THE AUTOMATIC AND REMOTE CONTROL OF STEAM TURBINE MACHINERY

BY

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INTRODUCTION

The invention of the atomic bomb and the need to protect engine-room personnel from radiation hazards, made the provision of some form of remote and/or automatic operation of steam machinery essential. (*Journal*, Vol. 8, No. 1—*Atomic Explosions ; Radiation Hazards in Machinery Spaces*, by Cdr. A. G. B. Norman, D.S.C., R.N., and F. B. Chambers, Esq.).

The first underwater explosion of an atomic bomb took place at Bikini in 1946, but it was some time before the effects were fully analysed by the United States Navy and an even longer period elapsed before results filtered through to the Admiralty. Indeed, it was not until early in 1950 that the necessity to protect engine-room personnel from the radio-activity contained in the base surge was fully appreciated.

History

In 1950 a small number of large and important ships were under construction, and it was decided to incorporate protection against radiation as far as possible, without causing delay in their completion. The ships concerned were : *Ark*

Royal, *Hermes*, *Centaur*, *Bulwark*, *Albion*, *Majestic*, *Bonaventure* and the three *Tiger* Class cruisers. A number of frigates were also being built. With these small ships, the problem of fitting remote and automatic controls and open stokeholds within the small spaces available and without undue complexity was so large that the attempt was abandoned. Practical schemes were worked out for the larger ships, but the builders of *Centaur*, *Bulwark* and *Albion* were fully involved with a large merchant ship programme and were unable to fit the new devices within a reasonable time. The fitting of such controls to these ships will be carried out later during modernization. In the remaining ships, remote operation, from two machinery control rooms, of the fan control valves, manoeuvring valves, feed and fuel pump stop valves, emergency feed and fuel shut-off valves, and wide range burners will enable the ships to be steamed for at least one hour without the engine and boiler rooms being manned. The system in *Ark Royal* was devised and installed in haste and the necessary development work was not undertaken before installation, so much of it is open to criticism. It will not, therefore, be repeated. In *Ark Royal*, the power medium employed is high pressure oil, following the well advanced commercial and aircraft practices. At that time, high pressure hydraulics appeared to offer the only practical solution of power transmission over 100 ft or more, as required in this ship. The principle is that the ordinary throttle valves fitted to the machinery are each turned by a separate hydraulic motor geared to the valve spindle ; the direction of rotation being determined by admitting the pressure to the appropriate side of the motor. This is, in fact, a rather crude method. Here also, due to the short time available, shock-proof units could not be obtained and ordinary commercial articles containing cast-iron parts were fitted. These units are supported on resilient mountings.

METHODS OF REMOTE AND AUTOMATIC CONTROL

Rod Gearing

In small ships, the distances involved for remote operation are small and the power lost in rod gearing is not, therefore, generally of great importance. Remote operation of valves will, therefore, be by rod gearing or some other suitable direct mechanical control, wherever this is practicable. Both *Bonaventure* and *Majestic* have combined engine rooms and boiler rooms, and rod gearing is being employed for all services except the main manœuvring valves, which are operated hydraulically because of the power losses in the rod gearing.

Water

This has been rejected as a control medium because it lacks lubricating properties and because of the corrosion problems involved. In general, oily liquids have definite advantages over water, and the question of the power medium for servo and remote operation of steam machinery in H.M. ships necessitates a choice between the use of air and oil.

Air

Advantages

(*a*) Is comparatively cheap both in first cost and to instal. In general only one small copper pipe is led from one point to another as the air, which is expendable is exhausted to atmosphere.

(*b*) Is chemically inert.

(*c*) There is no fire risk.

(*d*) Small leakages do not affect the satisfactory operation of the system as a whole or indeed the particular unit on which the leak occurs.

(*e*) In big ships, large quantities of low pressure air at 100 lb/sq in are available, and only small compressors are required as stand-by.

(*f*) Air is compressible, and power gains are available by expansive working.

(*g*) Both British and United States industry is well advanced in the knowledge and manufacture of pneumatic controls, although these are sometimes unsuitable for naval use.

(*h*) Air, due to its compressibility, is self damping and, provided the length of pipe between units is more than about 4 ft, variation or hunting in one unit will not be transmitted to the next.

Disadvantages

(*a*) The air must be cleaned and dried before admitting it to the system.

(*b*) The compressors are bulky and require maintenance. This disadvantage is not usually serious as compressors have to be fitted for other purposes.

(*c*) Air is compressible and therefore unsuitable for very quick responses. It is, however, possible to obtain response periods of about $\frac{1}{3}$ second with pneumatics, which is adequate for the control of machinery in H.M. ships.

(*d*) Better results are obtained by using diaphragms than by the use of pistons, which are likely to be insufficiently accurate positionally. With manœuvring valves, however, where fluctuating out-of-balance forces are present, neither diaphragms nor pistons are likely to provide a satisfactory answer.

(*e*) An air system may, in certain circumstances, require to have a lubricant added, which adversely affects maintenance.

Oil

Advantages

(*a*) Oil is a lubricant, which is an advantage for rotary motors.

(*b*) It is incompressible and therefore suitable for quick responses.

(*c*) High working pressures up to about 3,000 lb/sq in give reduced weight and size.

(*d*) Industry is well advanced in the knowledge and manufacture of high pressure units and the system should be reliable if properly engineered.

Disadvantages

(*a*) Is likely to be costly.

(*b*) Supplies of oil have to be carried for replenishment.

(*c*) Viscosity changes, due to temperature variations, may affect the operation of the system.

(*d*) Leakage of air into, or oil from, the system adversely affects its accuracy.

(*e*) The possible leakage of oil within the engine room, largely due to the high pressures employed, constitutes a fire danger.

(*f*) The relatively large and heavy piping required for high pressures is difficult and expensive to run.

(*g*) Oil is incompressible and cannot be used expansively.

(*h*) There is risk of explosion, as occurred in U.S.S. *Leyte* and *Bennington*, if high pressure air is admitted rapidly to a system containing oil.

(*j*) Considerable force is needed to churn the hydraulic system in hand control if it remains connected.

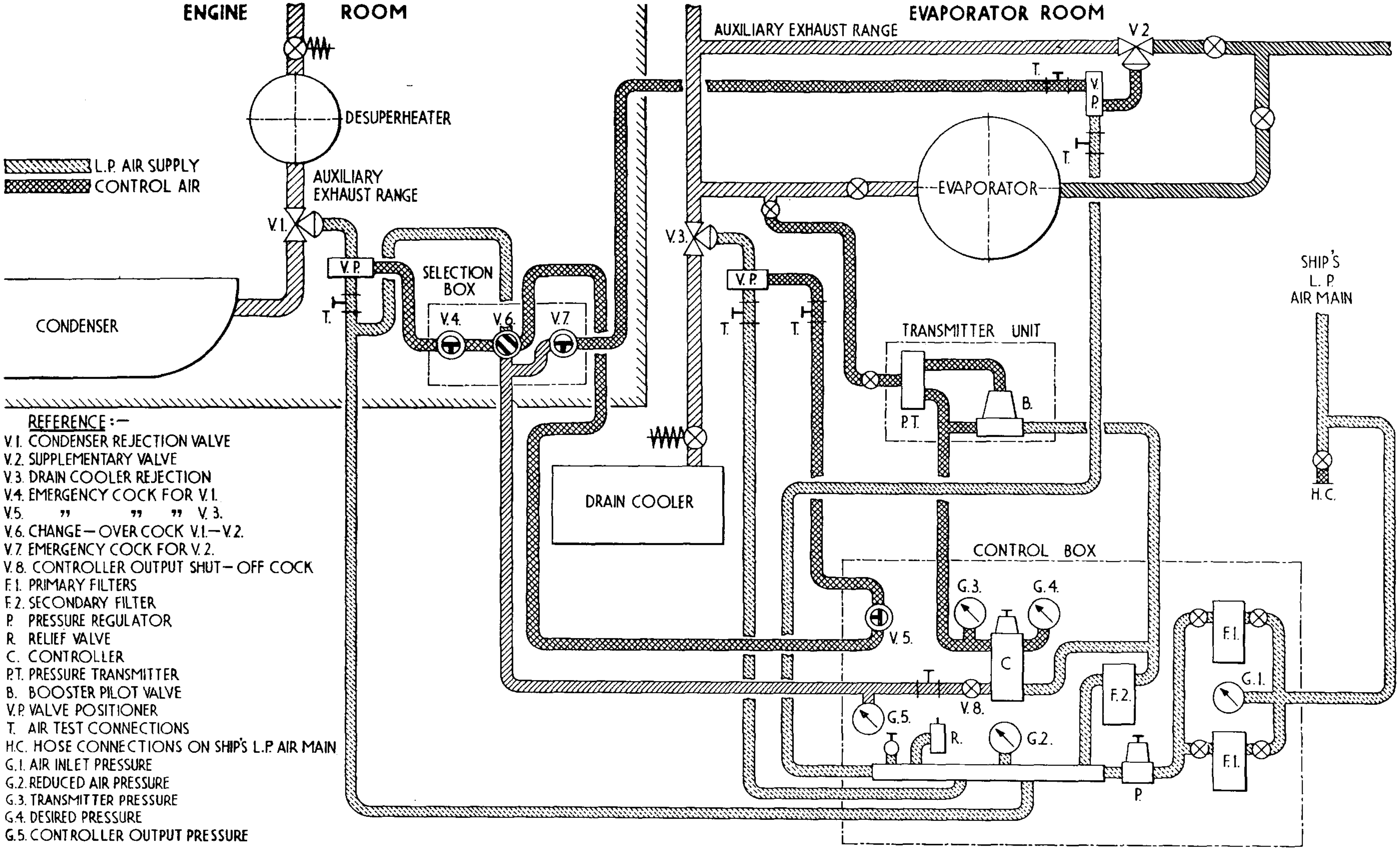
ENGINE ROOM
EVAPORATOR ROOM
AUXILIARY EXHAUST RANGE
V 2
DESUPERHEATER
L.P. AIR SUPPLY
CONTROL AIR
AUXILIARY
EXHAUST RANGE
V.1.
V.P.
T.
CONDENSER
SELECTION
BOX
V.4.
V.6.
V.7.
V.3.
V.P.
T.
T.
EVAPORATOR
V.P.
T.
T.
SHIP'S
L. P.
AIR MAIN
TRANSMITTER UNIT
P.T.
B.
H.C.
DRAIN COOLER
CONTROL BOX
G.3.
G.4.
V. 5.
C
F.1.
F.1.
G.1.
F.2.
V.8.
G.5.
R.
G.2.
P.
REFERENCE :—
V.1. CONDENSER REJECTION VALVE
V.2. SUPPLEMENTARY VALVE
V.3. DRAIN COOLER REJECTION
V.4. EMERGENCY COCK FOR V.1.
V.5. " " " V. 3.
V.6. CHANGE—OVER COCK V.1.—V.2.
V.7. EMERGENCY COCK FOR V.2.
V.8. CONTROLLER OUTPUT SHUT—OFF COCK
F.1. PRIMARY FILTERS
F.2. SECONDARY FILTER
P. PRESSURE REGULATOR
R. RELIEF VALVE
C. CONTROLLER
P.T. PRESSURE TRANSMITTER
B. BOOSTER PILOT VALVE
V.P. VALVE POSITIONER
T. AIR TEST CONNECTIONS
H.C. HOSE CONNECTIONS ON SHIP'S L.P. AIR MAIN
G.1. AIR INLET PRESSURE
G.2. REDUCED AIR PRESSURE
G.3. TRANSMITTER PRESSURE
G.4. DESIRED PRESSURE
G.5. CONTROLLER OUTPUT PRESSURE

Fig. 1

HYDRAULIC OR PNEUMATIC CONTROL ?

Careful consideration was given to all the factors involved, including the different types of hydraulic and pneumatic equipment available ; air seems to be the most suitable, where rod gearing or other mechanical equipment cannot be used. The following conclusions were also reached :—

(*a*) The complexity of full automatic combustion control precludes its application to H.M. ships, at least for the present, except possibly for boilers supplying steam catapults, where it may prove essential. Fully automatic combustion control equipment is being fitted in carriers now being built for the United States Navy, but this has not so far proved entirely satisfactory on trial.

(*b*) The combustion of the fuel in the furnace should, if possible, be controlled by a single regulator.

(*c*) The number of hand operated controls should be kept to a minimum consistent with reliable operation of the system as a whole, from which it follows that automatic controls must be fitted to much of the auxiliary machinery.

AUTOMATIC CONTROL OF AUXILIARY MACHINERY

Auxiliary Exhaust Range Pressure

At a point adjacent to the evaporator, the auxiliary exhaust is connected to a pneumatic transmitter which feeds a pneumatic controller. This controls the exhaust pressure, by causing a supplementary valve to open admitting steam into the auxiliary exhaust range from the auxiliary superheated range if the exhaust pressure falls. Auxiliary exhaust steam is rejected similarly by a rejection valve to the condenser at sea, or to the drain cooler in harbour, if the exhaust pressure rises. A simple system of this sort is working satisfactorily in *Eagle* despite a number of teething troubles. With closed exhaust pressure controlled at 10 lb/sq in. the maximum variation at the evaporators is less than 1 lb/sq in. The evaporators can, therefore, be run on closed exhaust under steady and manœuvring conditions without priming. Until recently *Eagle*, in common with most other ships, had not used closed exhaust steam for evaporating and the exhaust had been rejected to condenser. Using the 100 tons per day evaporator plants in ' X ' and ' Y ' units on closed exhaust, the condenser rejection valve is slightly open at all speeds up to 26 knots. In ' A ' and ' B ' units using the 240 tons per day evaporators the supplementary valve admits live steam into the exhaust range all the time. Assuming that 400 tons of fresh water are required in *Eagle* per day at sea and that the cost of water made from live steam is 10 shillings per ton, the saving in fuel by fitting exhaust pressure control is about £150 per day. Furthermore, the endurance of the ship is increased by about 5 per cent. A diagrammatic sketch of the *Eagle* installation is shown in FIG. 1. FIG. 2 shows a diagrammatic arrangement of a diaphragm operated valve, with a valve positioner. The valve positioner is a simple hunting gear or, in the words of the control purist, gives ' negative feed back '. The exhaust control arrangements to be fitted in *Hermes* and the *Tiger* Class cruisers are an advance on those in *Eagle*. If there is insufficient exhaust from the auxiliaries to run the evaporators and maintain the exhaust steam pressure at 10 lb/sq in, up to 6,000 lb per hour will be bled from the pass-out valve on each of the turbo-alternators. The supplementary valve, admitting steam from the auxiliary range, will only open if the supply from the turbo-alternators is inadequate or if they are shut down. This will result in even greater economies, particularly in harbour, as all steam used for evaporating will have done work in a turbine.

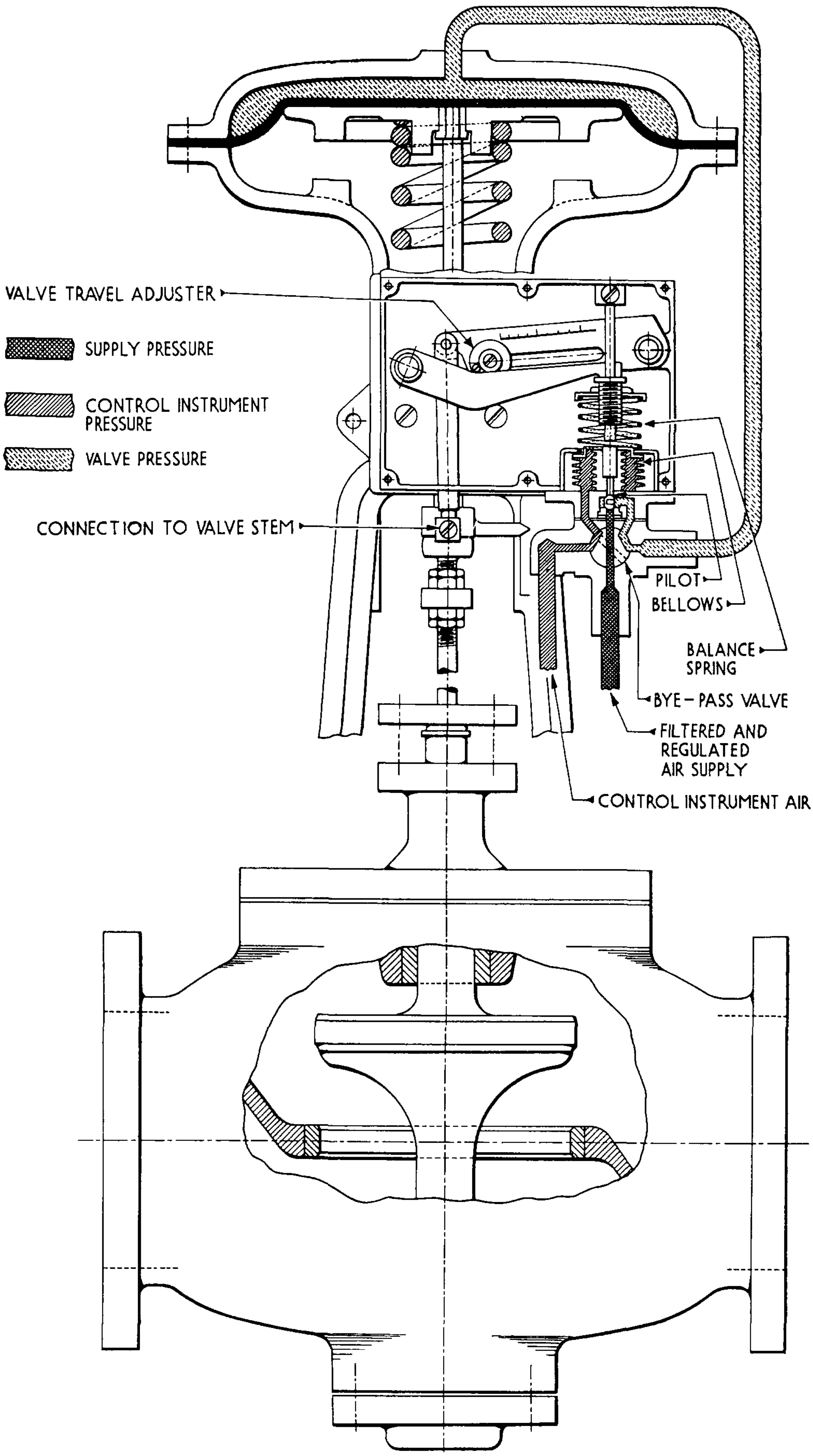
VALVE TRAVEL ADJUSTER
SUPPLY PRESSURE
CONTROL INSTRUMENT PRESSURE
VALVE PRESSURE
CONNECTION TO VALVE STEM
PILOT
BELLOWS
BALANCE SPRING
BYE-PASS VALVE
FILTERED AND REGULATED AIR SUPPLY
CONTROL INSTRUMENT AIR

FIG. 2

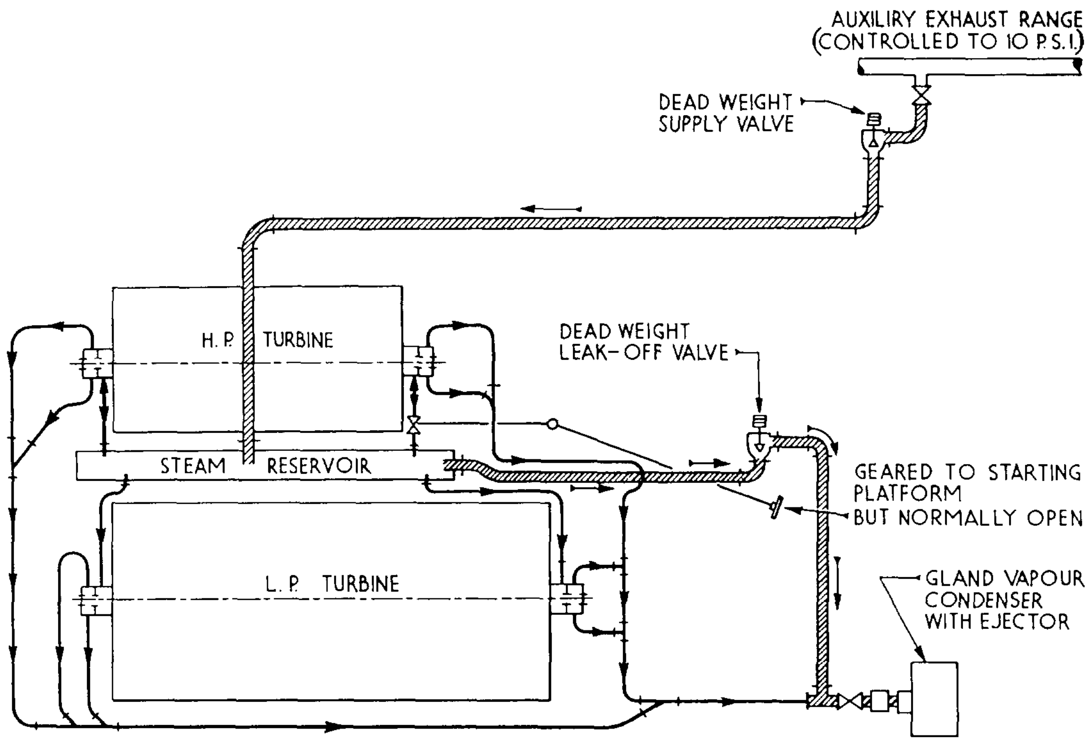

FIG. 3

Gland Steam Pressure

This is a simple system, and the forces required to control the small valves makes servo operation unnecessary. Weight loaded valves maintain the pressure in the gland steam system to within $\frac{1}{2}$ to $1\frac{1}{2}$ lb/sq in. Such an arrangement is shown in FIG. 3 and is now functioning satisfactorily in H.M.S. *Ark Royal* and in the first of the new *Blackwood* Class frigates.

Lubricating Oil Temperature

Servo operation is necessary here, as large forces are required to move the valves, admitting water to the lubricating oil coolers. These forces are not easily or reliably obtained from direct acting thermostats. The air servo thermostatic device to be used in conjunction with the diaphragm operated valve is shown in FIG. 4.

At full power the load-carrying capacity of the oil must be maintained if failure of bearings and/or gearing is to be avoided. Here the overall efficiency of the machinery is relatively unimportant and losses due to increased fluid friction can be accepted. The lubricating oil temperature at full power will, therefore, be controlled from the oil outlet temperature of the hottest bearing, which in general is the H.P. forward, but consideration is being given to an arrangement so that, as the power is reduced, a differential control, feeding back from the water valve, will allow the lubricating oil temperature at the outlet from the cooler to rise at cruising power ; as the viscosity of the oil is reduced with rise in temperature, this would give reduced fluid friction and therefore increased overall efficiency as the loading on the bearings and gearing is reduced.

The lubricating oil temperature is measured at the outlet from the hottest bearing and any change at that point will be the first indication of a larger temperature variation which has already taken place in the oil flowing through the system. Hunting of the system may occur unless any temperature change at the measuring point is counteracted by a much larger proportional movement of the control valve. The valve movement should then be gradually corrected

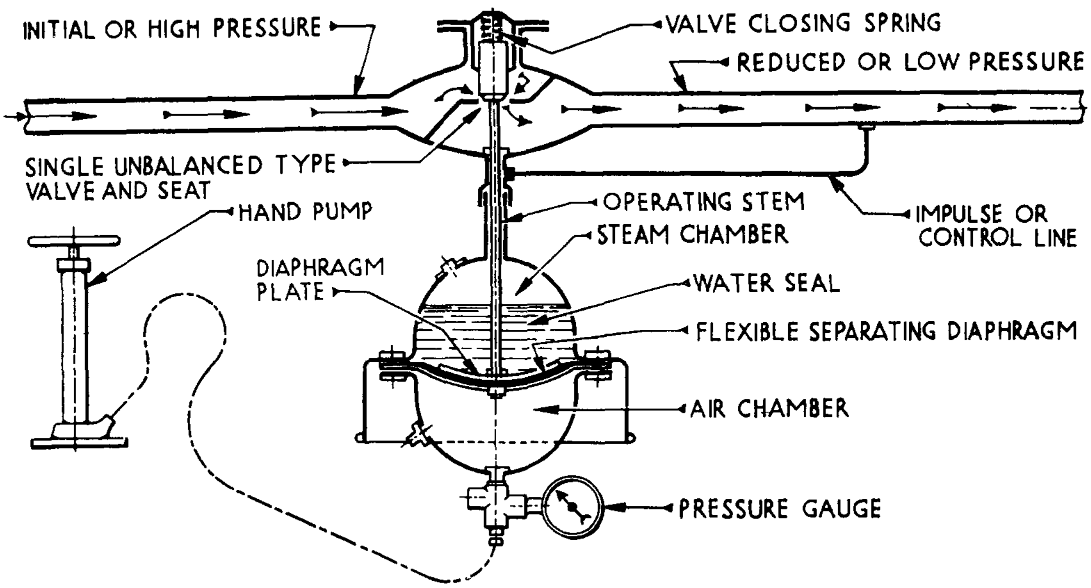

FIG. 4

to give the valve position for the desired temperature. It may be necessary to incorporate this type of anticipatory mechanism in the lubricating oil temperature control system, but a simple system will be tried first and a more complex one will only be fitted if experiments show this to be necessary.

Furnace Fuel Oil Temperature

The problem is similar to the control of lubricating oil temperature but is potentially simpler because the differential control is not required and need not be considered. Control is effected by a diaphragm valve in the steam supply to the heaters, and means are included for varying the temperature at which the system will control the furnace fuel oil discharge. This will enable the temperature for the best burning characteristics of the oil to be used. In the interests of simplicity no true anticipatory control is fitted, although it may prove desirable, after experiments, to incorporate a derivative turn. The control of oil temperature is a means of controlling its viscosity. Similar oils may vary considerably in characteristics ; and in particular the rate of change of its viscosity with temperature. The control of oil temperature is not, therefore, a very satisfactory method of controlling viscosity. Furnace fuel oil sprayers are designed to give the correct spray when supplied with oil within certain limiting viscosities. The demand for wide range burners and increased efficiency of combustion will probably narrow the viscosity limits of the oil supplied to the sprayer, and it will then be necessary to control viscosity more accurately, and to discontinue control by means of specifying *ad hoc* temperature limits. The Fisher Governor Co. are engaged in developing a patent held by Mr. J. M. Ford, late of the Admiralty Gunnery Establishment, to give viscostatic control of oil by regulating its temperature. This device will be tried at Pametrada and if successful will mark a great advance in lubricating and furnace fuel oil viscosity control.

Evaporators

In future ships, it will always be possible to run evaporators on constant pressure exhaust steam, except in emergency. The brine level will remain constant as it will overflow from a weir. Two main problems of satisfactory evaporator control, variation in steam pressure and variation in brine level, are therefore eliminated, and tests show that once evaporators are set satisfactorily they should run without attention for many hours. The purity of the water will be safe-guarded by means of a dumping valve which opens and rejects made water to bilge if the chlorine content exceeds 0·02 grains per gallon. A warning light will show in the machinery control rooms and on the engine-room platform if a dumping valve opens. The dumping valve remains open until closed by hand.

Turbo-Alternators

It is intended that in future, turbo-alternators should run without a watch-keeper. They will be fitted with the following safety devices :—

(1) A vacuum trip, which stops the machine if the pressure in the condenser rises above 20 inches of vacuum.

(2) A lubricating oil pressure trip, which stops the machine on lubricating oil failure.

(3) Lubricating oil temperature trip, which stops the machine if the lubricating oil temperature rises above 140°F.

(4) A reversed current trip, which stops the machine if the current is reversed.

(5) An overspeed trip coupled with an emergency hand trip, which stops the machine if it overspeeds.

Devices 1 and 3 are fitted with a dash-pot arrangement and there is a delay of 30 seconds before the machine actually trips. If one of the trip mechanisms starts to operate, a warning light shows at the engine-room platform and in the machinery control room.

Diesel Alternators

These will in future also run unattended. They are fitted with the following safety arrangements :—

(1) An overspeed trip combined with an emergency hand trip, which stops the machine if it overspeeds.

(2) An underspeed trip, which stops the machine if it slows down due to overloading.

(3) A lubricating oil pressure failure trip.

(4) Lubricating oil temperature trip.

(5) A reverse current trip.

(6) Cooling water temperature trip.

Numbers 2, 4 and 6 are fitted with a 30-second dash-pot delay. As with the turbo-alternators, warning lights are fitted at the engine-room platform and in the machinery control rooms.

L.P. Air Compressors

These machines are of major importance as they supply power for the controls. The quantity of air required for servo and automatic control and for the operation of diaphragm valves is small, but that required for rotary air servo motors for the manœuvring valves is large. It is not necessary, therefore, or desirable from the maintenance aspect, to run the ships main L.P. air compressors in harbour. Ships will be fitted with an L.P. air bottle of at least 100 cu ft capacity. An electric automatic starting switch makes if the pressure in

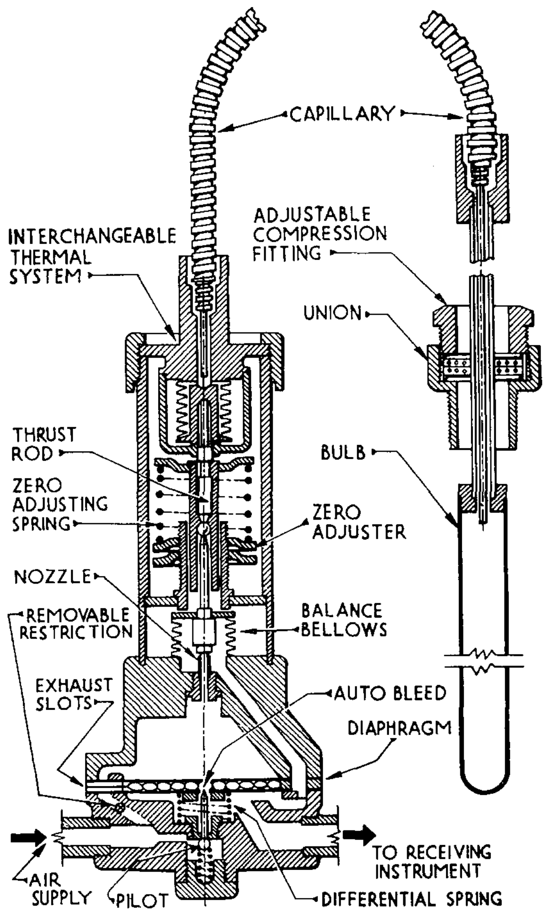

FIG. 5

the bottle falls below 80 lb/sq in and cuts out when the pressure rises to 120 lb/sq in. One charge of air should run the controls in harbour for about 12 hours. If L.P. air is being used in large quantities, it is necessary to keep the machine running, as frequent operation of the electrical contacts tends to burn them out. An unloading device is fitted and when the air bottle reaches 120 lb/sq in, the suction valve to the compressor shuts, but the machine continues to run. It is intended that compressors should be on electric start at night or when the load is low, and on unloading during the day when the load is high. The L.P. compressors will take their suction from the gas citadel. This will prevent radio-active material being distributed throughout the ship through the servo control system. A small stand-by ' garage ' compressor will be fitted in each machinery control room and this will start automatically on air failure from the main L.P. compressors.

Steam Reducing Valves

There are a number of services within a ship which require reduced steam and this reduced steam pressure must remain constant under closed down conditions. The spring-loaded type of reducing valve has never been really satisfactory, and indeed never can be, as, unless the length of the spring is infinite, the reduced steam pressure is dependent upon the opening of the valve. Use of servo operation to maintain reduced steam pressure cannot be justified, on the scores of expense and complexity. Efforts are being made, therefore, to develop a satisfactory steam reducing valve which does not suffer from the inherent effects of the spring-loaded type. A satisfactory valve, which is used extensively by the United States Navy, has been developed in the United States by the Grove Regulator Co. (FIG. 5). A valve of this type will shortly be undergoing trials at Pametrada. If these trials are successful, this type of valve will be fitted in future ships.

Steering Gear

This has for many years proved to be very reliable in operation and it is considered that the well tried types which are usually fitted can be left, without risk, unattended.

REMOTE CONTROL FROM MACHINERY CONTROL ROOM

The automatic systems of auxiliary machinery control already mentioned. if functioning correctly, run completely unattended, except for periodic checks, and no arrangements are fitted for control from the machinery control room.

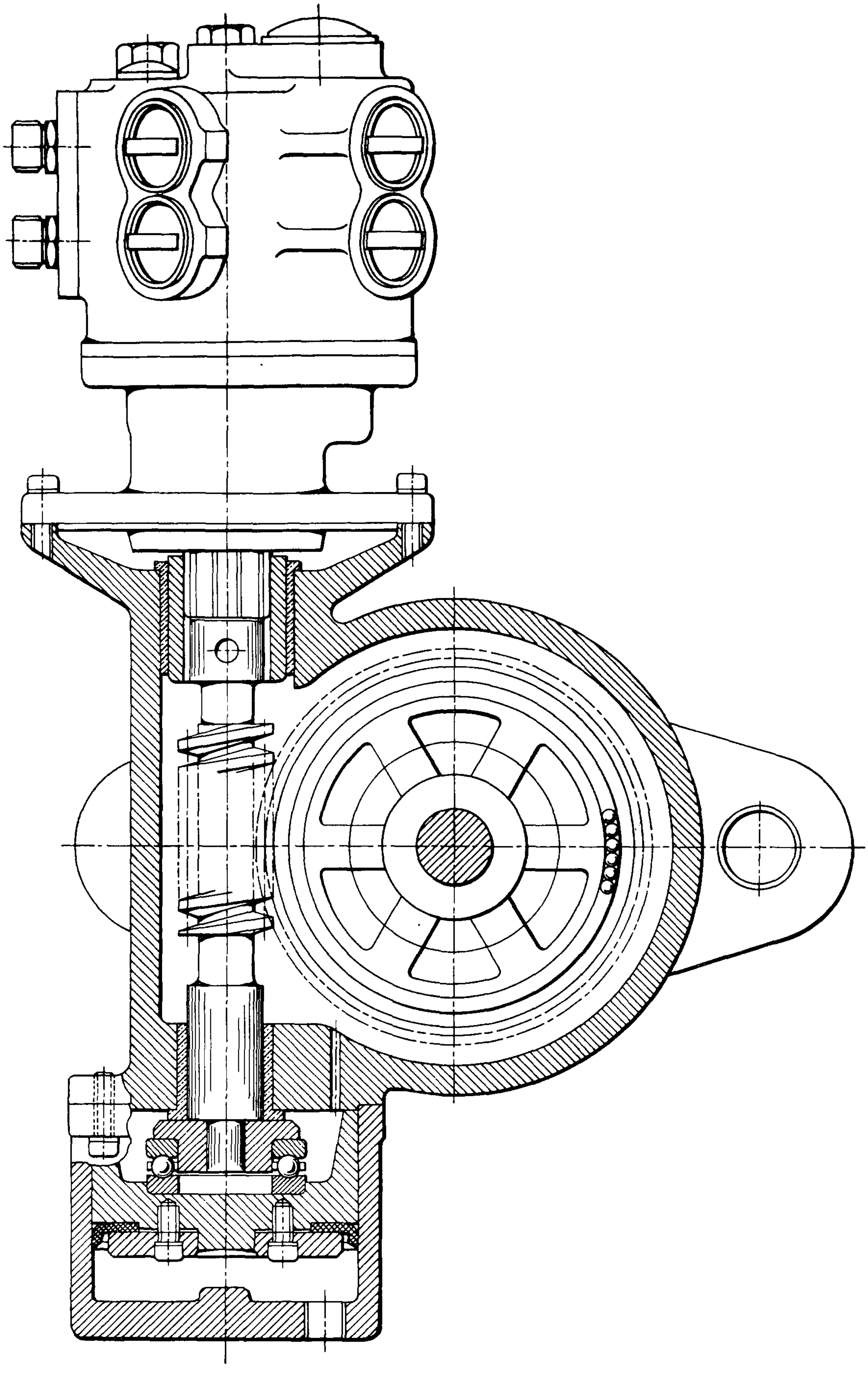

FIG. 6

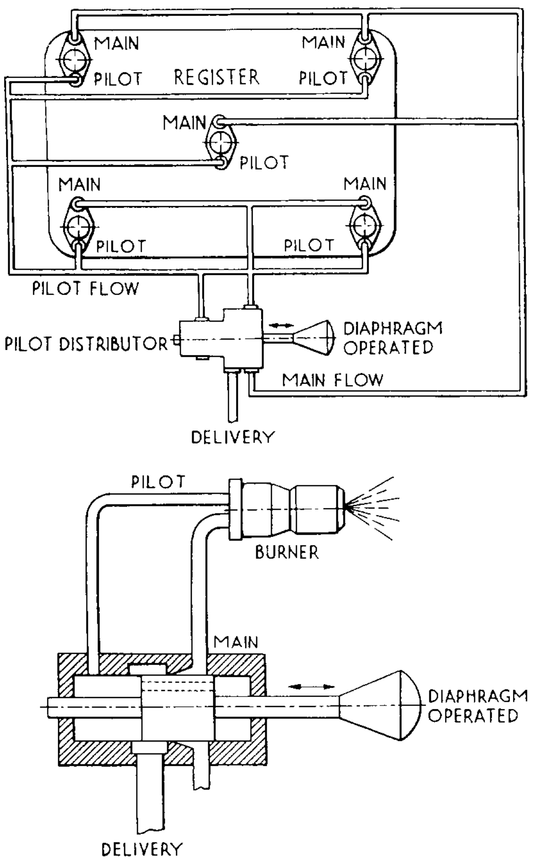

FIG. 7

However, in every case where a remote or automatic servo control is fitted, there is an over-riding hand control. If the servo mechanism or air supply fails or it is unsatisfactory, the system can be put into hand control and be operated in exactly the same way as is normal at present in H.M. ships. Air operated diaphragm valves controlled by manually operated levers in the control room, can be used to operate the feed and fuel pump stop valves, feed check and fuel shut-off valves in the case of emergency.

The Manoeuvring Valves

Both ahead and astern will have rotary air servo 'windy' motors fitted below the manœuvring handwheels, these motors being supplied with air at 100 lb/sq in. The control of air supply to the windy motors both in quantity and in direction will be effected by two small low pressure air servo levers operated in the machinery control room. These motors automatically clutch in when air is put on and de-clutch when the air is taken off. A drawing of the motors to be used for trial in H.M.S. *Cumberland* is shown in FIG. 6.

The Lucas Duplex Wide Range Burners

These are in essence, two different sized sprayers in one sprayer body and the pressure to one or both is controlled by a piston valve. A diagrammatic arrangement of the Lucas Duplex system is shown in FIG. 7. The Duplex system fitted in H.M.C.S. *Bonaventure* is supplied with fuel at 550 lb/sq in. The primary burner gives satisfactory combustion from 240 lb per hour to 900 lb per hour output and both primary and secondary burners together from 900 lb per hour to 2,300 lb per hour. This range of output is such that it should be possible to steam the ship with all burners on, from stopped to full power.

The Fuel Control Valve

This is operated by a diaphragm, the position of which is changed by turning a knob in the control room. This fuel control knob also operates another controller which actuates the valve controlling the steam to the fans. Arrangements will be incorporated to ensure that, on increasing power, the increase in fuel supply lags on the increase in air supply, and on decreasing power the decrease in air supply lags on the decrease in fuel supply. The position of the valve controlling steam to fans can be varied by a trimming control which does not affect the fuel supply to the boilers.

Operation

Operation of the main machinery from the main machinery control room will, therefore, be effected by moving three hand-operated levers :—

(1) Supplying air for the operation of the main manœuvring valves.

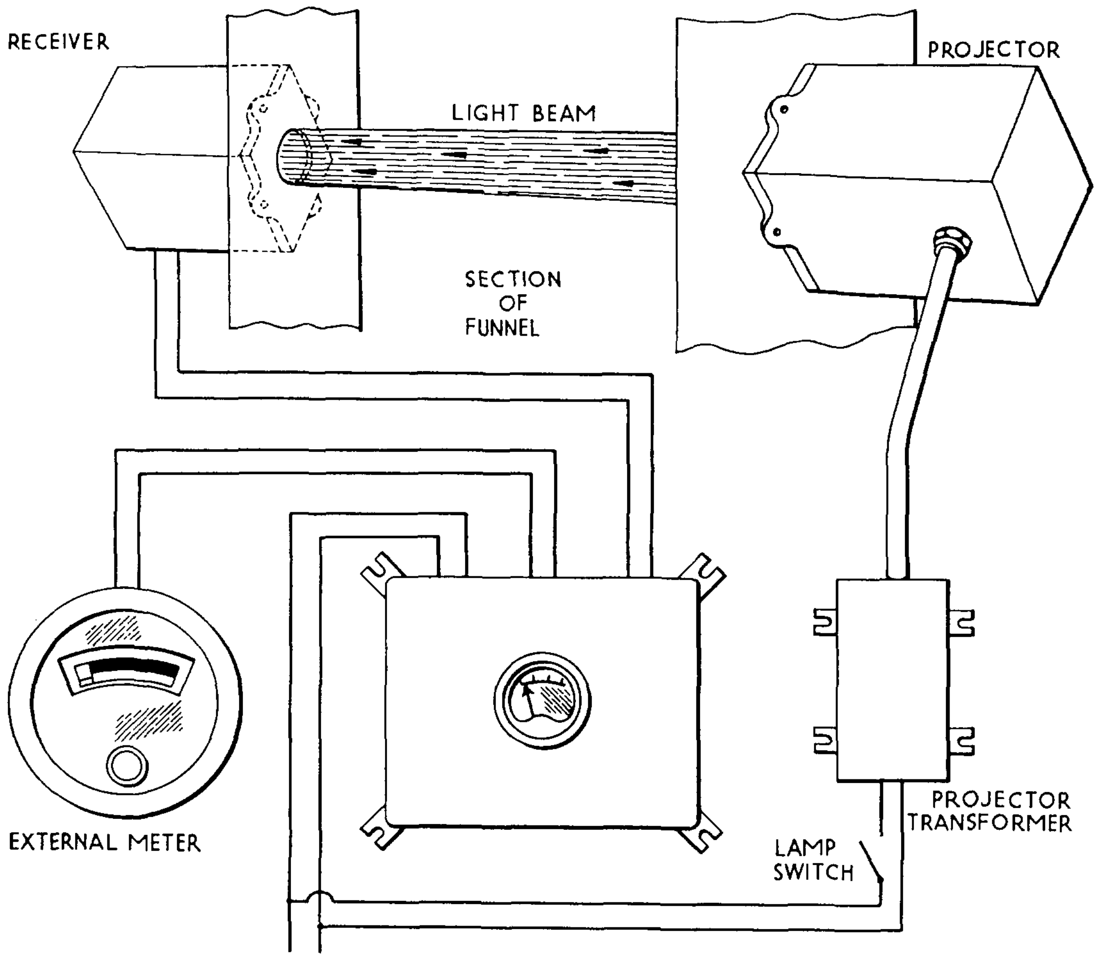

FIG. 8

(2) Varying fuel supply to boilers to maintain correct boiler steam pressure.
(3) The air control which is itself moved by the fuel control, but which can be trimmed independently to maintain a clear funnel.

As the fuel and air valves are geared together, the air supply to the boiler will be approximately that required to give the correct air/fuel ratio. The efficiency of combustion should, therefore, be improved but it is necessary to provide the air trim to cover variations in conditions.

A second set of combustion controls, exactly similar to those fitted in the machinery control room, will be provided in each boiler room with the appropriate change-over cocks so that they can be operated from either position.

Radiovisor Smoke Density Meters

These will be fitted in each uptake and will repeat in each boiler room and in the machinery control rooms. A diagrammatic arrangement of this equipment is shown in FIG. 8. It is claimed by the company that if the pointer is kept just on the point where a slight haze is measurable this will indicate the most satisfactory carbon dioxide reading and hence the most satisfactory combustion. This equipment is now being tried at Pametrada.

Pneumatic Devices—Their Operation

The basic principles of pneumatic controls were described by Lieut.-Commander L. E. Edwards, R.N. (Retd.) in the *Journal*, Vol. 7, No. 4, *Automatic*

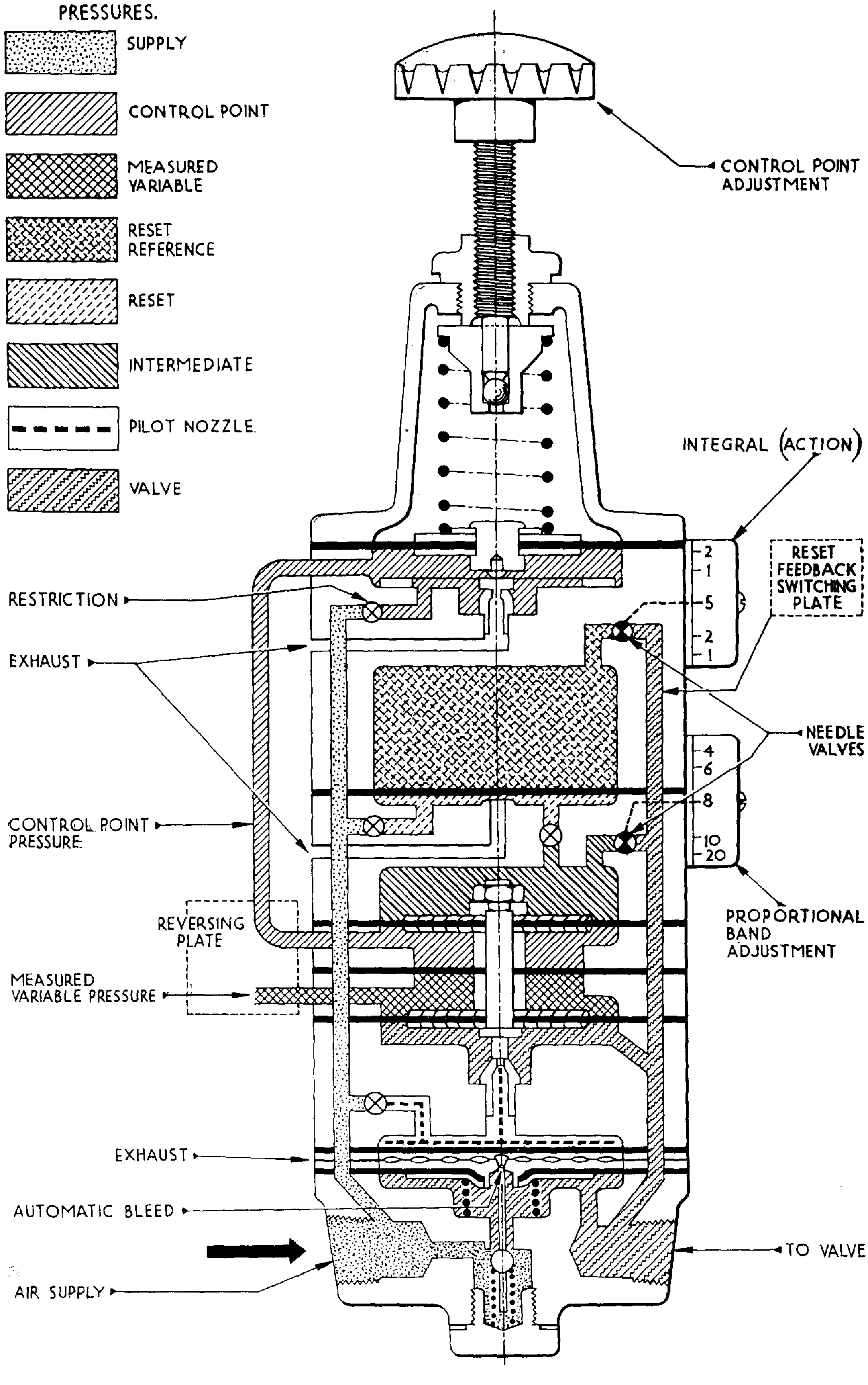
PRESSURES.
SUPPLY
CONTROL POINT
MEASURED VARIABLE
RESET REFERENCE
RESET
INTERMEDIATE
PILOT NOZZLE.
VALVE
CONTROL POINT ADJUSTMENT
INTEGRAL (ACTION)
RESET FEEDBACK SWITCHING PLATE
RESTRICTION
EXHAUST
NEEDLE VALVES
CONTROL POINT PRESSURE
PROPORTIONAL BAND ADJUSTMENT
REVERSING PLATE
MEASURED VARIABLE PRESSURE
EXHAUST
AUTOMATIC BLEED
TO VALVE
AIR SUPPLY
2
1
5
2
1
4
6
8
10
20

FIG. 9

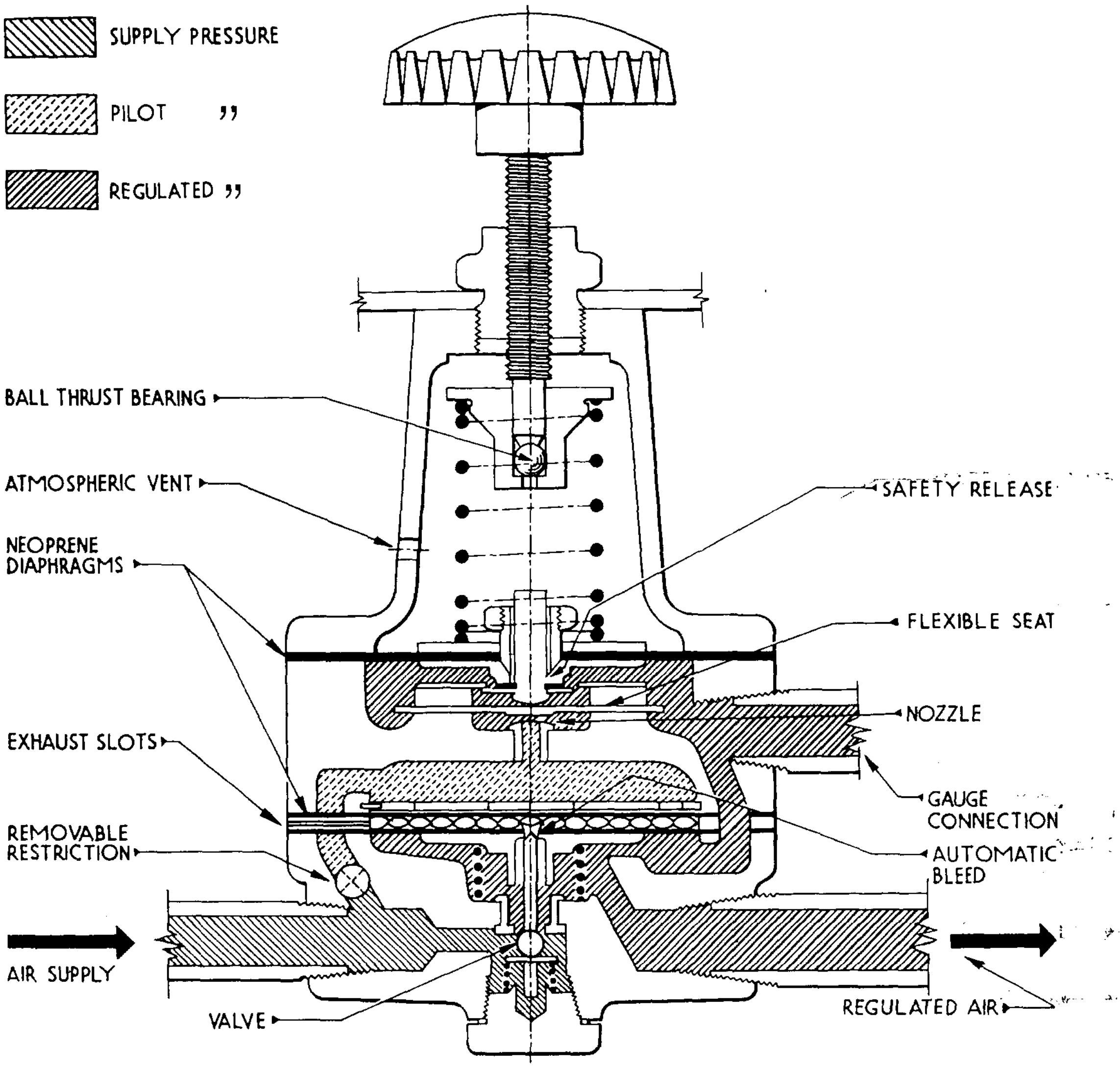

FIG. 10

Control by Pneumatic Devices. FIGS. 9 and 10 show how these basic principles are translated into engineering.

CONCLUSIONS

The overall system described here has advantages over other systems now in use because it is not so complex as full automatic boiler control, but it does give an air/fuel ratio which is almost correct. Deviations from the desired figures can easily be corrected by movements of the trimmer controls. Such a system will ease the watchkeeping load and make available men for maintenance. It must be emphasized that this type of control is a tool which will enable the steam cycle to be varied in ways which have not been possible in the past. This must eventually result in a rise in the overall efficiency of the cycle and in a smaller number of men being required to operate it.