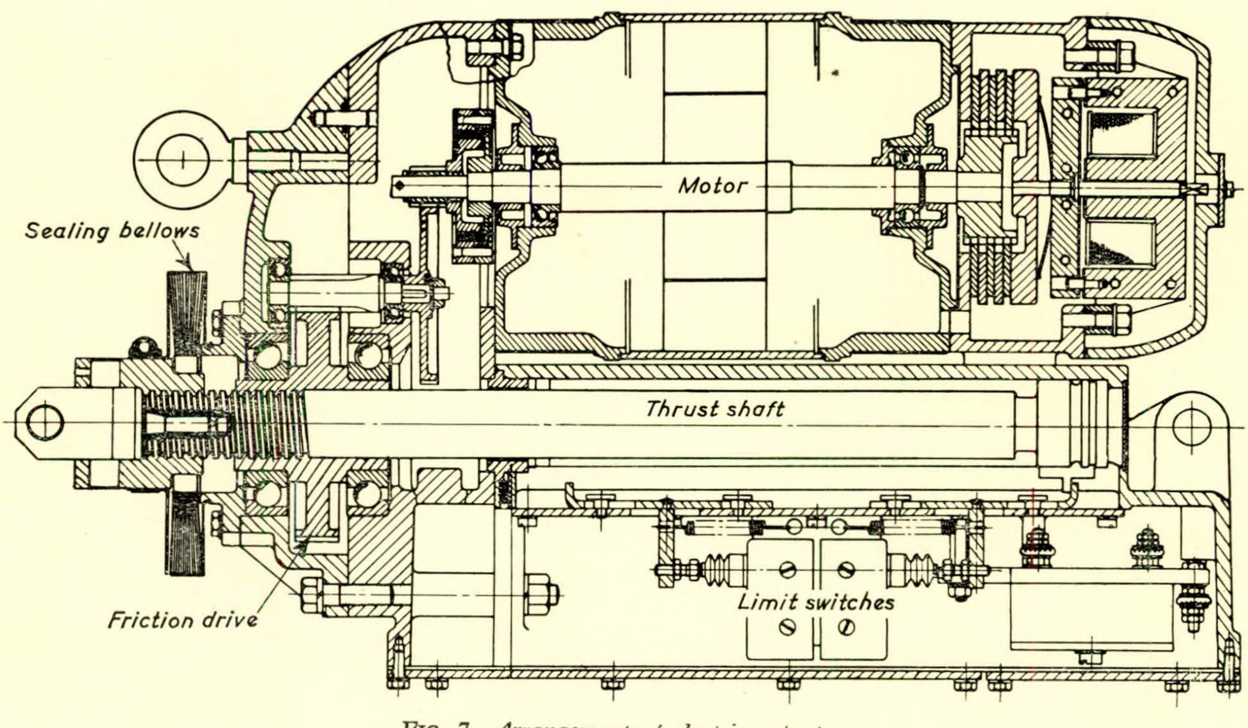

FIG. 7—*Arrangement of electric actuator*

to be in tension when transmitting the greatest force as this enables lighter sections to be used and eliminates lost motion due to flexing.

There are not very many purely electrical distance controls apart from the simple systems used for controlling lighting and small motors. It is absolutely necessary with electrical operation to fit some type of indicating system, be it only a lamp or ammeter, to enable the operator to know that his initiating movement is being followed. A simple example is the use of a remote push button for starting an electric motor. In order to advise the operator on the success or failure of his initiating action it is usual to fit a lamp alongside the push button and connect this in the motor side circuit of the starter.

The distance control of electrical machinery is simple and can be carried out by direct means such as a remotely positioned rheostat for speed control of motors or indirectly through relays. The latter system is used extensively for the control of high voltage systems since the control circuit may be operated at 25 volts, thus reducing the risk of electric shock. The problem becomes more complicated when it is required to control a linear mechanical movement by electrical means or any discontinuous operation requiring a large number of adjustments in unit time. Typical examples of such problems are the regulation of dampers and valves. Where it is possible, magnetic means are employed for linear movement but this is restricted by the power requirements of the controlled element. For on/off operation, magnetic valves are used extensively in the smaller sizes and lower pressures (up to 8-in. diameter valves and approximately 100lb. per sq. in. gauge pressure). For high power output requirements it is necessary to use electric motors in conjunction with suitable gearing which changes the rotary into linear movement where required or enables the motor to operate at a reasonable speed and thus reduce the torque. Fig. 7 shows a typical example of a motor system for regulating dampers and it should be noted that limit switches must be fitted at the extremes of movement to prevent electric power being applied to a stalled motor. Indication of the "slave" position is transmitted back to the control point either continuously by means of an indicator graduated from "open" to "shut" or intermittently through lamps actuated by contacts fixed at, say, three points (open; centre; shut) in the travel of the "slave" arm.

The fluid method covers both pneumatic and hydraulic operation, the former requiring a constant air supply of approximately 100lb. per sq. in. gauge while the latter usually employs a pump supplying oil under pressure. The pneumatic system uses low pressure air at 17lb. per sq. in. gauge (some types use a slightly higher pressure) in the control circuit regulating the higher pressure air entry to the "slave" which consists of a double acting piston and cylinder arrangement fitted with a control valve as shown in Fig. 8. The arrangement employs a feed-back system which gives a definite piston position for a given control input pressure and the relationship between these two variables may be adjusted initially by modifying a cam profile.

The hydraulic system when used for manual control does not incorporate a positioning device, operation being accomplished by means of a switching valve which admits oil under pressure to one or other side of a piston housed in a cylinder. The operator switches oil to one side of the "slave" and then returns the switch to the neutral position when either the indicator shows the required movement or the process change has been affected.

Connexion between "slave" and regulating unit is made through a short mechanical linkage and means are provided in both systems for equalizing pressure on both sides of the piston to enable local hand operation to be carried out. Lamps or continuous indicators should be fitted to the controlling element, preferably fixed to the regulating unit arm, so that disconnexion between it and the "slave" would be immediately apparent.

It is not uncommon to see systems in which the "slave" units are pneumatic or hydraulic while distance control is exer-

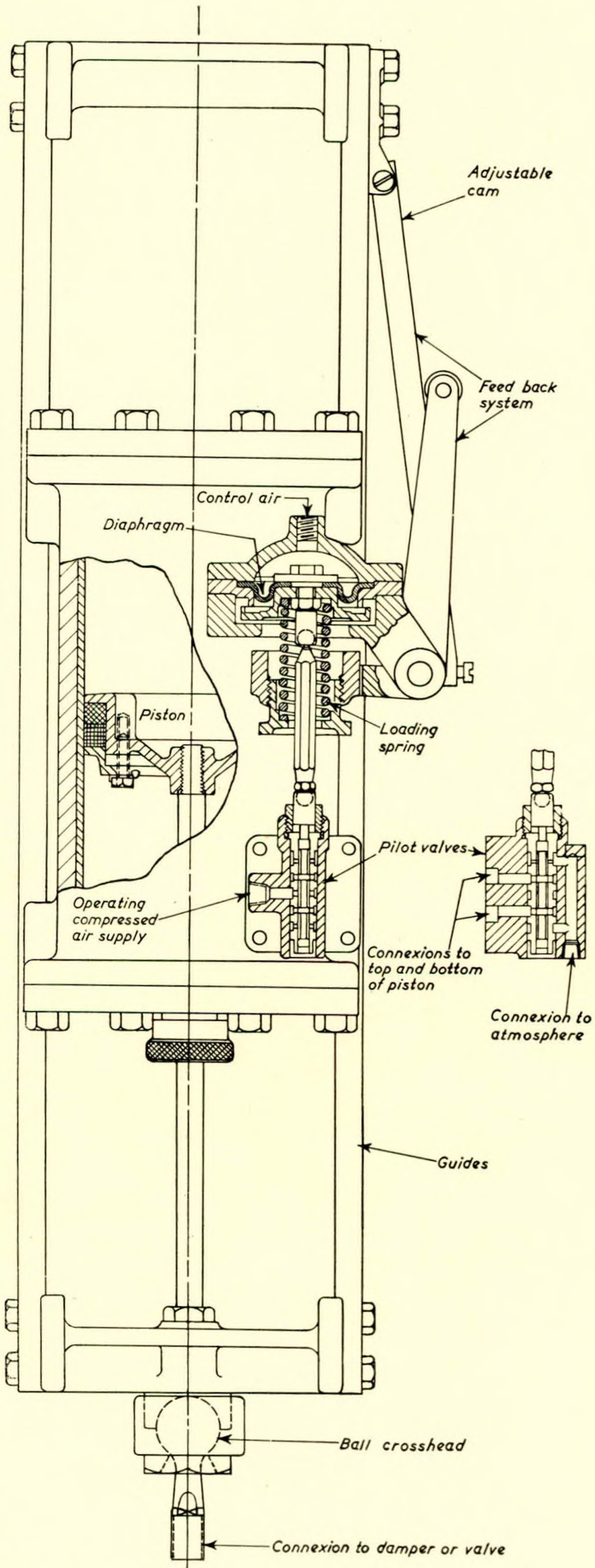

FIG. 8—*Arrangement of pneumatically operated regulating unit*

cised by electrical methods. It is convenient occasionally to employ pneumatic control actuating a hydraulically operated "slave" and at least one control system uses electric motors mounted at the remote control point and driving the regulating unit through a system of wires.

An interesting remotely operated system for bringing into action oil fuel burners is shown in Fig. 9. The burners are fitted with individual forced draught fans and the whole equipment is mounted in a very compact manner. The burner and associated equipment is inserted and retracted by a semi-rotary movement and the whole operation is controlled by a single push button. Ignition of the oil is carried out automatically and a light sensitive cell supervizes this operation and also shuts down and retracts the equipment in the event of flame failure. The oil valves are operated through mechanical linkage during the inward and outward travel of the burner which is carried out by a pneumatic power cylinder.

The equipment is a good example of combining electric, pneumatic and mechanical operations to give smooth and positive control from a remote point. The operator has knowledge of the operating position and condition by means of lamps on the panel containing the initiating push buttons.

Automatic Control

Before discussing this type of control it is necessary to understand the terminology employed. The author has endeavoured to restrict as far as possible the use of terms peculiar to instrument engineers but the following words being necessary are defined:—

Desired value: The figure of pressure, temperature or other physical quantity at which it is required to control the process.

Proportional control: A system in which the regulating unit moves a constant amount for each unit change in controlled value from the desired value.

Proportional band: The variation above and below the desired

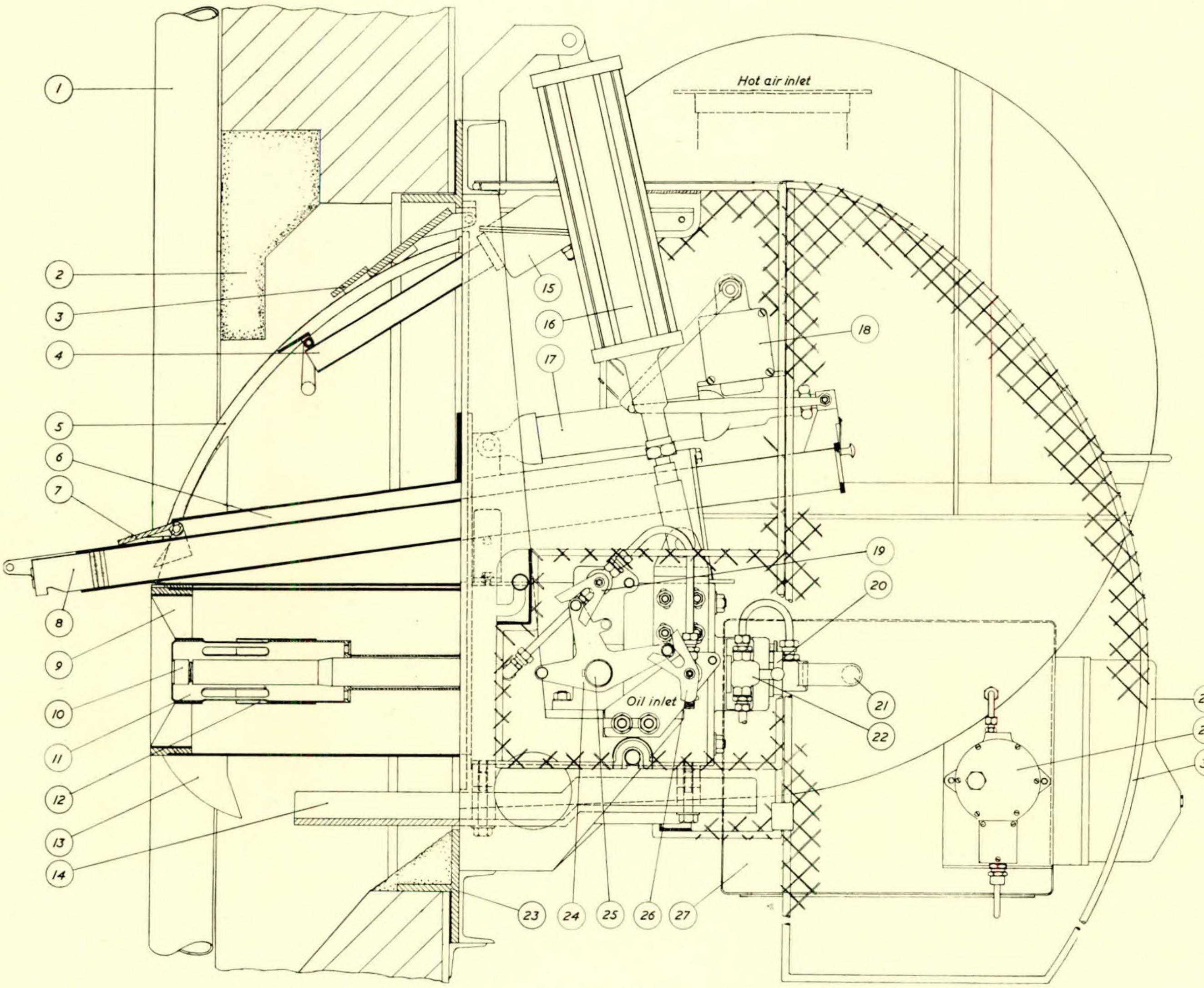

FIG. 9—*Automatically operated oil burner*

(1) Water tubes; (2) Plastic refractory arch; (3) Secondary sealing plate; (4) Viewer extension tube; (5) Air cooled guide rails; (6) Ignitor housing; (7) Ignitor housing door; (8) L.T. ignitor; (9) Swirler blades; (10) Sprayer; (11) Shroud; (12) Sleeve; (13) Secondary plate lifting cams; (14) Main sealing plate; (15) Electronic viewer; (16) Main air cylinder; (17) Ignitor air cylinder; (18) Auxiliary switch box; (19) Secondary oil valve fork; (20) Oil valve interlock handle; (21) Sprayer handle; (22) Manual oil valve; (23) Main frame; (24) Valve actuating quadrant; (25) Shaft; (26) Primary oil valve fork; (27) Distributor box; (28) Fan contactor; (29) Air pressure switch; (30) Wire guard.

value necessary to move the final regulating unit from one limit to the other.

Integral control: A system in which corrective action is applied whenever there is a deviation from the desired value and, in addition this action changes at a rate varying directly with the deviations.

Derivative control: A system in which corrective action varies directly with the rate at which the deviation changes.

Floating control: A system in which any deviation from the desired value will set the regulating unit moving at a predetermined speed in the required direction.

Cascade control: A system in which one controller alters the desired value of one or more other controllers.

The author hopes that the foregoing definitions will be more easily followed than the complicated and correct ones found in the British Standard covering a glossary of terms for automatic control systems.

There are two main types of automatic controls, one being designated self-actuating and requiring no external power, while the other requires a source of fluid or electric power for its operation. The self-actuating type is designed on the basis of a closed system depending on expansion of metals, vapour and liquid or utilizing the power in the controlled system by means of diaphragms or pistons. The metal expansion type is used for local operation in such apparatus as steam traps where the movement required is small. Vapour- and liquid-filled systems are used generally only for temperature control and are restricted to the moderate upper limit of about 450 deg. F. It is sometimes possible to utilize the power in the controlled system and a quite common instance of this is the pressure reducing valve. All these instruments have the disadvantage that they have only proportional action and are not suitable, therefore, for very accurate control. The self-actuating types are extremely useful where no external power is available and a breakdown in, for example, electricity supply does not, therefore, inconvenience the plant operation.

In the second system, whether it be fluid or electrically operated, there are a number of common main items which are normally included in the complete circuit as follows:—

(1) The detecting and measuring elements which may consist of a thermometer and bourdon tube or some differential pressure measuring device. These elements sense the change in the desired value and transmit this change to another mechanism.

(2) The equipment which connects the measuring unit to the controller. In the simple system this would merely consist of connecting piping or direct mechanical linkage or it may consist of an instrument transmitting a fluid or electric impulse.

(3) The automatic controller. This varies widely depending on the type and sensitivity of control required and may incorporate both indicating and recording equipment. In general the controller consists of a system, sensitive to the transmitted change received from the measuring unit, which converts minute movements into an impulse which can be utilized for the operation of large and powerful equipment.

The controls are normally based on a primary system which sends out an impulse which is proportional to the deviation from the desired value but they very often also incorporate extra functions for imposing on the primary impulse additional features to give both integral and derivative action.

(4) Relays. In all automatic control systems it is very important to have some means by which the automatic function may be cut out to enable the operator to control manually the system from a remote point. This may be carried out by means of a relay or by blocking the impulse from the automatic control line to the final controlling unit and substituting a manually-controllable impulse.

Some controllers only carry out a proportional function and if it is required to impose integral and derivative action on the output then these are carried out by means

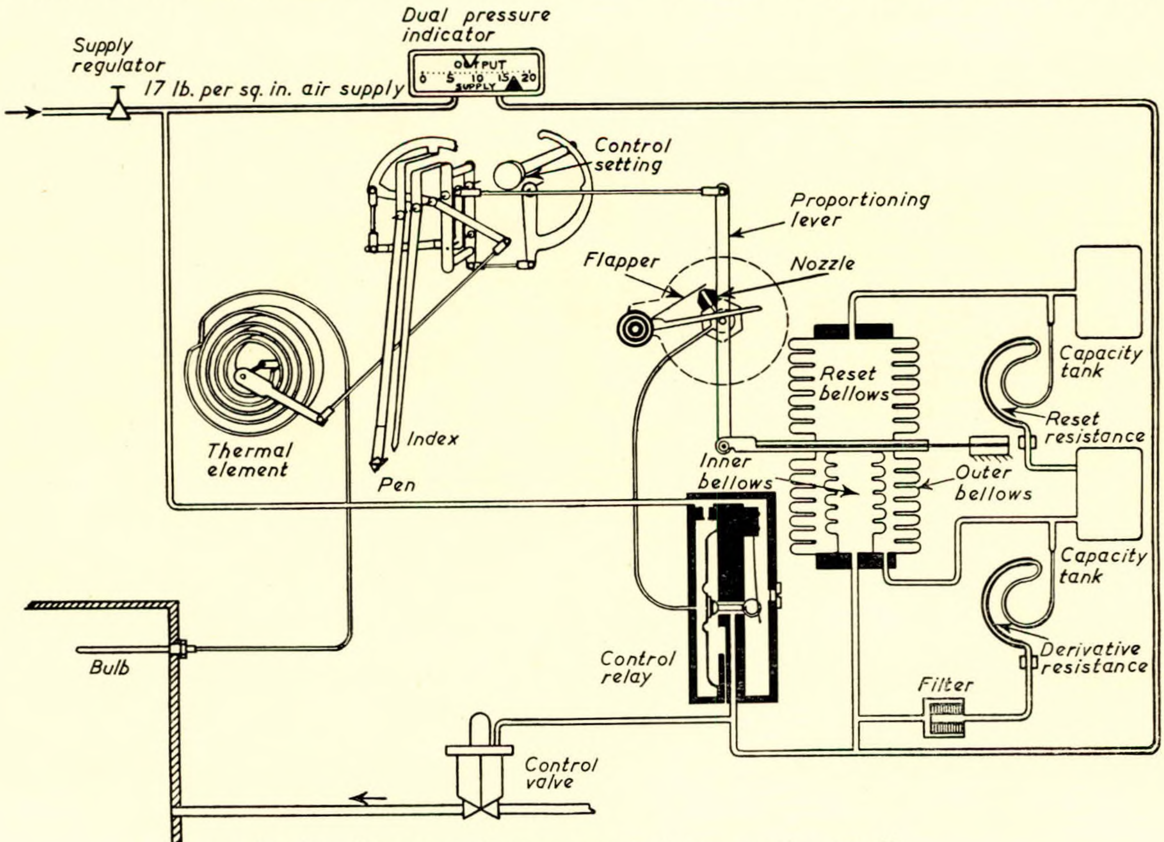

FIG. 10—*Diagrammatic arrangement of a pneumatic controller*

of relays incorporating the necessary diaphragm chambers to produce the required result.

(5) The final regulating unit (or "slave"). This element can vary very widely, depending on the duty it has to perform, and may be a simple diaphragm-operated linkage or a self-contained electro/hydraulic system. The more complicated electro/hydraulic system and also the pneumatically-operated power cylinder incorporate a self-positioning system.

(6) The connecting means. The final control of the operation is carried out in most cases by some type of mechanical linkage connected to the final controlling unit and may consist of a system of levers or gearing.

In choosing an automatic control system the main aim should be simplicity, as the more complicated the mechanism becomes so the skilled maintenance requirements increase. Where possible, what is termed a "closed loop" system should be employed. This name is given to a system in which the detecting element controls through an automatic controller the regulating unit which directly changes the condition of the plant. It is not always possible to install such a system and under these circumstances an "open loop" or "cascade" system is employed. The "open loop" type of system is usually necessary in controlling such phenomenon as temperature in which deviations from the desired value may be brought about by more than one external source of change which is not directly controlled by the system. It is also necessary when, for instance, the final product control is obtained through the regulation of an intermediate fluid which is in turn itself controlled. For example, if temperature control is carried out by varying the amount of water flowing through a heat exchanger where the water supply pressure may be very variable, then it would be necessary to install a water flow controller having its desired value set by a temperature controller; this brings the system down in line with a more simple type of control which could be installed had the water pressure been constant. This type of system where one controller is set by another is known as the "cascade" method.

Where it is possible in a system to choose between the application of pressure and temperature control the former would in most cases be preferred since it is easier to design a suitable instrument. A pressure control system may be designed with a detecting element having a very low inertia, while in measuring temperature, especially under high pressure conditions, the heat inertia involved may be quite large. For temperature control the quickest acting arrangement is a combination of a resistance thermometer or thermocouple with an electronic controller.

In choosing the type of control to be installed an assessment of the system should be made based on site conditions, power source available and accuracy requirements. It serves no purpose to install a controller having proportional and integral action when a deviation from the desired value due to a load change is of no consequence. Integral action is required if it is necessary to maintain the desired value over wide fluctuations in the process load. It is necessary to incorporate a derivative function where it is required to overcome inertia or initial lag either in the process itself or some part of the controlling system. For example, in controlling rotary equipment driven through a variable speed hydraulic coupling,

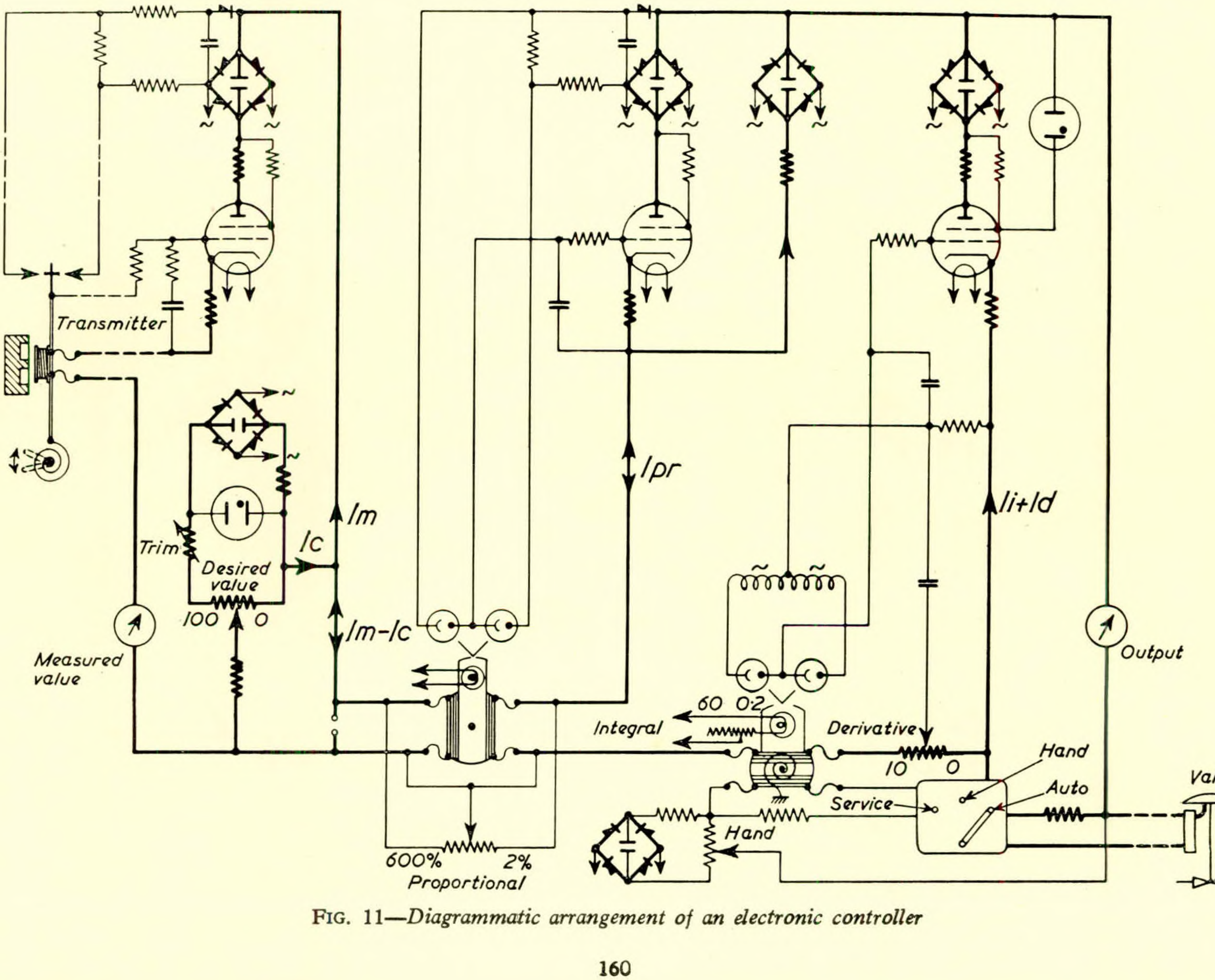

FIG. 11—*Diagrammatic arrangement of an electronic controller*

the element actuating the hydraulic coupling would have to be moved beyond its normal corrective position initially in order to overcome the oil pick-up lag.

From the previous paragraph it will be seen that derivative action produces an acceleration effect which dies away with time. In pneumatic systems this is sometimes carried out by restricting the rate at which the proportional device reacts to unbalanced conditions but some types employ separate relays to give the accelerating, or temporary over-correcting, effect.

Figs. 10 and 11 show diagrammatic arrangements of typical pneumatic and electronic controllers respectively. From the diagrams it would appear that the pneumatic system is very much simpler but it should be remembered that electrical circuits nearly always look more complicated than equivalent mechanical ones. Both types shown include proportional, integral and derivative functions and each function may be adjusted separately, by means of a graduated pointer or knob. The proportional adjustment varies the range of the controlled function necessary to produce full travel of the final controlling unit and the graduated scale is normally marked from zero to 100 per cent of the instrument range. Integral and derivative function adjustments are usually graduated in time intervals of minutes. The integral of a deviation is the time taken to restore the controlled value to the desired value and this speed of correction will vary with different installations, being a compromise between system stability and recovery rate. Integral action continues until the process has been restored to the desired value. Derivative time may be defined as the time interval in which the increase in proportional action is equal to the derivative action when the error is changing at a constant rate. Derivative action is only initiated by a changing error and is not sensitive to the magnitude of error.

When the control room is situated a considerable distance from the point of measurement and the regulating device, it becomes necessary to fit a transmitter to the detecting element. The controller can then be fitted close to the final controlling element while the indicating, recording and remote manual control equipment may be positioned in the control room. This type of arrangement reduces the control lag which may be present due to long transmission lines.

ARRANGEMENT AND APPLICATION

Two very important aspects in instrumentation are the position and arrangement of the equipment and this should be carried out with a view to giving the operator confidence and reducing fatigue. It sometimes happens that a comprehensive instrument arrangement is spoilt by the omission of one or two items such as position indicators, thus leaving the operator in some doubt as to whether his signal has been obeyed. It only requires one breakdown to cause the operator to lose confidence in the equipment and thus bring about a fall in the operating efficiency. Anybody who has been in this kind of position will understand the anxiety which can be caused where the operator has responsibility for expensive equipment or where dangerous conditions can arise. The author therefore thinks it is essential that the result of any modification carried out by the operator should be made immediately apparent to him, even if this is shown without any great degree of accuracy.

With regard to fatigue, it has been found that an operator will carry out supervision of current operation more conscientiously if excessive movement is not entailed. The necessity for more or less continuous movement in order to observe conditions rather leads to a falling off in enthusiasm, especially during night hours, resulting in less efficient operation than would have been realized by the installation of properly arranged instruments. A very good example of poor instrumentation and controls was to be found in the boiler rooms of most naval ships built prior to 1946 where the operator in charge was often in a state of nervous exhaustion at the end of a four-hour watch with a "sticky" feed regulator and a large amount of manœuvring, even though the number of men under him was about 50 per cent greater than should be required. The reason was, of course, the bad positioning of instruments, together with a lack of remote controls. Forced draught pressure was positioned in front of the fan control but it was necessary to move from boiler to boiler and dodge backwards and forwards in order to obtain a view of the smoke lamp. The oil fuel output control was normally a few yards away from the fan control while although observation of water level may have been a good neck exercise it wasted time and frayed nerves. Short, sharp dashes were required to operate feed valves when a regulator was sticky while the usual signal for "shutting off" or "putting on" oil fuel sprayers was the unnerving crash of a large wheel spanner on a metal handrail. This type of system can easily be avoided without sacrificing either reliability or spending very much money on the installation if sufficient thought is given originally to the layout.

On land installations it is now becoming the practice to group all essential instruments at one control point and to arrange them so that the main indications necessary for the

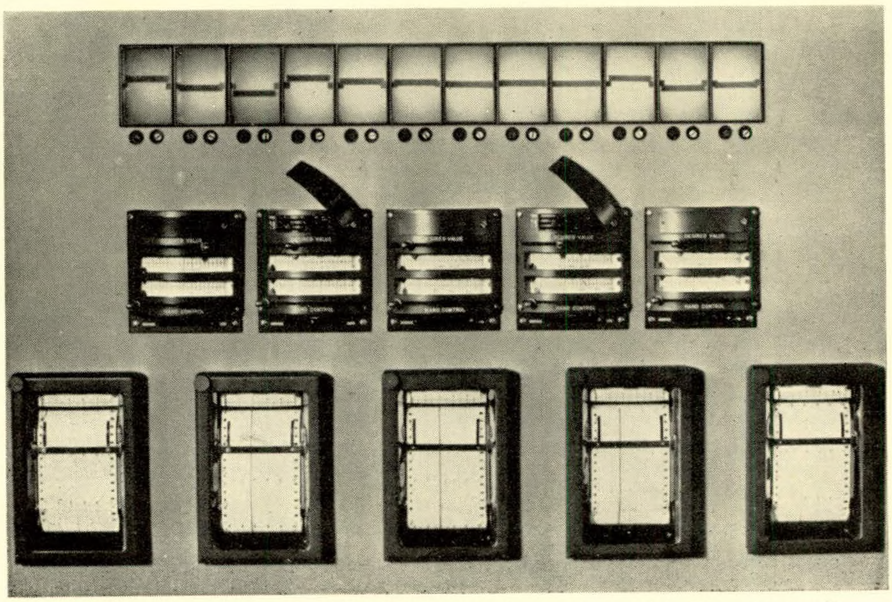

FIG. 12—*Control panel with miniature instruments and "in line scanners"*

continuous operation of the plant are situated immediately in front of the operator. For a quick check on plant conditions the indicating instrument is most convenient and more easily read than a recorder, so that it is often better to install an indicator in front of the operator and to position the record of the same value on a side panel. Where there are several units to be controlled it is now becoming the practice to have one main control room from which it is possible to control the entire plant, and local operations, if necessary, are carried out by other operators with a wandering brief who receive instructions by loud speaker or telephone.

It is obvious that with larger installations it would be difficult to arrange normal instruments in a small enough space for convenient observation from one point. In order to overcome this difficulty miniature instruments have been developed both for recording and indicating. It is becoming accepted practice to eliminate all high pressure lines from the control room panel and substitute transmission of the important variables by either pneumatic or electrical means. The panel instruments are then designed to indicate and record the desired range of values when receiving a pneumatic or electric impulse of, say, from 3 to 15lb. per sq. in. gauge or 0 to 30 milliamps respectively.

To enable the operator to observe at a glance any deviation from correct operation the main indicating gauges are sometimes arranged so that all the pointers are in a horizontal line when the plant is operating correctly; any deviation from the normal operating position is then readily observable. This arrangement sometimes leads to complications in endeavouring to design indicators for widely different quantities but with all the pointers in the same relative position. In order to overcome this a system sometimes called "in line scanning" has been developed; this system employs the use of an indicator receiving an impulse from the measuring unit transmitter and incorporating a manually-operated counter loading arrangement, so designed that the indicating pointer is horizontal when the transmitted impulse is exactly equal to that imposed on it by the manual adjustment. This system has the added advantage of flexibility and may be employed where process requirements are changed from time to time. Where the indicated value is under proportional control only, a restricted movement is employed corresponding with the width of the control band; that is to say, in indicating a pressure from a controlled system having a proportional band width of 20lb. per sq. in. the "in line scanner" would have a restricted movement so that a deviation of plus or minus 10lb. per sq. in. would not move it appreciably out of line.

Fig. 12 shows a control panel incorporating miniature instruments and "in line scanning" indicators. An additional feature very often employed for refinery and chemical process control panels is a mimic diagram. This is a diagrammatic line arrangement of the process with instruments situated at the points which they actually control and is demonstrated in Fig. 13. This system is sometimes used for steam power plants where the boiler and turbine panels are combined but it becomes a little unwieldy and the tendency is towards a diagrammatic line arrangement with instruments located on the panel in the most convenient way and linked to the diagram by easily discernible lines.

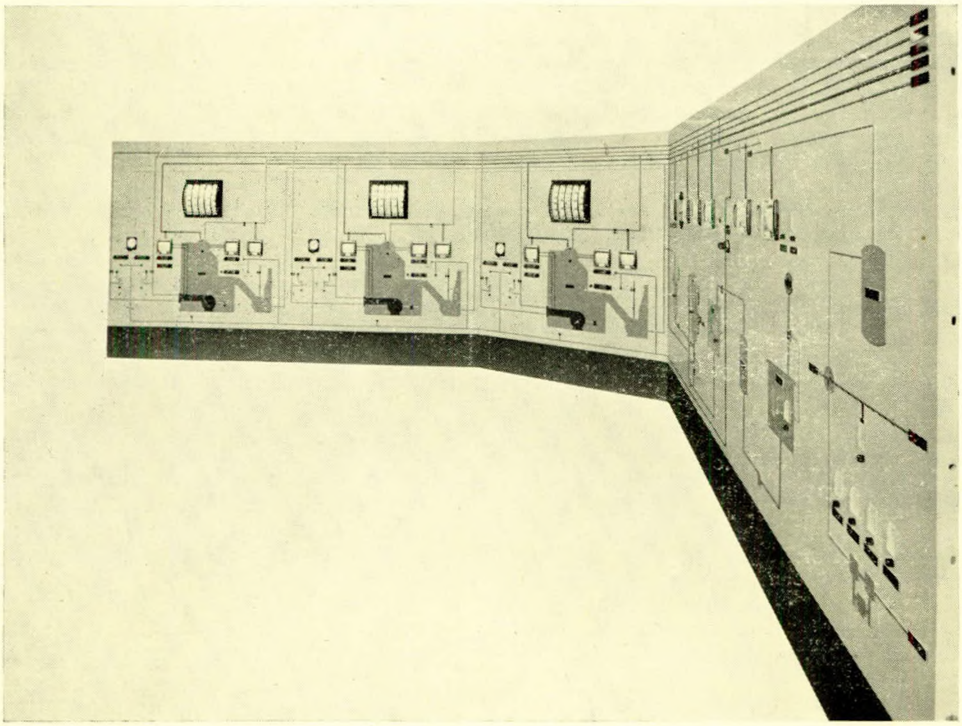

FIG. 13—*Control panel with mimic diagram*

A modern instrument and control panel for an oil-fired boiler having an evaporation of 375,000lb. per hr. with a steam pressure of 950lb. per sq. in. gauge and final steam temperature of 925 deg. F. controlled over a load range of 280,000lb. to 375,000lb. per hr. is shown in Fig. 14. The only true automatic control on this unit is applied to the steam temperature and boiler water level, the combustion efficiency and boiler output being controlled manually. An annunciator system is employed for the alarms and such items as the drum level recorder, gas exit temperature at the induced draught fans, etc., are mounted on the rear of the panel.

Manual control of fuel oil pressure, forced and induced draught fans, main steam and feed stop valves is carried out at the panel and it is not necessary for the operator to leave the firing floor under normal operating conditions. The control of the fans is carried out electrically by means of torque units actuating vanes at the fan inlets. The arrangement is not right up-to-date as each boiler is supplied with its own panel and transmitters have not been used so that steam, water and

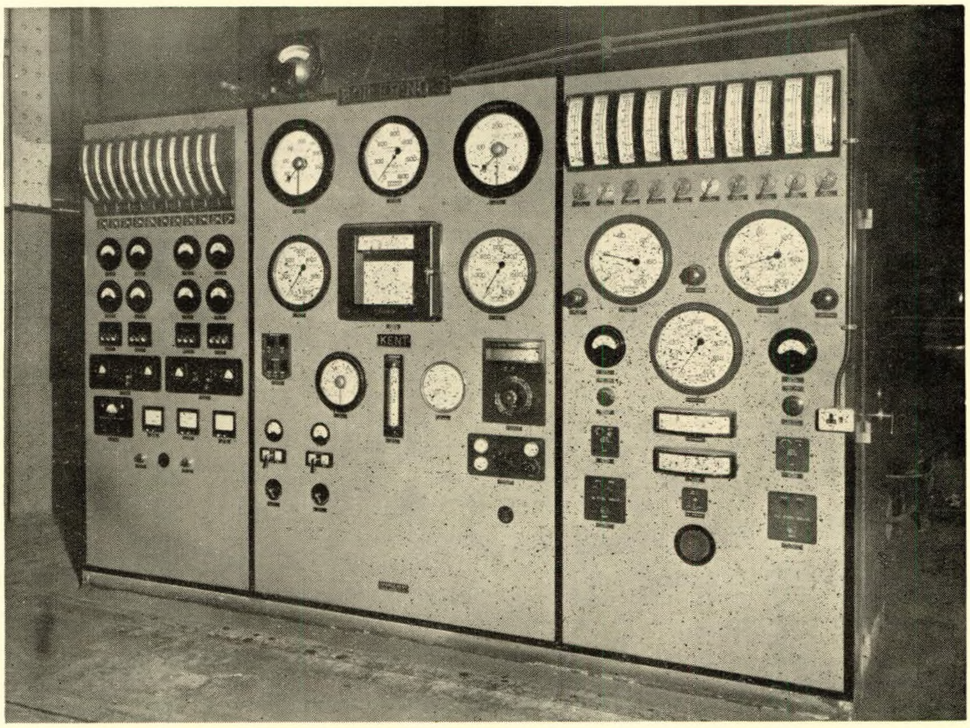

FIG. 14—*Control panel of a large manually controlled power station boiler*

oil fuel pressure lines enter the panel. However, it is a good example of the way to reduce operator strain by limiting the distance to be travelled during a shift.

Fig. 15 shows the control desk of a refinery plant and it will be apparent that one operator could very easily control quite a vast system of complicated machinery by the correct arrangement and application of modern instruments. It is very often the practice to situate equipment out of doors and when this is the case it is easier to get an operator to carry out routine jobs if this can be accomplished within the shelter

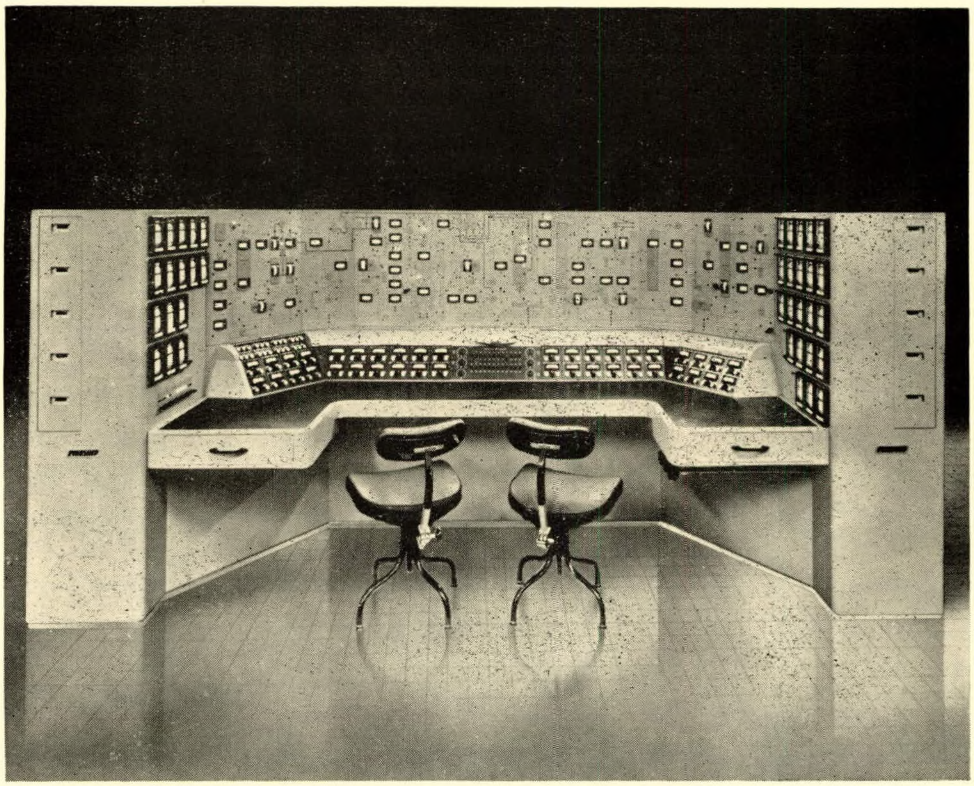

FIG. 15—*Control desk of a refinery plant*

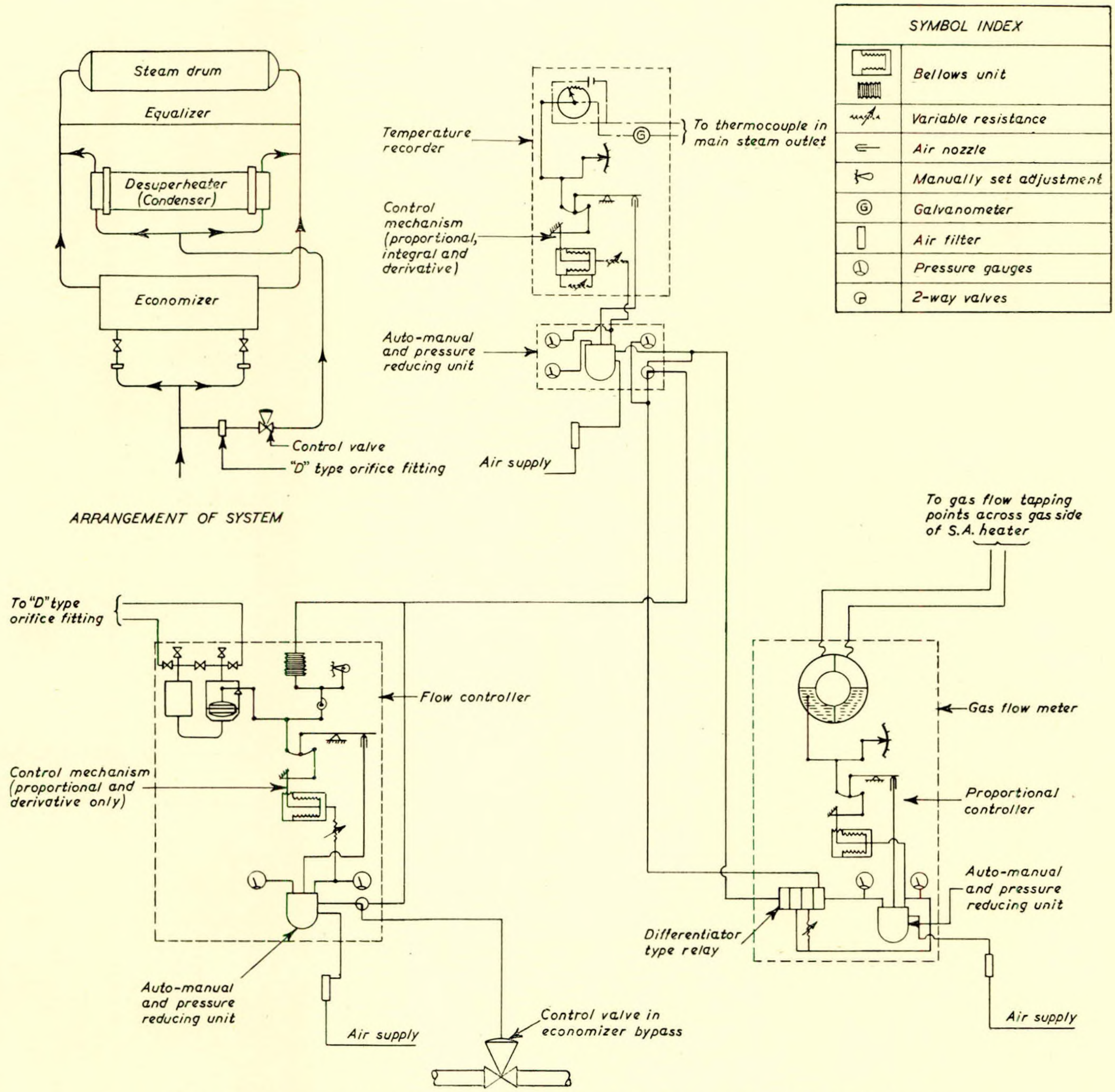

FIG. 16—*Diagrammatic arrangement of an automatic steam temperature control system*

of a control room. Another important aspect is lighting and the author wishes owners of plant and those responsible for the layout of equipment would take more guidance from the vast amount of study carried out on this subject in industry. Insufficient or gloomy lighting is most trying when concentration over long periods is required.

Having briefly discussed some of the more important aspects of instrumentation and controls, examples of actual systems now in use will be described.

Fig. 16 is a diagrammatic arrangement of a steam temperature control system for a boiler and is a good example of the "cascade" principle. The steam temperature is controlled by passing cooling water through a heat exchanger in the steam path, this action varying the wetness of the steam entering the superheater and thus controlling the final temperature. Cooling water is supplied by the feed pump and is tapped off after the feed regulator and thus load or water pressure variations will cause fluctuations in the pressure drop available across the heat exchanger. Therefore a water flow controller is employed which has its set point modified by an impulse from the temperature controller. In big boilers where the superheater has a large heat inertia the steam temperature is then more sensitive to gas flow than to the corrective applied on the steam side and thus a sudden load change may cause short time peak temperatures. A method employed to modify or forestall this tendency is the gas flow controller which sends out an impulse proportional to the gas side pressure drop across a convenient part of the unit. This impulse is passed to opposite sides of a diaphragm in a relay which normally transmits output from the temperature controller. The line feeding one side of the diaphragm contains an adjustable restriction so that if this is wide open the impulse from the gas

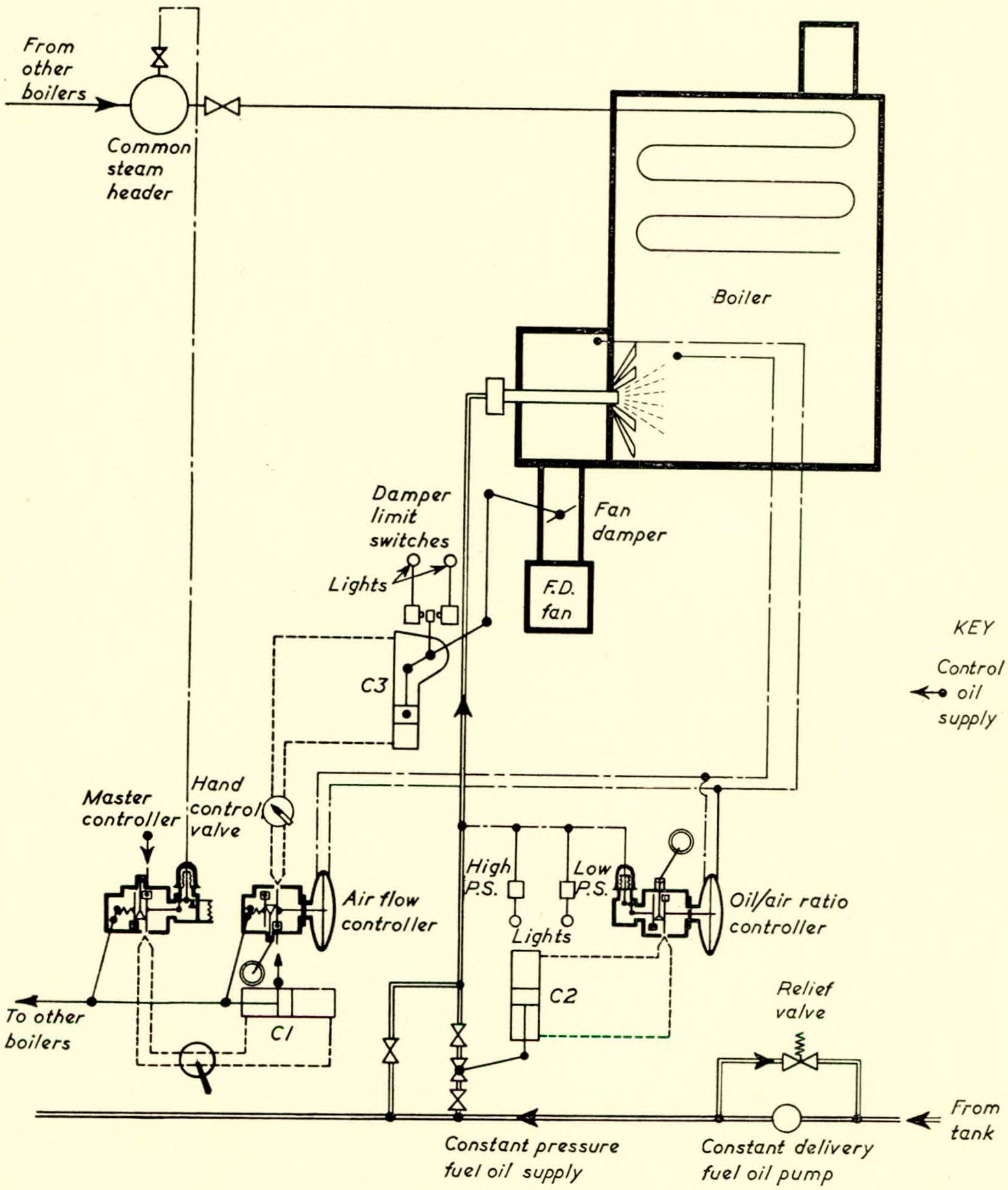

FIG. 17—*Diagrammatic arrangement of an automatic control system for marine boilers*

flow controller has no effect. If some resistance is imposed, then the impulse will be effective initially but the effect will die away in time. This gives what is known as an anticipatory action and assists in overcoming the system lags but it must be set with care to obtain the best results.

Fig. 17 is a diagrammatic arrangement of an output and combustion control system suitable for a ship's boilers. The arrangement shows the controls required for one boiler but it may, of course, be extended to cover several units when it would be necessary to increase in proportion all the equipment except the master controller. It is assumed that the firing equipment consists of one or more pressure atomizing oil burners having a range of control carried out by varying the oil supply pressure.

A master pressure controller, having both proportional and integral action, modifies the desired value of an air flow controller. This latter controller automatically maintains the pressure differential across the burners in accordance with its set point by modifying a damper in the F.D. fan air system through the medium of a power cylinder. The differential air pressure across the burner registers is transmitted to an oil/air ratio controller where it is balanced by the oil pressure existing in the supply line to the burners. Both the oil and air quantities bear a square law relationship to the pressure drops across the oil gun and the burner register respectively and, therefore, the oil pressure in the supply line may be directly equated to the differential air pressure across the burner register. Once this system has been set initially the oil will always be fed to the burner at a rate to give the correct air fuel ratio.

The master pressure controller is actuated by the steam pressure in the main line and if this value is maintained constant, therefore, the boiler output will automatically be controlled in relation to the steam demand.

Each controller is fitted with a suitable switch device to enable operation to be carried out manually instead of automatically if required. Thus manual control of the steam output may be employed while still retaining the desirable feature of automatically controlling the combustion efficiency. If several burners are fitted to the boiler it is then necessary when the normal control range ratio of approximately three to one has been reached to shut off or light up by hand a suitable number of the burners. This operation of shutting off and lighting up burners will be automatically compensated by the oil/air ratio controller and it is usually not thought necessary to provide, on ordinary merchant ships at least, equipment for remotely controlling the isolation of oil and air to individual burners.

It will be seen from the drawing that certain safety devices and indications are provided to advise the operator when limiting conditions have been reached, thus warning him that a particular operation must be carried out, such as, for example, shutting off or lighting up burners. Dangerous conditions may arise in a boiler installation if the forced draught air supply fails, but it will be seen from the control arrangement that the scheme employed will produce safe conditions in these circumstances. Failure of the differential pressure across the burner register will immediately shut down the oil supply to the burners and also give warning by illuminating the "low oil pressure" lamp.

The control system just described is actuated by hydraulic means, oil being supplied at a constant pressure by means of a central pumping unit.

The following automatic system is applied to some small industrial boilers which utilize Dowtherm "A" as the vapour medium in place of steam. This type of unit is employed in certain chemical industries where high temperatures are required under saturated vapour conditions and it is quite usual to require extremely close temperature control of the order of plus or minus 1 deg. C. The control is usually carried out through a pressure controller as the temperature of the vapour is directly related to the vapour pressure. The system shown in Fig. 18 incorporates automatic sequence ignition and is designed so that in the event of a shut down the equipment endeavours to relight the burners immediately. The fuel used in the arrangement shown is town gas, which is burnt in a forced draught burner while the flue gases are exhausted from the unit by natural draught established by a chimney stack of suitable height. Control of air and fuel is carried out in a dual type of valve which automatically maintains the correct air/fuel ratio, thus achieving combustion efficiency over a wide range. The burner is fitted with a pilot jet which is ignited by a spark ignition system and the whole procedure of lighting up is carried out and monitored by the flame failure equipment. On pressing the start button and on the assumption that the electrical safety circuit is not broken, a purging period is initiated after which the spark ignition and pilot jet gas supply are turned on. A light sensitive cell is focused on the pilot jet and as soon as the flame has been established the cell completes the safety circuit and energizes the main gas magnetic control valve which then opens and allows the main burner to be ignited. After a pre-set period the spark ignition is switched off and it will be seen that if ignition is unsuccessful then the equipment will be shut down due to the light sensitive cell not completing the safety circuit. If, however, operation has been established and the safety system is interrupted due to any cause whatever, then the flame failure equipment will immediately initiate a "light up" cycle as previously with the exception that the purging period is omitted.

A pressure recording controller incorporating proportional and integral action modifies the position of the air motor connected to the air/fuel ratio valve. Solenoid operated valves are utilized for shutting off the gas supply to the main and pilot burners in the event of interruption of the safety circuit and it should be noted that a locked "out of sequence" switch is employed to allow the vaporizer to be operated while any maintenance is carried out on the flame failure unit. The type of burner employed requires a constant predetermined air and fuel gas pressure and these are automatically controlled by proportional regulators modifying damper positions. The

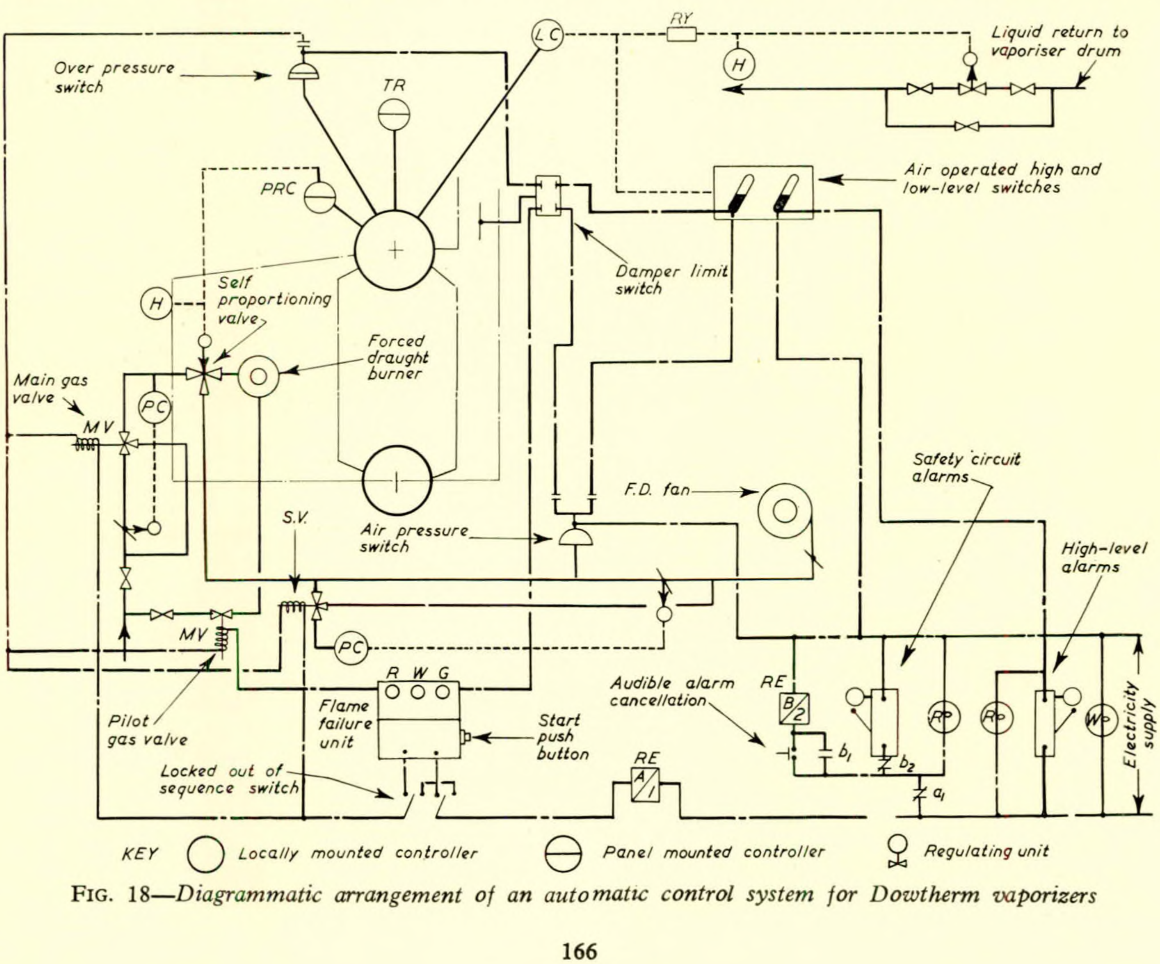

FIG. 18—*Diagrammatic arrangement of an automatic control system for Dowtherm vaporizers*

Dowtherm liquid level in the top drum is automatically controlled by means of a liquid level controller having proportional action only and set to a band width corresponding to the high and low level positions of the liquid in the drum. The output from this controller is connected to high and low level mercury switches mounted on actuating elements which are controlled by the impulse sent out by the controller. This impulse is also tapped off and passed through a suitable relay in which a readjustment of the proportional band is carried out, the modified impulse being then passed to a diaphragm motor operating a control valve in the liquid supply line.

The safety circuit consists of electrical contacts connected in series, the contacts being operated by the following equipment: —

Low liquid level switch
Damper limit switch
Over pressure switch
Flame failure unit.

In order to provide maximum safety the circuit must be completed for normal operation, the current flowing through it actuating a normally closed relay in the alarm circuit and thus if the circuit is broken the alarms will be brought into operation.

It should be noted that in the event of a safety circuit shut down during normal operation, the vaporizer pressure will fall and the recording pressure controller will send out an impulse calling for full opening of the proportioning gas control valve. If the fall of pressure is fairly rapid then before a re-light cycle can take place it is probable that the proportioning gas control valve will be in the wide open position and thus a large quantity of combustion air will be passed into the vaporizer, purging it thoroughly. However, on the re-light cycle being successful the slow opening gas magnetic valve will allow the passage of fuel to the burner but the quantity of excess air will be extremely high, with an added possibility of blowing out the pilot jet. In order to overcome this disadvantage, a three-way solenoid operated valve is situated in the primary impulse line to the air pressure controller and so arranged that on interruption of the safety circuit this valve connects the air pressure controller to the fan side of the air control damper, thus shutting the latter. The air control damper is fitted with adjustable stops so that when in the shut position a sufficient quantity of air is passed to purge the vaporizer setting.

Operation of the unit may be carried out mainly from the control panel on which is mounted the recording pressure controller, recording thermometer, indicating pressure switch and the automanual stations for controlling the fuel supply and the liquid return to the vaporizer. Lights are fitted on the panel to indicate that power is available and also the sequence of events taking place during automatic ignition. It will be noted that the high liquid level alarm is not linked into the safety system as this condition is not considered sufficiently serious to call for a shut down of the vaporizer and, therefore, separate audible and visible alarm warning is given.

CONCLUSIONS

This paper has only covered a small part of instrumentation and controls and although the scope was necessarily narrow it has been impossible to deal with the various aspects in any great detail. Modern instruments are becoming more complicated as the duties allotted to them are gradually increased in complexity and sensitivity. It is obvious, therefore, that the field is rapidly becoming one for specialists and the mechanical or marine engineer can only hope to obtain a general knowledge of the design and application of instruments normally used in his special sphere. In the author's opinion, however, it is essential for an engineer to obtain this general knowledge in order to appreciate the problems involved and also to make the best use of the systems evolved to assist him in his major function of designing and operating processes and power plant. The necessity for regular maintenance and adjustment of instruments and controls cannot be over-emphasized and laxity in this direction has often been responsible for the attitude that "instruments are very nice and impressive but are not to be trusted".

There is still a body of opinion which thinks an operator should spend a certain proportion of his time in walking from point to point in order to keep him "on his toes", but the author does not subscribe to this view. Instrumentation and distance controls are installed to enable the number of operators required for running a plant to be reduced and also to increase operating efficiency. In most cases well kept instruments will carry out a given operation more efficiently than an operator and most definitely with less variation from day to day. With the advent of atomic energy and the necessity for handling material in positions where it is impossible for a human being to live, instrumentation and distance controls have really shown their worth. As it is possible and necessary to handle operations from behind massive concrete protection, it follows logically that there is no reason why similar equipment arrangements should not be used for processes and in ships. The idea that an operator must see directly the valves or burners he is controlling is rather old fashioned and it is certain that in the near future ships' main propulsion machinery will be under the direct control of one man situated in a control room positioned by considerations other than its nearness to the controlled units.

Television is rapidly becoming a necessity and one of its great advantages lies in the fact that failure of the apparatus cannot give an incorrect indication and, therefore, the equipment is essentially safe in operation. It is also fairly evident that electronic instruments and electrical controls will gradually displace the pneumatic and hydraulic systems which have given such good service up to the moment. There is a little difficulty at the moment in designing a sufficiently flexible, completely electric, controlling unit, as those at present available operate at a constant speed whereas the speed of pneumatic and hydraulic units can be made proportional to the size of the input signal. However, it is very doubtful if this state of affairs will last any great length of time. It is, therefore, the author's opinion that in the near future machinery and process control will be carried out by electronic and electrical means from a centralized control room which may be completely sealed for considerable periods in order to prevent the ingress of gas or radio active matter.

There is little doubt that equipment fitted on ships has to operate under extremely arduous conditions and the author would like to put in a plea for instruments and controls to be designed to combat vibration, shock and the salt laden atmosphere. In addition, instruments should be readily repairable or so designed that complete sections may be easily removed and replaced by spares. The latter method is preferable as it results in the minimum outage time of an instrument while allowing repair of the damaged part to be carried out at leisure. As the scope of instrumentation increases it is obvious that a specialist will be required for maintenance purposes although up to the present it is possible for an engineer to learn enough in a three months' course to enable him to carry out day-to-day maintenance on instruments fitted to the main propulsion units of a ship.

The author hopes that this paper will be of some assistance to engineers who are not already familiar with the various aspects of instrumentation and distance controls and will stimulate discussion on this extremely interesting field of engineering. To expert instrument engineers, apologies are due for the over-simplification of control systems and the rather brief despatch of complicated control problems.

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Fig. 6 was reproduced by permission of United Trade Press, Ltd., from an article entitled "Television Water-Level Monitor", by C. C. Whitehead in the June 1954 issue of "Instrument Practice".

Discussion

MR. W. MCCLIMONT, B.Sc. (Member) congratulated the author on a stimulating paper. The placing of such a forward-thinking subject on the syllabus was, he said, in the highest tradition of the Institute.

The question of instrumentation on board ship was not only one of devising elaborate equipment, as suggested by Figs. 13, 14 and 15 of the paper. With the owners of the scores of ships, many of them modern, whose instrumentation was really most unsatisfactory, he would plead: "Please do something to ensure that your instrumentation is worthy of the fine plants you are installing". It was always distressing to see an engineer looking ahead at a tachometer, over one shoulder at one gauge, over the other shoulder at another, while endeavouring to control a manœuvring valve whose position on the platform called for everyone else to bump into the wretched fellow. A sorry picture, but, with its many variants, unfortunately much too frequent. Some really serious consideration of the optimum arrangement of the instruments now in use was very necessary.

In his conclusions, the author spoke of the attitude that "instruments are very nice and impressive but are not to be trusted". That, unfortunately, was not true of most instruments on board ship. Most of them were trustworthy but very few of them were either nice or impressive. A panel of irregularly arranged circular gauges, some on closer inspection marked in degrees F. and not lb. per sq. in. with little brass plates often carrying erratically stamped references below each of them, and perhaps with some after-thoughts of gauges tacked to the edges of the panel—did all that really lead to efficiency?

Fig. 15 showed a control desk of a refinery plant, and what struck him most was the two chairs. The author condemned the theory of keeping an operator "on his toes" by making him walk about. Might he go further and suggest the introduction of these two chairs into the engine room? After all, if a man on watch was going to sleep, he would do so on his feet as readily as on a chair; anyway, he was more likely to go and sit down on a grating or some such place where he could not see the instruments he should be watching. The third engineer would always find himself a seat to have his cup of tea, and he would be better with a proper seat with the significant instruments strategically placed around it.

One use of the "closed circuit" television equipment which the author had not suggested was the installation of a camera in the engine room and a receiver in the chief engineer's cabin. That would be an admirable example of distance control. How advantageous it would have been to a certain chief engineer of whom it was reported that he could never enter his engine room because his health would not permit him to climb ladders and when he got to sea he found the lift would not accommodate his bulk!

Since he had been concerned for some time now with the environmental conditions in machinery spaces, there was one other desirable feature to which he did not think the author had made reference, and that was the positioning of ventilation relative to the significant instruments in an engine room. The author had very rightly stressed the importance of good lighting. The improvement of temperature and humidity conditions in the neighbourhood of instrument positions should be regarded not just as a contribution to the personal comfort of personnel but as a definite and measurable contribution to their efficiency. In this connexion, there were four main factors, namely, the temperature of the air, the humidity of the air, the amount of air movement and the effect of radiation from hot surfaces. If instruments could be concentrated conveniently at one or two points in the engine room, the first two of these factors—temperature and humidity—could be dealt with at an economic rate by the local delivery of conditioned air. The amount of air movement could be dealt with by designing the distribution of ventilating air in engine rooms instead of just pouring it in—and probably with much less fan power. The fourth factor, namely radiation, was really the most easily dealt with by proper siting of instruments and judicious shielding, but it was often a source of trouble on existing ships.

There were a number of the individual instruments and controls dealt with in the paper on which one could comment, but he proposed to confine his remarks to one instrument only, namely, the oxygen recording instrument which the author stated was now fitted in some power stations to give a continuous record of the dissolved oxygen content of the feed water.

This statement was surprising, as he did not think that an instrument of sufficient accuracy and reliability was available. There had been dissolved oxygen meters for some time now, but they had had three undesirable features, namely, that the lower threshold of detection was rather high; the "flushing" time of their cells had been too long, resulting in a lag of up to forty minutes in recording a fall of oxygen content; and the stability of the cell had been poor, causing drift of the readings in the space of a comparatively short trial.

An experimental instrument free from these disadvantages had been developed and subjected to extensive laboratory testing. It had also been used experimentally at a power station on the south coast. Considerable interest had been shown in its use for power station work, and arrangements were being made for the testing of prototypes in power stations and other advanced steam-raising plant. The British Shipbuilding Research Association hoped to take one to sea in the very near future, primarily as a research tool for the investigation of the whole field of the deaeration of boiler feed water. The co-operation of shipowners, whose help had always been given so generously in the past, would be sought in these trials which should provide valuable data on the significance of dissolved oxygen in the feed of marine boilers and at the same time aid the development for marine use of an instrument which promised to be of great value, particularly when operating at advanced steam conditions. In these researches, the Association were working in the fullest collaboration with Pametrada and the Admiralty.

In conclusion, the paper was one of great interest, and he hoped it would stimulate the interest in the marine field which the work put into it deserved.

MR. W. T. MARCHMENT also congratulated the author on an excellent paper and on the way in which he had dealt with a somewhat complicated subject. In one sense, he himself was present as an interloper insofar as he had a particular interest in the replacement of one medium of instrumentation and control by another—the replacing to an increasing extent of the present method of control by an electrical medium. He hoped he would be forgiven for that. The points brought out by the author were important because this was an age when more and more measurements were required every year to satisfy the requirements of modern plant control. Those important measurements (which had also demanded an increase in the speed of control) were leading to a stage when the operating panel had to be in a very small compass and led straightway, whatever medium was used, to the necessity of providing miniaturization.

Secondly, remoteness was becoming more and more compulsory and as the author pointed out, in the case of nuclear power plants, it would be essential for the control room to be entirely divorced from the machinery. It was important to note that the author also mentioned the question of the graphic representation of instrument readings. One had to couple with that consideration how quickly the operator in future would have to read. Therefore, it seemed that there would be a greater tendency in future for the instrument display not to be physically concerned with the layout of plant or the layout of the process sheet, nearly so much as to give the operator a quick appraisal of what was happening to the plant. This would be followed by a confirmation either with a recorder or—what was coming into even greater favour at the moment—an automatic logging device in which the deviations from control point could be logged automatically.

There was a point concerning the "slave" unit which interested him. The electrical slave unit at the moment was suffering by virtue of the fact that one could not, the author pointed out, make the speed of the motor proportional to the input signal or the magnitude of the deviation. This was not quite true, as simple apparatus exists up to ½ h.p. motors where it is possible to make the speed of a motor controlling a valve or damper proportional to the magnitude of the deviation. It was in powers very much larger than ½ h.p. that the difficulty arose, but they could, of course, be dealt with by such means as Ward-Leonard systems and other methods which, however, were rather complicated and expensive.

In engineering one was entitled to mix one's drinks to solve a problem. Therefore, one did not hesitate to telemeter and provide the proportional, integral and derivative functions electrically, and end up with hydraulic or pneumatic positioners to control valves and dampers.

Another point was the simplicity of solving equations in electrical controls. It was not, for example, always fully appreciated that in an air/fuel ratio one was referring to a quotient and this question of solving a quotient had been achieved electrically for many years by means of ratiometer instruments and other devices. There was an inherent flexibility which was provided quite automatically by electrical measurement, and he felt sure that this would come ultimately very strongly into the combustion field—the ability to measure ratios and multiply temperature by flow to get the B.Th.U's the ability to subtract and summate, were but a few of the ways in which such a flexible medium would make a great contribution to the requirement of control which the author foresaw in the future.

COMMANDER A. C. W. WILSON, R.N., said it gave him great pleasure to take part in the discussion of this most interesting paper. He must congratulate the author on his success in producing in such a compact and understandable form the essentials of this large field of modern engineering. He felt sure that all members present had enjoyed it, and others would do so. They would find it a great help in trying to get to grips with the subject. It was one, he felt sure, which would play a much greater part in all their activities in the future, in the marine field as well as in other fields.

At the Admiralty they were faced with a dilemma. It was abundantly clear that in any future emergency considerable dilution would occur, resulting in their sea-going equipment having to be maintained by relatively unskilled manpower and in world locations where access to manufacturers' servicing, spares, and so on was not available. In these circumstances, it was open to question whether the Admiralty should employ more and more automatics in an effort to dispense altogether with the human element, or whether they should go backwards and employ less and less, relying on ordinary rod gearing. Furthermore, unfortunately, Admiralty requirements were rarely met from normal industrial fields. In order to obtain satisfactory equipment a very great amount of exploratory and development work had to be undertaken, both by the department of the Engineer-in-Chief and by the particular section of industry concerned, before a satisfactory article was produced.

There were particular problems relating to weight and space. There were valves which were suitable for industry but which were very high and weighed about five tons. Robustness and the quality of being shock-proof were a great worry, while the materials had to be resistant to salt-laden atmosphere.

The shock aspect alone at once ruled out all types of flapper control and linkages, examples of which the author had just shown. There were, of course, ways round this difficulty.

Nevertheless, the Admiralty were taking an increasing interest in promoting automatic control. The Department of the Engineer-in-Chief were doing a lot of work on this matter, in conjunction with industry, on a very broad basis. It was designed to meet present-day requirements which would be incorporated in all new construction—separate air-conditioned control rooms from which all the machinery could be controlled from standstill up to full power, and so on. In particular, he would like to mention one or two items of interest to the Admiralty, some of which the author had already covered.

The Admiralty had developed several automatic steam valves of various sizes to meet all their requirements. It had taken a long time, and trials were continuing. Several were, or would be, at sea in the very near future. They incorporated valve positioners and all the devices shown by the author.

The Admiralty had also developed a very satisfactory shunt type combined deaerator and contact feed heater, which was now being installed in their new ships. This had taken a long time to get right; but one could now do anything one liked with the ship or machinery and it stayed in service; or if it decided to drop out, it shut itself out of the circuit automatically, and shut itself down, and one carried on without it. While this was being tested, they imagined they had got hold of a reasonably good dissolved oxygen meter or recorder. They got some good results from it which showed whether it was working or not. They believed them at the time, but he was not sure now whether they were all that good!

There was automatic operation of gland steam, lubricating oil, valves, fuel oil and so on, and several systems were under development—thermostatic, viscostatic and others which were now being made.

The main difficulty with regard to boiler control was a very real one and probably explained why they had lagged so far behind. The naval requirement for maximum efficiency at cruising power required a turn-down of about 15:1. This was not available in normal automatic systems. Considerable difficulty also arose in designing one owing to the relationship of an air quantity (Q) being proportional to the square root of the pressure drop. That was to say, even if one went up to 100in. maximum air pressure at 1/15th Q, the control had to be effected using air pressure drops of only a fraction of an inch water gauge.

However, they had now a complex system of fully automatic boiler control which was shortly going on trial with Pametrada which was designed to give a turn-down of 20:1. Unfortunately, it would not be immediately suitable for sea-going service, but it would provide valuable operating experience with fully automatic boiler control. It also included automatic sootblowing, which was just press-button or sequence from the control panel.

Current Admiralty thought on this boiler problem was turning more and more towards the direct control of air and oil quantities, probably cam-operated with possibly a servo follow-up or relay, and fitted with a manual trimming knob. This would automatically meter the air and the fuel in approximately the right proportions, thereby leaving the watchkeeper free to trim the installations and relieve him of the onerous and fatiguing duties which had been referred to by the author in his paper.

He might add here that the Navy had already provided seats for their watchkeepers. They were improving a little as compared with the bad old days!

They had not been able to find a satisfactory CO_2 meter, however, to trim with, because they could not get one which gave a rapid enough response (less than about 3 or 4 minutes). They were therefore pursuing the idea of trimming by means of a photoelectric smoke meter instrument such as the author had showed on his panel.

The author mentioned some of the difficulties of remote level indication. The main problem was the boiler gauge glasses, and these had normally to be done uphill in new naval designs. That was to say, one wanted the indication above the actual position of the gauge glass. So far, they had not been completely successful with the liquid type and were now looking to a remote servo operated pneumatic type of indicator.

Television was undoubtedly attractive for this duty, but unfortunately naval service could not rely upon it as the No. 1 means of remote indication. Maintenance of electronics in modern ships was already stretched to the limit and could not necessarily be relied upon for instrument service under battle conditions. Furthermore, there was a difficulty with electrics as a control medium in naval engineering circles, and they were not favoured. First, there was a sea water hazard, and then there were domestic difficulties with separate electrical branches of artificers. Then again they liked to keep their machinery going, even if all the electrics had failed and this had been very useful in the past, and he dreaded to think what would happen if all the machinery came to a halt every time the electrics failed, especially under action battle conditions.

High pressure hydraulic fluids also were not favoured, because there was a considerable fire and explosion hazard when mists were formed. This was now thought to be an extremely serious hazard. The mists of hydraulic fluids were inflammable, and severe explosions could take place if there should be a small leak in a confined compartment or if mist formed in one. For the time being, the Admiralty were pursuing almost entirely the pneumatic field.

In conclusion, he would like to assure the meeting that the Admiralty viewed this field of engineering with very great interest indeed. They were endeavouring to reap the full benefits of all the work that was being done, and he felt that the paper would assist them as it would assist others to pursue this aim.

MR. R. E. J. PUTMAN drew attention, in support of the author's remarks about electrics, to the inherently low inertia of electrical transmitters. It was a basic fact that the forces in an electrical transmitter were very much lower than in a mechanical transmitter. As a result, the whole design became lighter, and for marine installations this was important. When a ship was rolling and pitching in heavy weather, one did not want the instruments to respond to these movements, and it could be shown that where telemetering was required, electrical transmitters were rather superior in that respect.

Another advantage of transmitting one's readings was safety. One knew how many leaks were developed in the course of a ship's life in an instrument panel with water and electrics mixed up behind it, and the effect of dripping water could be serious. It was important to keep the water out if at all possible. There was a good case on this ground for transmitting signals rather than bringing the fluids themselves into the panels.

On the turn-down of burners, he would like to ask the marine engineers how far they were prepared to go into automatic control of oil burners. At the present time, turn-downs were low. 2:1 was the average and 4:1 was very good. He believed one firm claimed 10:1 but he had not seen it in action yet. As a result, if one wanted fully automatic control of a marine boiler, it involved the frequent igniting and extinguishing of oil burners. This could be an expensive business if done automatically. He had seen the burner which had been projected on the screen in operation and it worked very well, but with eight or twelve of them the increased cost of the burner installation would be considerable. Among other things, with such burners it was possible to bring in burners automatically in a predetermined sequence should one fail for any reason, so as to maintain the total number of burners in operation at a fixed value according to the load.

Many things were possible with automatic control equipment, but he would like to hear from the people who had to operate or build ships just how far they were prepared to go in fitting such equipment in the boiler room, and particularly for operating the burners.

MR. C. A. SINCLAIR (Member) commended the author on his bravery, in that at a time when so much was being said about cost and about the time spent ashore by engineers studying for certificates in the marine world, he boldly walked into the lion's den with proposals which would increase the capital costs, increase specialized maintenance, and bring a number of engineers ashore for a further three months or, alternatively, increase the engine room staff. It would seem that if the shipowner were to be enticed into adopting this extra liability, there must be some greater incentive than the knowledge that the engineers would go off watch having suffered less fatigue than in times past. This incentive, one would judge, would take the form of economies in fuel consumption and possibly to a certain extent of a reduction in maintenance by ensuring that the plant was operating at its optimum efficiency. It would be of interest to many members if some figures could be given of the expected economies.

It did seem that in the search for efficiency one had to face an increasing degree of complexity, but from experience he had found that the modern pneumatic and hydraulic controls as applied to feed and combustion equipment were reliable. It was with alarm that one heard of the camera and television equipment portrayed, although its use was understandable where large boilers were used, as in land practice. It was most important that the camera and television system could not indicate a false level, as the author had stressed. But he also stated that that was only as true as the fact that the gauge would not indicate a false level. There was still the same possibility, added to which was the fact that the wrong information would be conveyed to the automatic feed control if there were a false gauge level showing.

At a meeting at one of the other technical societies recently for the reading of a paper* on boiler explosions, there was a reminder of the many accidents that had occurred because undue reliance had been placed upon automatic equipment. On the other hand, if boiler ratings continued to increase, it would seem that there might be a call for even some anticipative form of control in relation to boiler water level, owing to increased sensitivity to firing rate. Was such a state of affairs envisaged by the author?

In view of the importance of condensate temperature on modern turbo installations at sea (where so often the advantages of the regenerative effect condenser were lost due to improper adjustment of the circulating pumps), he suggested this might be a part of the plant where automatic as distinct from distance control might to advantage be employed.

There was a large body of feeling amongst engineers that both instrumentation and distance control could with advantage be improved without the added complication of automatic control. In view of the many variables, the latter must greatly increase the complexity of the whole system. Did the author subscribe to this view? It still left the possibility, as the author said, of ill-judged changes, although it facilitated the making of changes.

The author mentioned the *p*H meter, the oxygen meter and the salinometer, with recording instruments. He would ask whether anything was being done in relation to total dissolved solids; whether a recording instrument was available or likely to become available—something, say, giving a recording of the weight of the circulating sample through a chamber of known dimensions or a recording of the buoyancy of some immersed vessel, as means of recording through electrical conductivity were not considered to be accurate as to total dissolved solids.

The author did not seem to see in merchant practice the necessity for having control of the air/fuel ratio to the individual fires. He himself would put in a plea for this form of control; for in view of the large proportion of time that merchant vessels spent manœuvring and the possibility of damage to refractories or impingement upon heating surfaces of cold air, its importance could not be overlooked, even though the overall air/fuel ratio might be correct.

There was a final matter of which the author should be reminded. Although his ideas in relation to automatic control and, indeed, his ideals might be high, in the marine field—as had often been stressed at the Institute—was conservative if for no other reason than that the equipment, once installed, must operate for long periods during which manufacturers' representatives could not just slip aboard. Confidence must therefore be built up both in the operating personnel and in those responsible for the original installation.

Mr. F. E. C. Jarrett (Member) said he felt he must support Mr. Paddon Row, to a certain extent sadly. The complications envisaged in the paper somewhat alarmed him. He was quite distressed when he saw the diagrams and wondered what further complication they were going to take to sea. He had had the misfortune to serve on board one of the ex-German ships, the *Potsdam*, where instrument control played a major rôle. He said "misfortune" because he had after to explain why they did not continue using the German machinery; but that ship had been running a long time now as the *Empire Fowey* and nothing had been heard about her at all: she had been running quite well with conservative British engineering.

The original machinery, as many engineers would know, was not suitable for ordinary merchant service. The Germans had some other idea for that ship at sea. But she was a ship with characteristics which, whether one liked it or not, might be necessary in future developments. She had a very high rate of steaming with forced circulation and quantitative control of water, fuel and air. The boilers of the present day, with natural circulation, might have to develop in the future to forced circulation types if further increased performance and reduction in weight and size were required. It might be the violence of the atomic fuels which might bring it about, but this was the tendency of the future and automatic control of instrument type might be a necessity. The *Potsdam* definitely had to have fully automatic boiler control to run successfully. There were two ships at the time with similar machinery—he thought the Orient Company had one of them—they were unfortunate enough to go out first and the *Potsdam* had to some degree the benefit of their experience. Instructions were received that they must get the automatic gear working; it was called the Askania gear, if he remembered rightly. It was not possible to get the German technicians to come to this country: they were probably in prison camps. One had to do the best one could. He had the job of putting this equipment right and the diagrams were just as complicated as those shown on the screen that evening, with the added difficulty that they were in German. However, the equipment was eventually sorted out and, despite the complication of the diagrams, the actual construction turned out to be not too difficult. With the gear in operation a run to Port Said was very successfully carried out. These boilers could not be run without that equipment. Therefore, developments in the future would tend to support Mr. Paddon Row's proposals.

Commander Wilson had commented on the standard of personnel. He himself did not think the application of this instrument control at sea would let them off lightly there, unless, of course, they could, if anything went wrong with a complicated set of equipment, wireless or telephone home and have the technician rocketed out. Otherwise, the skill of the engineer at sea would have to increase.

This was the kind of thing that happened. The heart of this particular equipment was a simple nozzle about the size of a pencil. It was balanced very sensitively, and it worked under a very small pressure difference. The small instrument box controlled the turbo feed pump which was doing 6,000 revolutions and discharging at about 1,650lb. per sq. in.

The control used to hunt a little and surge the feed pump. Hunting was caused by the small pencil shaped nozzle, and that was balanced on pintle bearings similar to the pintle bearings in an ordinary pocket watch. To stop the hunting he carried round a little magneto spanner and tightened up the pintles a fraction for damping. However, as he was sent for to do this at all times of the day and night he eventually passed on the job to a member of the engine room staff with the instruction that "all you have to do is to tighten this up a fraction". Soon after, he had just settled down in his cabin when all the lights went out and that miserable dying-down noise came up from the engine room. By the time he got down below everything was out: there were the blue lights, the emergency lights, and red lights, but everything was dead, the ship had stopped. The small magneto spanner was quietly but firmly handed back to him! It was unquestionable that personnel must be more highly trained if they were going to understand not only the ordinary complexity of the present-day marine equipment but the instrument that controlled it.

Electrical and electronic control had been mentioned. He had had his second engineer's certificate at the time, and he could manage the ordinary hydraulic control fairly confidently; but if the machinery had been electronically controlled, he would have been very worried indeed. Again, he would have

* Evers, J. 1954. "Inspection, Explosion and Breakdown of Boilers and Pressure Vessels". Proc.I.Mech.E., Vol. , p. . Also, Technical Report, New Series, Vol. II, p. 109. 1954. British Engine Boiler and Electrical Insurance Co., Ltd., Manchester.

been very worried if he had felt that the full control of his main machinery passed to an electrical engineer whom he had to rely on for vital control. He would sooner have some equipment which was in line with his own mechanical training and was robust, such as a hydraulic or similar system.

This particular system worked at a pressure of about 250lb., which was not high, and perhaps there was a danger of oil mist; but then perhaps they could have used other liquids inside. Ordinary lubricating oil was used and worked quite well, with little danger at that pressure.

He had thought he ought to make these points, because the experience in the *Potsdam* had been one of the few occasions when a ship's machinery had to run absolutely and completely on automatic control. It was his opinion that, in the future, for forced circulation and very high-rated boilers, the application of some of the equipment described by Mr. Paddon Row would take on greater and increasing importance.

MR. A. H. ISAAC said that, like an earlier speaker, he also felt something of an interloper. He had entered the hall knowing little about marine engineering, but after hearing the last speaker he wondered whether it was so different from the chemical industry, with which he was more familiar. Indeed, they had precisely the same problems there. As an outsider, he acknowledged the courtesy of the Institute in allowing him to contribute to the discussion.

Mr. Paddon Row had been somewhat apologetic about venturing into a field which he felt had previously been handled by specialists. As previous speakers had said, however, he had done so with great success.

It was an interesting thought that the whole field of modern process control was really an offspring of the marine engineer. The basic theory of modern process control was based on the work done at the end of the last and the beginning of this century on the steering of ships. The fundamental actions that kept a ship on a straight line governed all the problems in the process industries that were being tackled today under automatic control. The extension of this technique to marine engineering problems was thus the completion of the loop.

The automatic controller had advantages which Mr. Paddon Row had mentioned from the point of view of efficiency, safety, the comfort of the operator, and the ability to meet load changes with the minimum changes in the variables. But it was important to stress that many plants and processes today could not operate at all without automatic control. Generally speaking, an automatic controller only simulated what a first-class operator working twenty-four hours a day could himself do. But it did this continuously, smoothly and fast. Many rapid responding, low capacity, high throughput units, whether marine boilers or any other type of process plant, must eventually require automatic control. In fact, the transition from Lancashire boilers in land practice to the high-speed watertube boiler of today was accompanied by a transition from simple manual control through to the more complex automatic control systems for that very reason.

With regard to the design of instruments and instrument systems for marine use, he had always felt there was in many respects too much preoccupation in industry with the design and mechanisms of instruments rather than with instrumentation. The first stage was the acceptance of the technique of instrumentation; the idea and practice of doing things automatically, of measuring things at all, had to be put across with a subsequent examination of the actual mechanisms and means for doing it.

Generally speaking, industrial systems today had to meet very heavy and arduous duties which would be simulated or reinforced in the conditions in shipboard engineering. He could recall one instrument panel that was required to operate at a steel works. Ten feet behind the building, a railway siding along which trucks were shunted. To one side there was a steam drop hammer, and not very far away they were breaking up scrap iron by dropping a large iron ball on it. In addition, the atmosphere was heavily charged with corrosive acid gases. Such conditions were frequently met with and emphasized the difference between industrial instrumentation and the more lightly built laboratory equipment. The sacrifice of some degree of accuracy and sensitivity would generally be preferred if necessary in order to maintain robustness.

Difficulties connected with linkages and flappers had been mentioned. The pneumatic control system illustrated by Mr. Paddon Row was not of the very latest design. No doubt his lecture was written six months ago and designs changed too quickly. The first slide was more representative of modern techniques, where Mr. Paddon Row had described a force balance transmitter. In this construction, links, levers and flappers were largely obviated and the system had a high degree of feedback. In the operating condition all the components were relatively static and steady under the impressed pressures and, therefore, the effects of vibration and shock were much less. This, of course, had been a development in design in response to the requirements of industrial practice and would seem to have many potential applications in the marine field.

Experience of standard industrial instruments which had gone to sea was good. When an ordinary process factory was moved to sea, as in a whaling ship, one moved, lock, stock and barrel, all the processes and automatic controls, which were precisely the same as in any factory on land. In another direction, the oil refinery influence was spreading through their tankers into seagoing vessels, and a number of standard industrial instruments were utilized in many tankers today. The level in deaerators was one example and the control of humidity in the holds of tankers was another.

He would very briefly join issue with the author on one small point. There was some confusion in his paper between cascade control and open loop control, and this appeared to need some clarification. The author had referred, as an example of a typical system, to the control of the superheat of boiler steam by regulation of cooling water fed to a desuperheating condenser. This constituted a typical simple closed loop where a valve in the water line was operated by a temperature controller installed at the steam outlet. Fluctuations of water pressure could change the flow through the valve for a given position and this would not be rectified until the steam temperature had been upset. To overcome this, a flow controller located in the cooling water line whose set point was adjusted by the temperature controller would correct for these disturbances before the temperature had been affected. This was, as the author explained, a cascade system, but was still closed loop since the effect of the controllers was fed back into their individual loops and both were inherently stable. There was a further addition that could be made if the setting of the water flow were also given an arbitrary correction by a signal derived from the temperature of the hot gases entering the superheater. This was an attempt to anticipate changes in the superheater steam outlet temperature but was an open loop because there was no feedback into the system in view of the fact that the movement of the water valve had no effect on the hot gas temperature. In the same way, in the author's example of air flow-fuel flow ratio, fuel flow was controlled by a closed loop, but the signal from the air flow was a purely arbitrary correction to the value of this controlled flow based on combustion conditions—clearly another open loop system. These did emphasize the fundamental difference between the inherently stable cascade system which was closed loop, and the arbitrary correction in the open loop. The former was used whenever possible and the open loop system required great care in setting up and maintaining lest instability result. He felt that it might be assumed from the paper that these were the same.

Referring briefly to pneumatically operated controls, he considered that this type was simple in construction and robust in operation. The mechanisms could all be understood by the average engineer since they were all basically plumbers at heart and could appreciate readily flows, pressures and restrictions.

A lot had been said about power and it was useful to consider a standard pneumatic controller as an amplifier taking its initiation from a light measuring system and moving a large control valve or damper. The amplification factor obtained in a single stage with a fully stable output was of the order of 10^{10}, which was an impressive figure; 10^6 or 10^7 was probably nearer electronically in one stage. Such a factor was difficult to appreciate but rather loosely it meant that if a flea weighing 50 mg. hopped on the initiating device, a ton could be lifted by the output through one inch.

MR. H. S. RAO (Associate Member) said that he noticed that marine engineers preferred certainty and security in steering, operating and every other field. They were interested in ensuring that the machinery in their charge worked well and sometimes second engineers did not get much peace! They tried to see everything worked efficiently, but they were diffident about carrying out new and strange ideas which had not been tried in practice. However, they learnt a great deal during the time they spent ashore studying for examinations, and went back as better men, appreciating the necessity of all these current inventions.

He had learnt a great deal from the paper and if he had been able to read it only a few days earlier, he would have made a better job of his answers in the examination he had just taken, about the electrically operated oil separator and, of course, air/fuel control.

MR. F. P. ROUT did not wish to elaborate on what had been said about the application of modern instruments but would like to challenge the apparent belief that they were, of necessity, extremely complicated. In view of the experience of a previous speaker who had found that hydraulic (and presumably pneumatic) instruments were less complex than manufacturers' diagrams suggested, he would like to show that the same could be said of electronic methods.

Probably everyone present had encountered resistance bulb temperature measuring technique, where a remotely sited copper, nickel or platinum coil R whose resistance varied with the temperature, was wired as one arm $c\,b$ of a d.c. fed Wheatstone bridge (Fig. 19). Resistors R_1, R_2 and R_3 having fixed

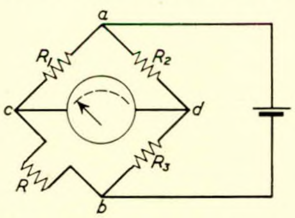

FIG. 19—*Temperature measurement—d.c. fed unbalanced bridge*

values, the change in resistance, with temperature, of R produced an out-of-balance voltage across the mid-points $c\,d$ of the bridge. The resultant galvanometer deflexion varied with the temperature at R, the dial being calibrated accordingly. The main objections to this system were (1) its susceptibility to supply voltage variations; (2) the presence in the measuring circuit of the galvanometer coil whose high resistance might vary with age or violent changes of ambient temperature, and (3) the effect of the motion of a ship on the long galvanometer pointer demanded by the system.

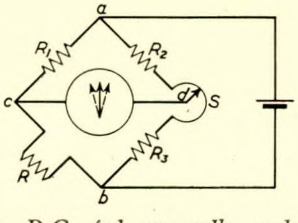

FIG. 20—*D.C. fed manually re-balanced bridge*

The next stage (Fig. 20) was to place slide-wire S (a variable resistance) between the bridge resistors R_2 and R_3. In this system the temperature was measured by adjusting the slide-wire to bring the bridge back to the point of balance, the skirt of the slide-wire knob being marked in appropriate units. Previous objections were overcome since, at balance (1) any supply voltage variation affected both limbs of the bridge equally; (2) there was no current through the centre zero galvanometer coil; (3) the pointer, since it was required merely to indicate a state of balance, only needed to be long enough to travel half-inch or so either side of the central zero position. Although this was a well-tried system, familiar to many members, objections were still raised (1) to the use of any form of galvanometer and (2) to the fact that manually balanced bridges were not able to be used for continuous indication.

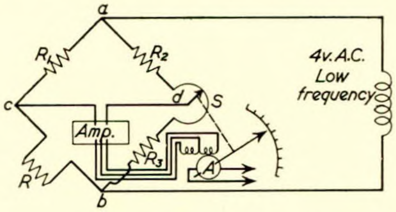

FIG. 21—*A.C. fed self-balancing bridge*

Although the bridge in Fig. 21 was a.c. fed (the four volts or so required could be generated by a single valve oscillator and need not necessitate the all too familiar rotary converter) the principle of operation was the same. With the bridge in balance, points c and d were at the same potential, but if one considered instantaneous values when the bridge went out of balance, c was either slightly positive or slightly negative with respect to d, depending upon the direction in which the slide-wire arm needed to be moved to restore the bridge to balance, i.e. depending upon whether the temperature (and hence the resistance) at R had increased or decreased. Since these voltages were too small to work effectively as such, use was made of the fact that the phase relationship between the unbalance voltage across the bridge $c\,d$ and the bridge supply $a\,b$ changed as the bridge passed through the point of balance. An amplifier with a twin output stage feeding the split field of a small d.c. motor could be arranged to respond to this phase change and cause the motor to drive the slide-wire arm in the direction required to restore the bridge

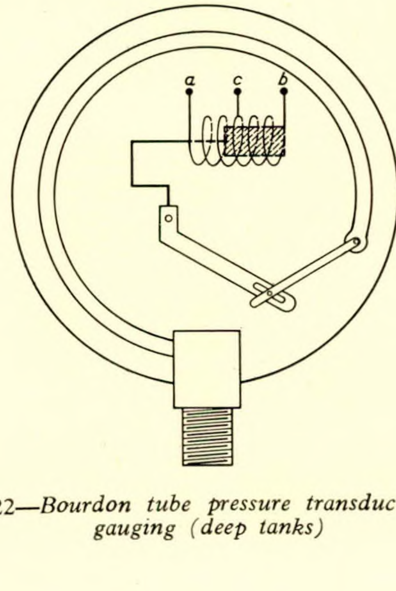

FIG. 22—*Bourdon tube pressure transducer—tank gauging (deep tanks)*

to balance. A coupled pointer would indicate the temperature.

In addition to temperature measurement, self-balancing bridge systems could prove very versatile. If one took a standard Bourdon tube pressure gauge and in place of the conventional sector, pinion, hair spring, pointer, etc., moved a slug through the core of a centre-tapped coil (Fig. 22), then as the pressure changed so would the inductive values and hence the voltage developed across the two halves. By wiring this centre-tapped coil as one limb *a c b* of a similar self-balancing bridge circuit, the system would then operate as a remote pressure indicator.

The same technique could be used to measure small mechanical displacements in addition to other pressure type applications, for instance, tank gauging. The pressure at the bottom of a tank (due allowance being made for the specific gravity of the contents) was a function of the actual level. With deep tanks (say, 30 feet of oil—approximately 12lb. per sq. in.) a Bourdon tube transmitter was quite in order, but for double-bottom tanks (say, 4 feet—less than 2lb. per sq. in.) the Bourdon tube would need to be replaced by a diaphragm (Fig. 23).

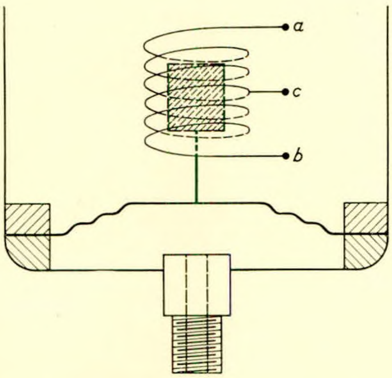

FIG. 23—*Low range pressure transducer (double bottoms)*

Allowance would be made at the transmitter for the specific gravity of the tank contents, thus one common indicator could be used to show the level in a number of tanks with widely different contents. By turning this unit on its side (Fig. 24)

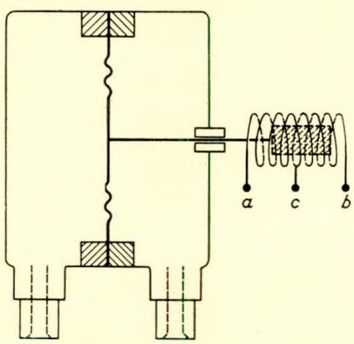

FIG. 24—*Differential pressure transducer—air flow measurement, for combustion control*

and using both sides of the diaphragm, one had a differential pressure unit for measuring air flow, the key to all forms of combustion control. Not only were these pressure, temperature, tank gauge, air flow, etc., self-balancing bridge amplifiers similar in principle, there was no fundamental reason why they should not be absolutely interchangeable. Completely a.c. fed systems using a two-phase servo motor were in industrial and occasional marine use, mainly on temperature applications.

To simplify matters in some fully controlled industrial processes, particularly in America, there was an increasing tendency to scan, automatically, all points of measurement but only record those where the level, flow, pressure or temperature, etc., was outside normal limits. This was the deviation recording technique referred to by a previous speaker. It seemed unlikely that this state of affairs, generally, would arise on board ship although the principle could be applied to main motor Diesel exhaust temperatures (Fig. 25) by taking

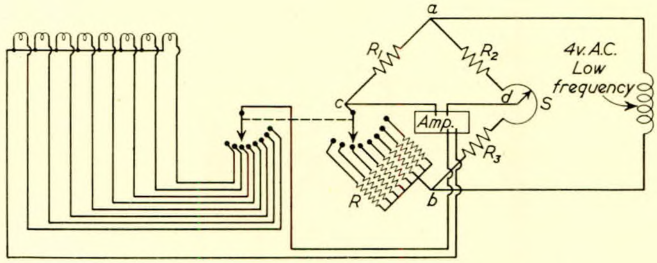

FIG. 25—*Indicator light bank form of Diesel exhaust temperature scanner*

a bridge circuit and using a motorized switch to couple each resistance bulb (one per cylinder) in turn into the circuit at *R*, at the same time connecting the amplifier output to the corresponding number in a bank of signal lamps so that if any exhaust temperature departed more than a set amount from the average value (i.e. the slide-wire setting) the corresponding signal light would come on. For logging purposes the motorized switch would be operated manually and the temperature measured by turning the slide-wire knob to the point of balance of the bridge—indicated by the extinction of the appropriate indicator light.

Not only indicating systems but control units, too, made use of the same fundamental principles. The Bridge in Fig. 26

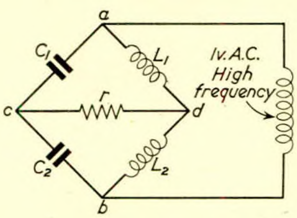

FIG. 26—*Basic R.F. bridge, for level control and indication*

was part of a single valve unit, the supply *a b* being maintained, by the oscillatory nature of the overall circuit, at a somewhat higher frequency than before to enable coils L_1 and L_2 to be the fixed limb *a d b* and condensers C_1 and C_2 to be the fixed and varying arms of the other limb *a c b*. In exactly the same manner as before, use was made of the change in phase relationship between the bridge supply *a b* and the out-of-balance voltage across the resistor *r* linking the mid-points *c d*, as the bridge passed through the point of balance, as a result of a change in value of condenser C_2. The out-of-balance voltage was re-applied to the valve circuit in such a manner that it either maintained oscillations (positive feedback) or suppressed oscillations (negative feedback) dependent upon this phase relationship. Since the anode current of a valve fell instantly to a low value when a circuit went into oscillation, and rose to a maximum when oscillations were suppressed, a relay placed in the anode circuit would operate as the bridge passed through the point of balance.

A mechanical analogy would be a steel rule clamped in a vice. If the free end were displaced the rule would start to oscillate, although this would soon die away. If the actual movement of the rule were used to trigger off a small power-driven hammer which, starting beyond the travel of the rule, moved through a greater arc, this arrangement would either maintain or instantly suppress oscillations, dependent upon whether hammer and ruler were moving in the same direction (in phase, positive feedback) or opposite direction (out of phase, negative feedback) at the moment of impact.

Moving back to Fig. 26, they had established that a relay could be made to operate as a change in the value of condenser C_2 moved the bridge through the point of balance. Now, if one fitted a probe at the desired level in a tank (Fig. 27) the probe and the tank itself formed the two elec-

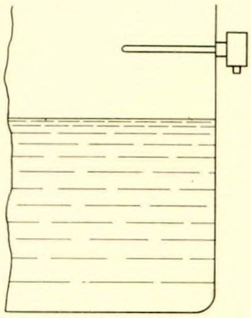

FIG. 27—*Probe arrangement—tank level control*

trodes of a condenser (wired into the circuit as C_2) the value of which depended upon the electrode sizes, their distance apart and the dielectric constant of the material between. Since the first two factors were constant the capacitive value of the arrangement therefore depended upon the material between probe and tank. Thus, if one adjusted the Bridge to be near the point of balance with the probe in air, the approach of oil, water or any liquid (conducting or non-conducting) or granular solid, would change the capacitive value of tank and probe, move the bridge through the point of balance and operate the relay. Similarly, if the setting-up was carried out with the probe in oil, the arrangement would react to an oil/water interface, this being the basis of the oily water separator controller to which a previous speaker had referred.

Reference had also been made to the use of television cameras and sight glasses for boiler level control. Providing that arrangements were made to stabilize the voltage feeding the bridge at *a b* (and this had already been done) the magnitude of the out-of-balance voltage appearing across *c d* could be used as an indication of the actual value of condenser C_2, instead of being re-applied (fed back) to the valve for oscillatory purposes, as was the case in level controls. If one had a metal cylinder in place of a sight glass, with a probe running through the centre (Fig. 28) then the magnitude of the out-of-balance voltage across the bridge would vary with the value of the condenser formed by cylinder and probe and would, therefore, be a function of the water level in the unit and hence in the

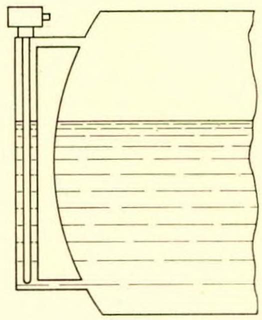

FIG. 28—*Probe arrangement—boiler level indication*

boiler. Naturally, from a purely mechanical point of view this instrument application needed to be carefully engineered, preferably making use of the specialized knowledge of the actual boiler maker.

On this subject there was a lot more that could and should be said, but he merely sought to establish the fact that a seemingly complicated range of instruments could be built up from simple fundamental principles. It should be added that although not fully exploited, most of these applications represented patented technique. A further point that all had in common was the fact that they were being investigated by a marine organization from a strictly sea-going point of view.

MR. R. J. HOOK (Associate Member) said he had a suggestion to make and he was glad that the previous speaker had preceded him because it would help to make his point. The author had rightly stressed the importance of obtaining the co-operation of the operating personnel whose task it would be to handle the gear.

Everyone agreed that the paper outlined the shape of things to come. For many marine engineers, particularly some of those who were not present, it would be a first introduction to the matters mentioned. In this connexion he felt that the favourable reception and adoption by marine engineers of this field of engineering might be more readily forthcoming if the diagrams contained in the paper were easier to understand.

The author had referred to various instruments and had indicated their respective applications, but the manner in which the instruments achieved their purposes were not at all clear in the paper, although the author had given a verbal explanation at the meeting.

When the paper was published in the TRANSACTIONS of the Institute he would like to see included an explanation of the diagrams in the same excellent manner in which they had been outlined that evening. Such an explanation was complementary and essential to the paper and would assist the marine engineer in obtaining a clearer understanding of modern instrumentation of the types to which the author had referred.

Correspondence

MR. L. BAKER, D.S.C. (Vice-President) wrote that the author had covered the mechanical aspects of instrumentation and control in an admirable manner but he had made few references to what one might call the "human" engineering angle.

On a previous occasion*, attention had been drawn to the need for this to be considered not only in the design of the instruments but also in the arrangement thereof: that was to say not only in the size, shape, graduation alone, etc., of the dials, but also the geometrical presentation.

The modern trend was towards increasing the automatic control of plant on the grounds that a man made mistakes, but so, unfortunately, did automatic controls, so the human remained (usually fewer in number) to over-ride the automatics when necessary. This resulted in the elaborate panels

* Mackworth, N. H. 1952. "Some Recent Studies of Human Stress from a Marine and Naval Viewpoint". Trans.I.Mar.E., Vol. LXIV, p. 123.

shown in Figs. 13 and 15. Little account seemed to be taken of the next major human limitation, viz. that the brain could only assimilate and interpret a limited amount of data in a given time; if too much data were presented the brain failed to register as much of it as was in excess of the individual's capacity.

The implications of this in relation to the "master control" human were several, of which the following were particularly significant to the present discussion: —

1. The man must be specially suited to the job and specially trained to absorb and interpret a large amount of data correctly.
2. This special man would be doing a dull, monotonous job which would not occupy the capacity of his brain. Special efforts would be needed to ensure that a long period of inaction did not produce staleness and inattention to duty. The similarity between this and the case of pilots and flight engineers would be noted, the solution for flying personnel being long periods of relaxation at frequent intervals.
3. In a real crisis, any man would probably be overloaded and, therefore, if the sequence of events were of subsequent importance to the analysis of breakdown, it was vital to record these events, i.e. the order of operation of safeguards on *one* instrument to eliminate possible errors in absolute time.

Having proceeded so far along the chain of logic it would appear that the next step was to make everything 100 per cent automatic, with a plant shut-down in case of failure of any one control and merely provide a man to start the plant up again when the appropriate corrective action had been taken!

MR. P. L. COWPER-COLES considered that the author had rightly drawn attention to the change of attitude during recent years by operators, owners and designers of ships of the Royal Navy and Merchant Services towards systems of centralized and automatic control. This change in outlook had been advanced by the necessity to consider the provision of air conditioned control rooms as a protection from radio activity during atomic warfare, and due to the noise factor the provision of control stations adjacent to the engine rooms for ships which might use high-speed Diesel engines.

Manufacturers and designers of control equipment were giving attention to the special requirements and operating conditions demanded by marine service. In that connexion a new fully patented range of remote control equipment was worthy of particular mention due to its broad applications combined with extreme simplicity and, most important of all, the fact that it could be fitted in a matter of hours to existing valves *in situ*. Thus, it enabled ships to be fitted with centralized or remote control systems whilst in service, as well as providing a standardized equipment for installation of complete systems at refits and for new building programmes.

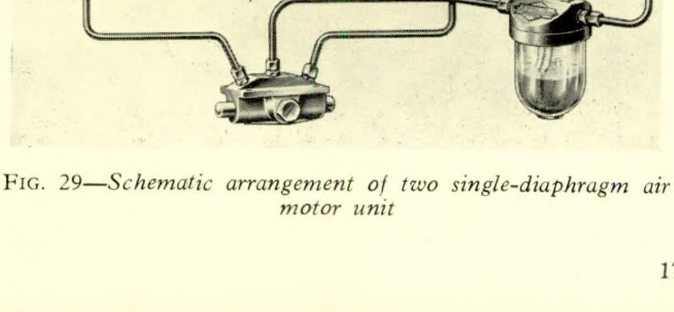

FIG. 29—*Schematic arrangement of two single-diaphragm air motor unit*

The system was operated by compressed air and consisted basically of fitting a toothed wheel to the valve turning member, which was rotated by means of the teeth and ratchets fitted to diaphragm air motors that were attached to the valve body. It was so arranged that when the motors were idle the ratchets retracted to leave the valve free for manual operation by the handwheel, if required. The equipment consisted of motor brackets, toothwheels and fittings, together with ancillary items for remote indication of valve position and for linkage into automatic and sequence control systems, used in conjunction with various combinations of two, four or more either double- or single-diaphragm air motors. A schematic diagram in Fig. 29 showing a two single-diaphragm motor set illustrated the method of operation. Fig. 30 showed a two double-diaphragm motor set fitted to a 32-in. valve controlling the main engine condenser cooling water on a modern tanker of 32,230 tons deadweight.

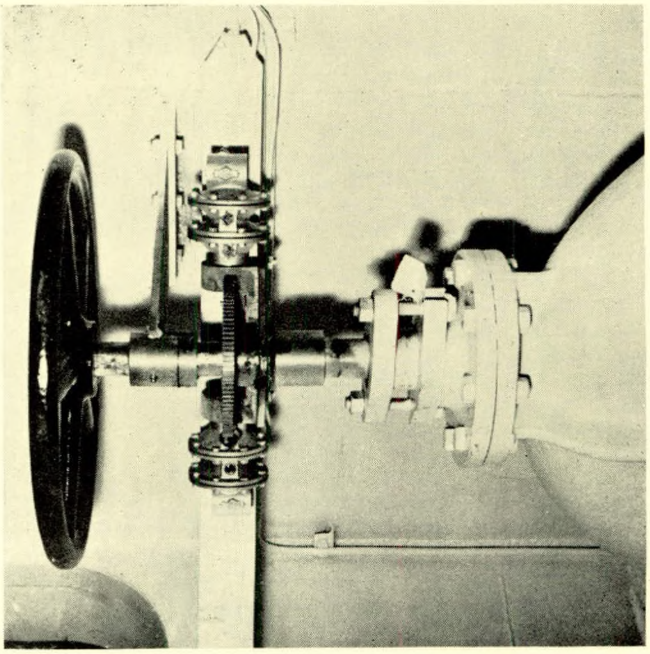

FIG. 30—*Two double-diaphragm air motor unit installed on a 32-in. valve*

A high torque system of this nature, in addition to valve operation, had found many other applications in both simple and complex control systems. These included sequence soot-blowing operation; stack damper, hopper feed, variable-speed gearbox and other lever setting adjustments; automatic temperature, level and pressure control, and the adjustment of screw-down gear for the continuous automatic control of gauge on strip rolling mills.

He would suggest that such an equipment would appear to have been designed to meet many of the requirements outlined by the author both in the body of the paper and, in particular, in the conclusions.

MR. E. F. D. WEBB thought the author was to be congratulated on the wide field he had covered in modern distance control and instrumentation, and a paper of this nature was especially welcome when it was prepared for the benefit of plant engineers, who were faced with such an embarrassing choice of distance and automatic controls for use on new plant, and very often had difficulty in seeing the wood for the trees.

There appeared to be a need for uniformity in method of obtaining control at a distance, as one encountered all too often a mixture of methods contained in one plant and presenting a frightening spectacle to the maintenance engineer when the back of a control panel was opened. For example, a mixture of hydraulic, pneumatic and electric controls, the latter often containing telephone type relay equipment, was often encountered, and whereas it was appreciated that certain processes could sometimes only be conveniently carried out by electrical means, it did sometimes appear that a more consistent use of distance control means could be employed.

The diagrammatic arrangement of an automatic control system for an oil-fired marine boiler, shown in Fig. 17, called for some comment. It was apparent that all turn down of the oil supply for burning was by means of fuel pressure supplied to the burner, which would give only a limited range of turn down before atomization of the fuel became unsatisfactory and, furthermore, the control of air supplied to the burner was governed by means of a damper, so that although the quantity of air supplied was regulated, the velocity of air entering the oil spray must be reduced as load was decreased, so that intimate mixture of air and oil became impossible at low load and poor combustion must result. The system illustrated would therefore appear to have an extremely limited turn down range for efficient combustion conditions, and would be hardly suitable for operation from an automatic control system if the boiler load was variable over wide limits.

Finally, with the ever-increasing use of the heavy fuel oils, might he suggest more careful consideration of the control of the physical conditions of the fuel oil supplied to the burners. The fuel oil preparation plant appeared to receive little thought in its design and automatic control aspects, and it seemed somewhat ironical that combustion engineers who would not dream of burning pulverized coal without the most careful attention to dryness, temperature and milling conditions, would often quite happily present fuel oil to an oil burning system at temperature and pressure conditions very different to those for which the equipment was designed, and were then surprised that indifferent combustion resulted.

Author's Reply

Mr. McClimont's reference to the unsightly panel arrangements so often seen was a good example of the policy of relegating instrumentation to a position of minor importance, an afterthought inserted without much thought or planning. The author most certainly advocated the provision of chairs in the engine room, as efficient observation could be carried out more easily when seated, particularly in a ship during rough weather. The author was grateful to Mr. McClimont for mentioning the great importance of environmental conditions and would like to suggest a fifth main factor—noise level.

The commonly known oxygen recorders did suffer from the drawback of severe time lag but were useful, nevertheless, where conditions were normally steady. It was of great interest to learn that an instrument had been developed which did not suffer from this drawback, as there was a very great need for continuous and accurate determination of the oxygen content in feedwater due to the severe fluctuating conditions experienced during manœuvring.

The author would like to thank Mr. Marchment for correcting the impression given in the paper that it was impossible to provide an electrical "slave" motor whose speed was proportional to the input signal.

Commander Wilson's contribution was extremely interesting and underlined the particularly difficult design requirements of the Admiralty. It was possible that the problem of a very wide turndown ratio might be met by the type of automatic burner shown in Fig. 9, load change being accomplished by the use of a large number of burners each having a small turndown ratio. The argument against the use of electricity as a control means did not appear to be particularly strong, as it was difficult to imagine that with reasonable arrangements for alternative supply sources this system would be any more susceptible to complete failure than a pneumatic or hydraulic control. The author was delighted to note that the Admiralty was taking steps to alleviate the stress of watchkeeping and hoped this good example would be extended in both the Navy and the Mercantile Marine.

Mr. Sinclair's question regarding the economics of automatic controls was an extremely difficult one to answer due to the many implications involved. Claims of increased boiler efficiencies of from 1 per cent to 2 per cent had been made but it would be appreciated that the figures could vary widely, depending on the efficiency of the manual control system it replaced. However, it would appear reasonable to assume that such facilities as automatic control of water level, gland steam and oxygen content of feedwater, could save considerable sums of money on maintenance.

The water level television instrument was only an indicator which brought the gauge to the operator and it had no direct connexion with the automatic feed water control system. The so-called three-element feedwater control system employed on large land boilers was an anticipatory type, where the steam and feed flows were balanced with final trimming carried out by the drum water level element.

The choice between automatic and remote manual controls would depend to a great extent on the complexity and layout of the machinery but as a general guide it was wise to control automatically all systems which required frequent and accurate adjustment, particularly where there was interference from external sources. The operator was then free to concentrate on the coarser adjustments and overall supervision.

The author was not aware of any fully automatic apparatus for continuous and accurate indication of boiler water total dissolved solids but there was equipment available for indicating conductivities up to 5,000 reciprocal megohms which would cover all normal conditions. So long as the boiler water treatment was reasonably constant, a conductivity reading was quite satisfactory for comparative purposes and good control might be obtained by daily laboratory checks, to determine the actual T.D.S. figure.

Mr. Jarrett's vivid description of his experiences with the Askania control equipment on the *Potsdam* underlined the necessity for a certain amount of personnel training in order to produce the correct attitude towards instruments. Failure to appreciate the sensitivity of equipment could very easily lead to the type of mishap described.

The author agreed that a certain amount of training was necessary for the men responsible for the upkeep of instruments but expert knowledge was not essential where the system was designed to allow for the easy substitution of faulty circuits. Standard tests were devised to locate faulty circuits and if average intelligence was uesd the location and replacement became a matter of minutes.

Mr. Isaac had made some very interesting points and had shown that it was quite possible to design instruments for very arduous conditions. The author agreed that the wording referring to "open loop" and "cascade" systems could lead to confusion and was grateful for Mr. Isaac's clarification.

The author felt that Mr. Rout's lucid explanation of the manner in which the more complicated electrical systems could be built up from first principles would be very helpful. One of the troubles encountered by the uninitiated when examining an electronic wiring diagram was to find a starting point, and familiarity with first principles was important.

Mr. Hook's comment that descriptions of the manner in which the various instruments referred to functioned would be a great help to engineers was quite correct but it would require another paper of approximately the same length to carry this out thoroughly. The author would suggest that anyone interested could obtain descriptive matter from instrument manufacturers, who were always very helpful, and a list had been given at the end of the paper of those who supplied diagrams and photographs, etc.

The "human" engineering angle referred to by Mr. Baker was, indeed, a very real problem and had been given considerable thought. The use of "in line scanners" shown in Fig. 12 of the paper enabled the operator to see at a glance whether the plant was operating satisfactorily and, in addition, any deviation was immediately apparent and the control point requiring adjustment was shown quite clearly. The modern tendency was to present the operator with the minimum number of instruments necessary to carry out efficient operation and such equipment as recorders and subsidiary measuring devices were positioned at the side of the main desk or other convenient place. Where posssible a "mimic diagram" could be used as this reduced the strain on the operator's imaginative powers and saved time when an instrument failed. The operator undoubtedly would have to be given special training but under day-to-day operation he would not have to absorb and interpret a large amount of data. The author agreed that the work of the remote control room operator would become, eventually, a specialized job, but this applied to a system where a vast quantity of complicated machinery was controlled from one centralized position.

The third implication mentioned was taken care of by the use of "interlocks", where mal-operation could produce dangerous conditions. It was usual to provide a degree of interlocks in accordance with the estimated skill of the operators but it must be remembered that although it was possible to make a system "foolproof" it was usually impractical to make it "silly fool-proof". Mr. Baker had pointed out that the logical implication was a 100 per cent automatic plant; this was being approached rapidly and Fig. 18 in the paper showed a dowtherm vaporizer control arrangement approaching this. With the addition of a time cycle instrument (which was not very costly) the system could be started up from "cold" and would continue under auntomatic control by the pressing of one push-button.

The remote control equipment described by Mr. Cowper Coles was a very interesting example of the possibility of converting existing installations to meet modern requirements. It would be necessary, of course, to enclose the ratchets and gear-wheel for many applications and it appeared that simple lever movements had to be carried out through gearing or a screw action.

In answer to Mr. Webb, the author agreed that the system shown in Fig. 17 of the paper was extremely restricted and where a wider automatic control range was required very high pressures were employed or alternative systems of oil firing were used, such as steam atomizing and return flow. It was true that the oil pumping and heating sets had been a little neglected, as it was feasible to employ viscosity control rather than temperature control and the author was in full agreement with Mr. Webb's plea for greater consideration of this aspect.

The author would like to take the opportunity of correcting the statement made on page 154 of the paper that the type of water level gauge filled with non-miscible fluid was unsuitable for fitting above the level of the fluid interface to be measured. Since writing the paper he had been informed that recent tests had been carried out successfully with this type of level gauge fitted sixteen feet above the level to be indicated.

The interest shown in this paper had been very gratifying and indicated the engineer's growing awareness of this important aspect of engineering. The discussion had been both illuminating and very interesting and the author would like to thank all those taking part in it for their constructive thinking. Thanks were also due to the Institute of Marine Engineers for their progressive thinking in promoting such a paper when the necessity for drawing attention to this branch of engineering was now abundantly apparent.

In conclusion, the author would once again like to tender his sincere thanks to all those people who had so willingly helped in the preparation and arrangement of the paper.