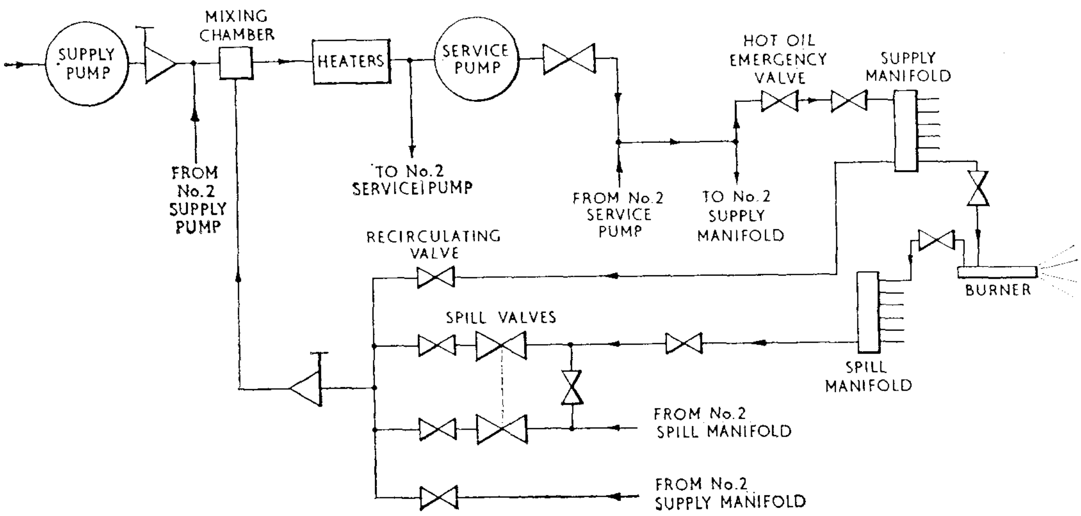

FIG. 1—DIAGRAMMATIC ARRANGEMENT OF TIGER CLASS F.F.O. SYSTEM

OPERATION AND MAINTENANCE OF AN AUTOMATIC BOILER CONTROL SYSTEM

BY

LIEUTENANT J. P. W. MIDDLETON, R.N.

INTRODUCTION

The author's experience of automatic boiler control is limited to one commission in a *Tiger* Class cruiser. This article, therefore, is far from being a comprehensive guide. It is hoped, however, to highlight some of the fairly general misconceptions about the system which arose during the period. It is certainly true that a disproportionately large amount of time was required both for training and for direct supervision which the hard pressed Marine Engineer Officer of a small ship, perhaps, like his staff, meeting automatic control for the first time, could ill afford.

THE OVERALL ARRANGEMENT

Tiger Class cruisers are fitted with four conventional Admiralty 3-drum boilers with economizers. Air is supplied to the enclosed air casings by trunking from Allen's turbo-driven blowers, of which there are two in each of the two boiler rooms. The Lucas spill fuel system is fitted in conjunction with six Lucas wide-range burners on each boiler. An A.E.I. (ex Sunvic) control system maintains the desired steam drum pressure in the boiler(s) by pneumatic control of fuel pump speed, spill valve opening and blower speed. A separate system maintains the fuel at the desired temperature. The principles of a typical system and a description of the fuel system appear in References 1 and 2, though an additional pneumatic loop to control the fuel pump speed overcomes the disadvantage stated in the last paragraphs of Reference 2. A diagrammatic sketch of the fuel system is shown in FIG. 1.

THE CONTROL SYSTEM

The parallels between 'manual' and 'control' functions have been described in References 1 and 3. They may be summed up as the three functions:

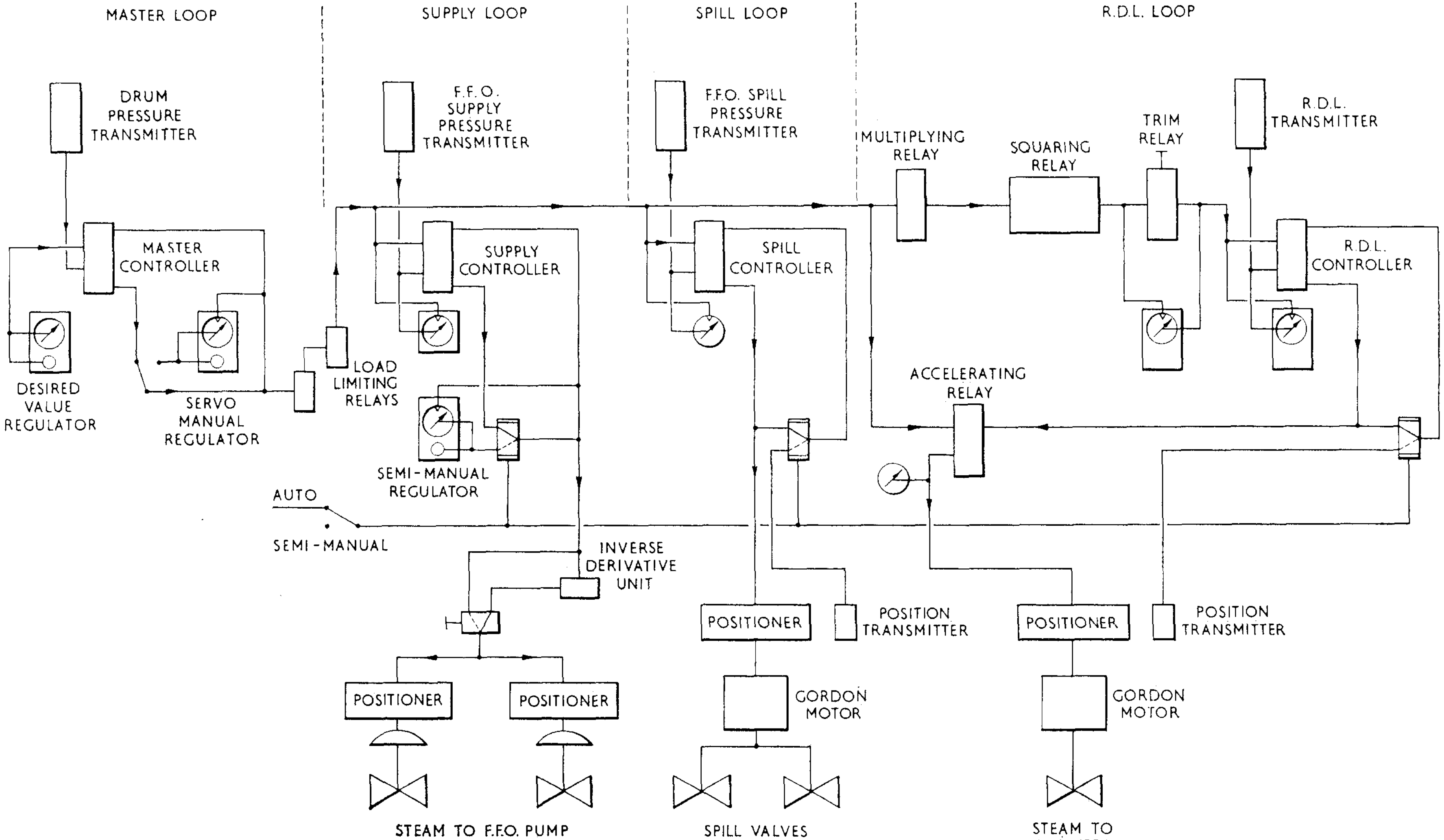

FIG. 3—DIAGRAMMATIC ARRANGEMENT OF COMBUSTION CONTROL SYSTEM

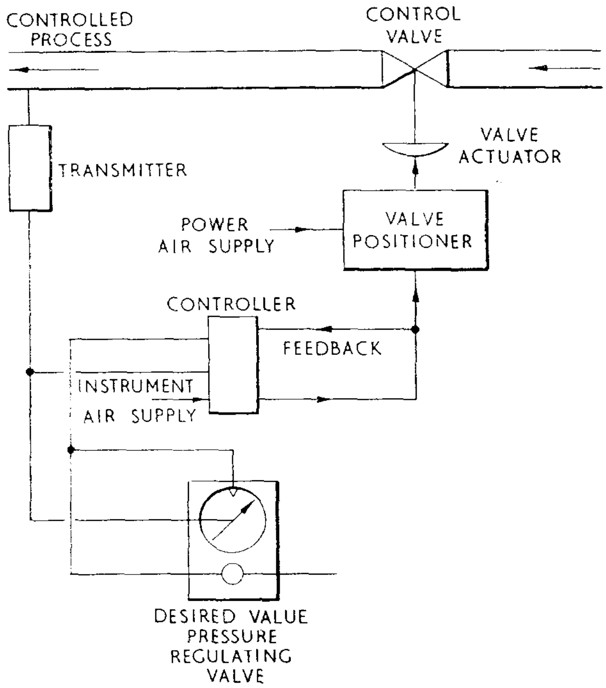

FIG. 2—TYPICAL BASIC CONTROL LOOP

(*i*) *Observe*—where the P.O.M. (E) looks at the pressure gauge;

(*ii*) *Compare*—where the observed pressure is compared with the required pressure;

(*iii*) *Adjust*—where the fuel and air flow rates are adjusted to remove the error between observed and required pressures in the case of steam pressure.

The corresponding control elements are:

(*i*) *The transmitter*—which 'senses' the actual pressure and converts it into an air signal which is transmitted to

(*ii*) *The controller*—which then compares this 'measured variable' (MV) with the 'desired value' (DV). Any difference between these signals causes a change in the controller output and this signal actuates

(*iii*) *The valve positioner*—This controls the power air supply to the actuator and thus positions the control valve in relation to the controller output signal.

The remaining requirement is for a pressure regulating valve to produce an air signal input into the controller proportional to the desired value.

Each part of the system (master fuel supply, fuel spill, air) consists basically of a closed loop containing these elements. A typical example is shown in FIG. 2.

The output from the master (steam pressure) controller is used as the DV in the other three loops as shown in FIG. 3. Thus when the system is selected 'automatic', only desired steam pressure and desired fuel temperature need be 'set' on the panel.

Certain refinements are fitted:

High and low pressure relays: fitted on the master control output to prevent the master signal going outside the 3–15 lb/sq in. limits and thus outside the rangings of the fuel and air loops.

Servo-manual/automatic change-over switch: whereby the master signal (i.e., steam pressure controller output) is cut out of the system and a manually set DV is fed to the other loops, thus allowing operator control of output.

Squaring, multiplying and trim relays: to modify the master signal to produce the air/fuel relationship required throughout the power range. These could be replaced by a suitably cut cam on the blower control cam positioner; the trim relay allows a bias to be fed in manually.*

Accelerating relay: to minimize the deleterious effect of blower inertia.

Inverse derivative relay: to 'smooth' the fuel pump output and slow down the supply loop response.

**Departmental Note:*

Though a cut cam can be used, it should be used to calibrate the master signal and should not be fitted to the positioner where it can induce instability. Provided the boiler black and white smoke lines are of a reasonable form, it is better to programme the line by pneumatic instruments.

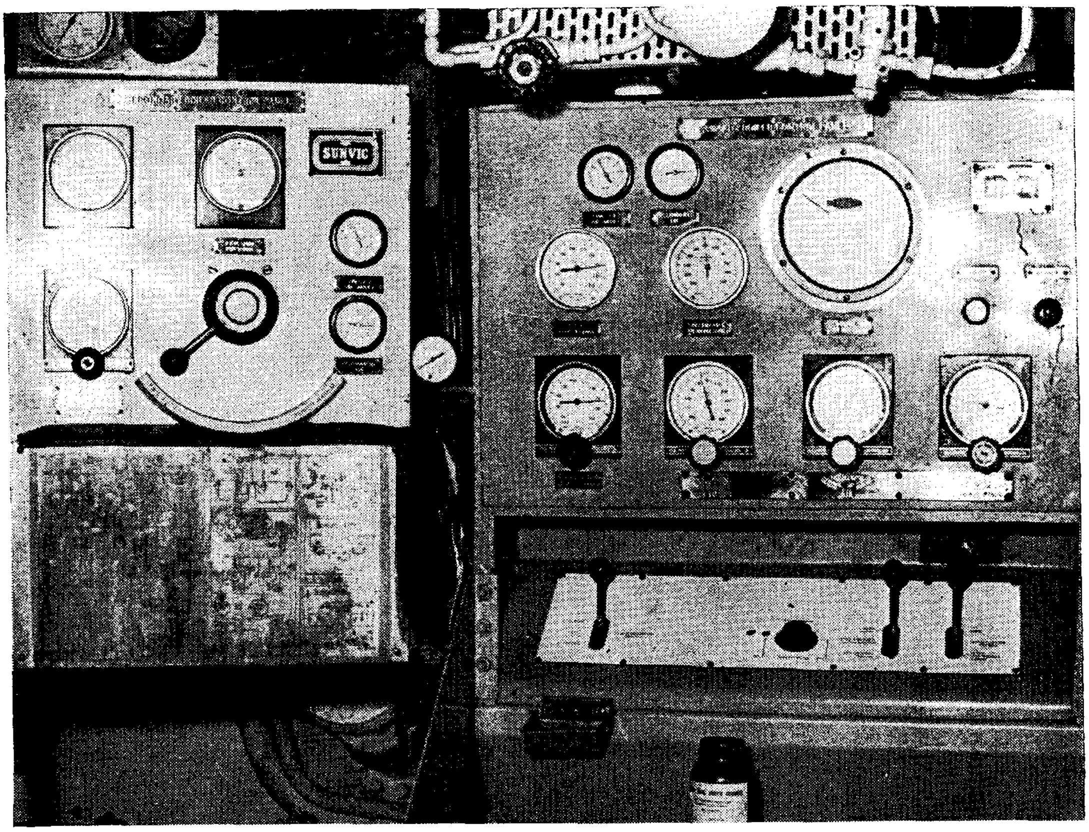

FIG. 4—THE BOILER ROOM P.O.M.(E)'S NEW TASK; BUT IT IS ONLY THERE TO HELP HIM

Feedback: is provided to stabilize the controller output (as it is fed through the integral throttle it is used to produce the integral effect). Where the controller output acts on a valve positioner, a switching arrangement allows valve position to be fed back in the manual state—thus ensuring that controllers are in balance at the moment of clutching in the automatic system.

Methods of Control*

(*i*) *Automatic*—automatic control of everything;
(*ii*) *Servo*—hand/pneumatic control of output, all systems follow single knob;
(*iii*) *Semi-manual*—F.F.O. temperature in automatic, hand control of spill valves and blowers, F.F.O. pump controlled by pneumatic knob;
(*iv*) *Manual*—hand control of everything.

OPERATION

The concept of automatic control is so completely new at present to some otherwise experienced watchkeepers that a great deal of time has to be spent in their training at sea. It has, in fact, appeared that the difficulty in understanding the watchkeeper's task increases proportionally with the amount of watchkeeping in 'traditional' boiler rooms. Some ex-Chief M(E)s of great experience re-entered as P.O.M.(E)s found it almost impossible to assimilate

* *Departmental Note:*
These are the terms used in H.M.S. *Lion*. The terms for later construction are:
(*a*) Auto;
(*b*) Servo-manual—p.r.v. output substituted for master signal;
(*c*) Manual.
In later ships with A.E.I. equipment each of the air, supply and spill loops can independently be put into servo-manual control.

TABLE I

System	*Valve*	*Failure State*	*Operator's Action*
Boiler	Steam to F.F.O. Pps.	Open	Slow pump by governor
Control	F.F.O. Spill Valves	Set	Adjust by hand as necessary
	Steam to Blowers	Set	Adjust by hand as necessary
F.F.O. Temp. Control	Steam to F.F.O. Heaters	Open	Throttle steam by master valve
Exh. Press. Control	Supplementary Valve	Shut	None possible

the new language, whereas L.M.(E)s gaining their boiler-room ticket in the ship had relatively little trouble.

The first point of importance to make to the P.O.M.(E) is that his task in steaming the boiler room is quite unchanged: he is, as always, responsible for the water level and steam pressure in his boilers, maintaining a clear funnel, and the correct operation of the auxiliary machinery in his care. The 'black boxes' often seem to cloud this basic issue. Clearly one does not require the P.O.M.(E) to have an intimate knowledge of the control system, but he must be completely clear and confident about how to *change* methods of control. The point to be impressed is that the system is only there to help him do his job; if it ceases to help him, he must select a method of control where he *has* control. Once the operator appreciates this and is dextrous at changing methods of control, and familiar with the different characteristics of the wide-range burner, the only other 'new' information he requires is the 'fail' state of the various control valves. Thus in the case of failure in control air or assumption of full manual control, the spill valves and blowers, operated by reciprocating air motors, will fail set, while the diaphragm-operated Fisher valves will open or close according to the arrangement of the diaphragm and spring. TABLE I shows typical failure states.

It may be necessary to give watchkeepers some arbitrary limits of performance at which they should select (semi-) manual control until they become experienced. These will vary with the plant concerned, the confidence in the system and previous experience, but an error on the side of discretion will generally be preferred. Some suggested for an A.E.I. system are:

(*i*) Failure to remain within the black/white smoke limits without continuous use of the trim knob;
(*ii*) Continuous hunting of one or all of the control elements over a range of greater than 1 lb/sq in. system air pressure;
(*iii*) Continuous misalignment in any element of over 1 lb/sq in. system air pressure;
(*iv*) Steam drum pressure variations while manœuvring of an order unacceptable in a conventional boiler room (say, 20 lb/sq in. either side of the ordered pressure, depending on safety valve settings).

The P.O.M.(E)'s duties remain otherwise unchanged; however, the postulated removal of the water tender to the machinery control room demands an even higher standard of detailed knowledge and vigilance from the Petty Officer, who will only have with him one young M(E), quite possibly a J.M(E)—especially in ships on Home Sea Service.

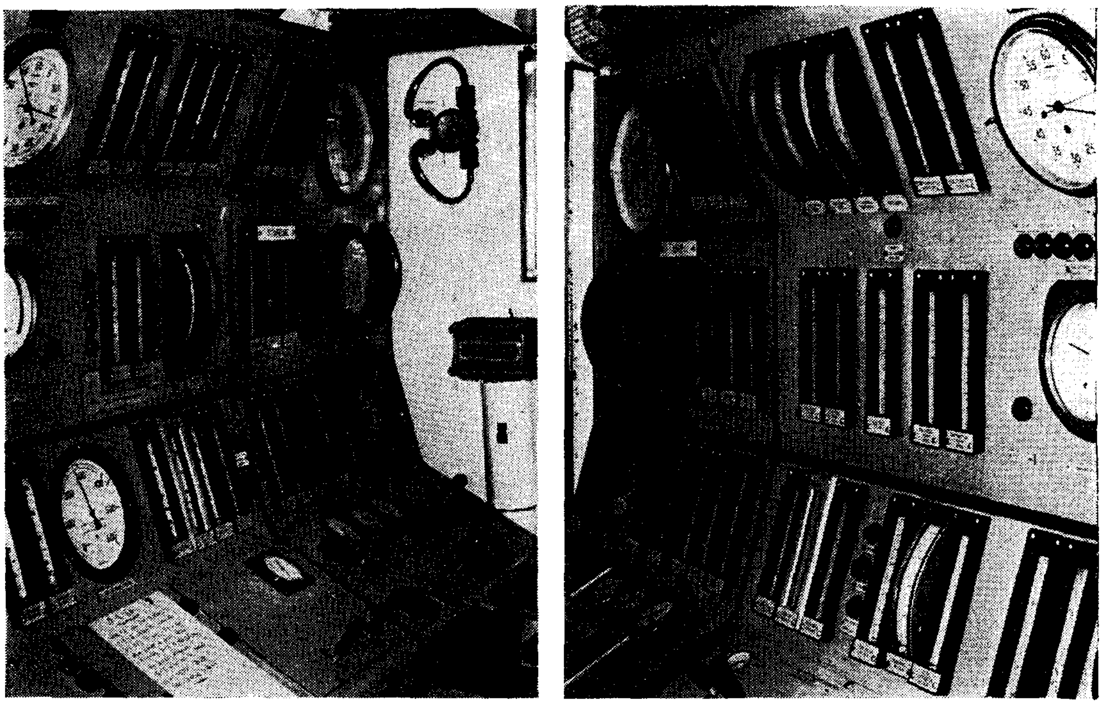

FIG. 5—TWO VIEWS OF A MACHINERY CONTROL ROOM—THE WATER TENDER OPERATES HERE, LEAVING A P.O.M.(E) AND SOMETIMES ONLY A J.M.(E) IN THE BOILER ROOM

Two common problems arise with the automatic control system. The first is that the operator seems to be dubious of the system's ability to cope, especially when manœuvring. This leads to a tendency to 'tweak', notably the air trim knob. If the system is working correctly this is unnecessary and operators should be encouraged to leave it alone unless it is quite clear that the system is not coping. The second problem is that manual control is not as easy as in an older boiler room, due to the displacement of valves and gauges. It is advisable, therefore, to allow the watchkeepers as much practice as possible in manual control; this must be carried on throughout the commission, since constant practice is required. A 'work-up' by itself is not enough.

Despite these rather gloomy remarks, it is true to say that once watchkeepers have been trained the system is of the greatest benefit, quite independent of the A.B.C.D. function. It allows the watchkeepers much more freedom to move around and monitor the running of the auxiliaries, state of systems, and so on—and of course to get on with the cleaning!

MAINTENANCE

Failures of the automatic control system should seldom prevent the ship from going to sea, or achieving full power. It should be remembered that the control system is often only an aid to the watchkeepers and there should never be any hesitation about steaming in manual whenever necessary. It is, however, possible for a suspected fault in the control system to mask a real fault on the mechanical side. An example of this was a failure to achieve full power on a particular fuel pump. This was wrongly attributed to bad setting-up of the diaphragm Fisher valve supplying steam to the pump, whereas the fault really lay in the pump hydraulic governor.

It is fair to say that faults occur comparatively rarely in the actual pneumatic components and systems. The old faults in operation are still as prevalent as ever. Obstructed downtakes, air casing leakage, incorrectly opened-out fuel systems, valves half open, rod-gearing jams—this type of failure is the common rule, not the exception. Thus the first requirement for the maintainer is an extremely clear understanding of the systems and mechanical components; in this context an exact knowledge of gauge connection and sensing point positions is important.

INSTRUMENTATION

The accuracy of pneumatic and 'steam' (steam, fuel, air pressure) gauges is important for the testing and tuning of control systems. Little progress can really be made until datums can be established readily; the Budenburg 10–1,000 lb/sq in. dead-weight tester, the Wallace and Tiernan 0–30 lb/sq in. pneumatic calibrator, and the A.E.I. test set represent the minimum essential requirements. It is worth remarking that the A.E.I. 2-in. 0–30 lb/sq in. pneumatic gauges commonly fitted to diaphragm valves have seldom been found to be sufficiently accurate for good setting up. It is a basic principle that it is pointless to set up any system without a definitely known datum, and an hour spent calibrating a few gauges usually pays handsome dividends. This point often requires emphasis.

STATIC AND DYNAMIC TESTING

It is often difficult to get an opportunity to test the system thoroughly. The problem is that either the boiler room is steaming, in which case there are fairly close limits on what can be done to the steam pressure by varying the output; or else the boiler room is shut down, when it is often undesirable to have steam in it for maintenance considerations. The ideal method of testing is obviously a period of strenuous manœuvring to a prepared time schedule, but the tightness of ships' programmes and the seamen's aversion to soot on the upper deck often makes this impossible to arrange. Steady steaming conditions allow a static test of alignment, but this should ideally be checked in steps over the full working range. In any case, most of the commoner evils experienced concern the dynamic performance of the system.*

The system can be tested in a shut-down boiler room provided steam is is available to a fuel pump and a forced-draught blower. In this case a 'closed loop' is used: the supply and spill manifolds are connected through a fuel hose, and the system is worked through the limits in servo control, or in auto using an injected simulated steam pressure signal in place of the steam pressure transmitter. This is still not completely satisfactory, since no fuel is 'lost' into the furnace, which causes too much interaction between supply and spill pressures, and a departure from the normal working conditions. A burner simulator, which would 'spill' fuel back to the tanks, has been proposed as an A. and A., and would overcome this disadvantage.† It is important that when carrying out a 'closed loop' the full power condition is simulated, for obvious reasons. If difficulty is experienced in lining up the air and fuel flows over the whole working range, they should be lined up for the low power condition, since the black/white smoke limits are close together at this point, and the boiler spends the majority of its steaming time at low power.

* *Departmental Note:*
Dynamic checks can be carried out on a system which is 'steady' steaming by either putting in a large variation in desired value or by going into servo-manual and putting in a step change. This check will show up most faults. In a two-unit (or more) ship another way of carrying out the dynamic checks when steady steaming is to put one unit into servo-manual and cross-connect the two units. By use of the servo-manual control in one unit, heavy changes can be introduced into both systems.

† *Departmental Note:*
It is intended to make this part of 'B' Series trials and to try out this method in H.M.S. *Fearless*.

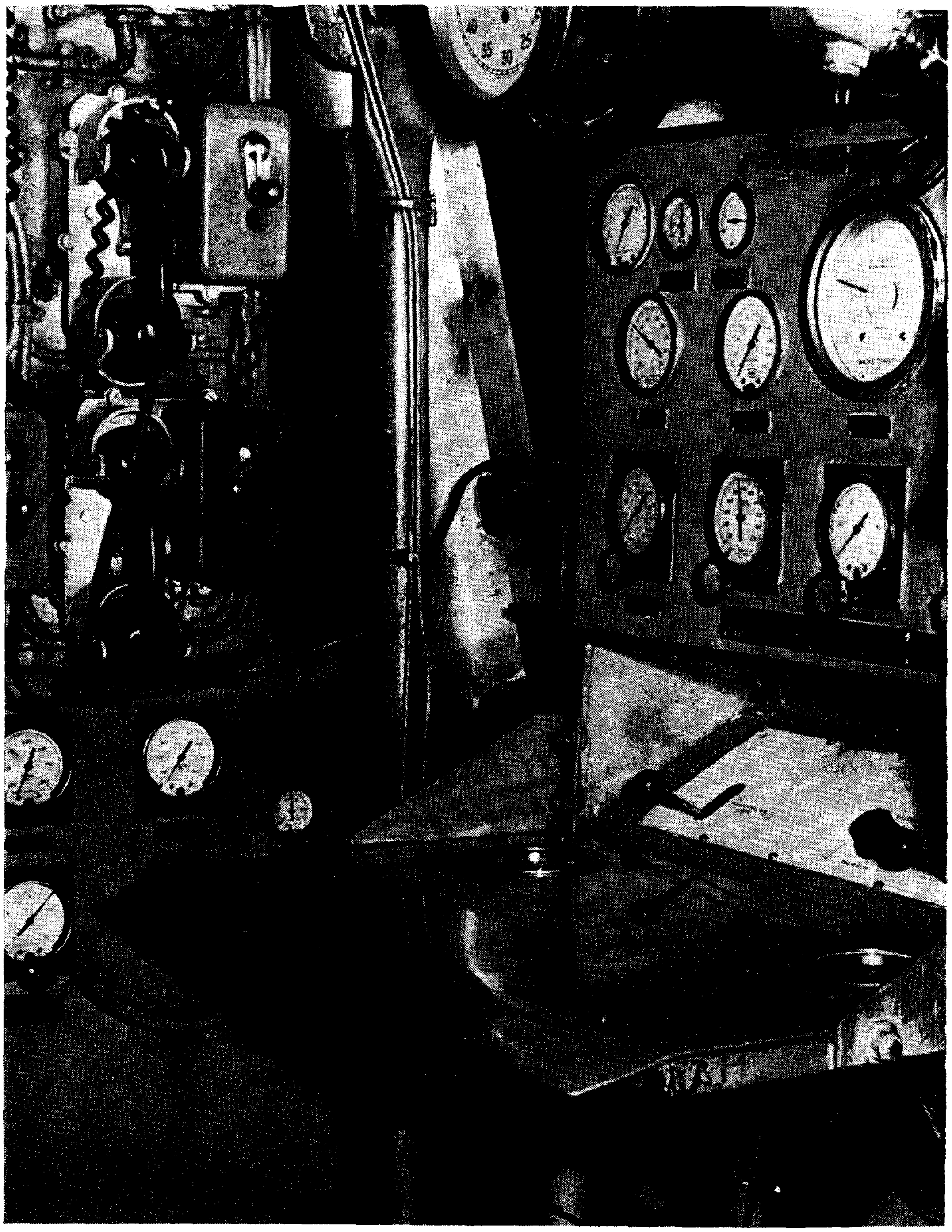

FIG. 6—THE CONTROL PANELS ARE OFTEN POORLY SITED FOR CLEANLINESS AND MAINTENANCE

FAULT-FINDING

It is not easy to detail any exact procedure for fault-finding, since much of this depends on experience and 'feel', but a general procedure is suggested below.

(*i*) Check round for obvious operating errors, i.e., burners not correctly flashed, blower flaps partly shut, steam or fuel master valves not wide open.

(*ii*) Compare readings of 'steam' and pneumatic gauges. Large errors may mean the failure of a pneumatic transmitter.

(*iii*) Collect as much data as possible about the fault by quizzing the watch-keepers and try to simulate it again. Work the system in different methods of control to try to isolate the fault to an individual system.

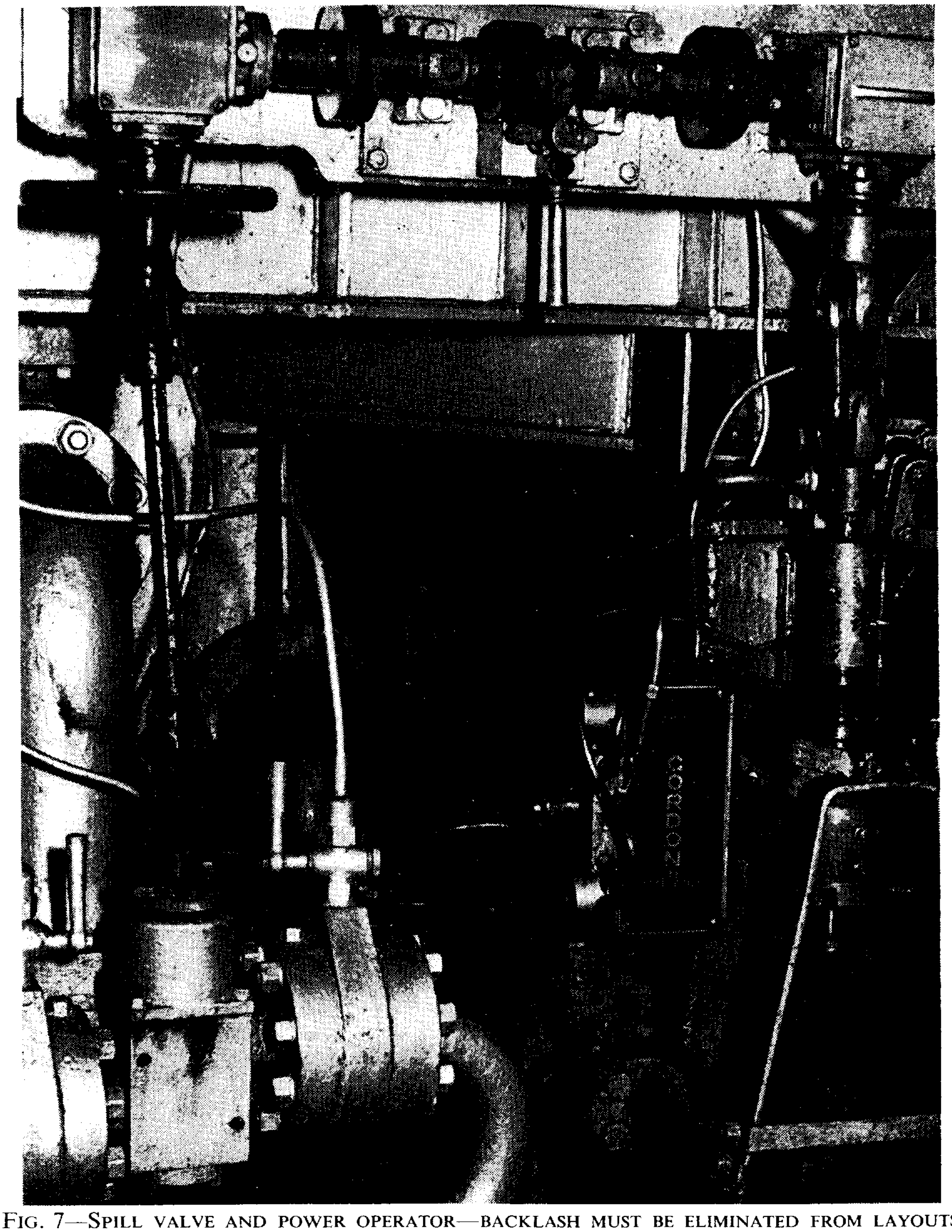

FIG. 7—SPILL VALVE AND POWER OPERATOR—BACKLASH MUST BE ELIMINATED FROM LAYOUTS OF THIS TYPE

(*iv*) Check the system settings; 'phantom tweakers' are a constant hazard.

(*v*) Check the system for air leaks or backlash—either is disastrous.

(*vi*) Check any mechanical items in the system (e.g., tight valve glands, cam positioners, rod gearboxes or universal joints).

(*vii*) Clean orifices on pneumatic components. In connection with this point, clean dry air is of paramount importance; the regular blowing down and cleaning of air filters is essential.

(*viii*) If no success has been achieved, it is seldom worth jumping to conclusions and removing components on hunches, unless the maintainer is extremely experienced; a full check of the system, using gauges of known accuracy to measure inputs and outputs should now be made.

TABLE II—*Typical faults experienced*

Symptoms	*Cause*	*Initial Action taken*	*Subsequent Action taken*
Full-power work-up–blowers surged and failed to keep clear funnel	Obstructed downtakes	Assumed 'servo'—reduced output intil clear funnel achieved	Cleared downtakes
Impossible to keep a clear funnel in one boiler room—Steady steaming on both boilers	Different number of burners inadvertantly flashed on each boiler	Put same number of burners on each boiler	
Blowers developed very low frequency hunt	Squaring relay oscillating in tune with ship's rolling	None	Full check on system ending in pen-recorder trial located fault. Cured by mounting relay fore-and-aft not athwartships
Blowers ran up to high speed in 'auto' with attendant white smoke	Fractured bellows in R.D.L. transmitter	Put blowers in hand control	Replaced transmitter
F.F.O. pump running unusually fast	Recirculating valve not fully shut	Checked recirculating valve	
F.F.O. pump running very fast, spill valve shut, steam pressure falling, no spill pressure indicating	Spill valve spindle sheared internally, valve being open when indicating shut	Assumed 'semi-manual'. Changed to simplex burning by shutting burner spill cocks	Refitted spill valve
Spill valve tended to 'creep', assuming correct position after change in output, then drifting off	Spill controller out of zero	Assumed 'semi-manual'	Re-zeroed spill controller
Blower and spill valve power operators failed to operate on assuming auto/servo control	Baldwin air change-over switches failed to change over, due to corrosion between dissimilar metals of piston and cylinder	Assumed 'semi-manual'	Refitted Baldwin valves, using pistons and cylinders of the same material

It is appreciated that these general remarks are in no sense explicit, and indeed it is scarcely possible to lay down anything more definite. But it is worth repeating that a careful study of the actual behaviour of the system and of the layout of the whole arrangement, is often more fruitful than hours of fiddling.

Some Faults experienced

As a matter of interest, some faults experienced in H.M.S. *Lion* and the remedial action taken are shown in TABLE II. A cross-section of problems ranging from the simple to the quite complex has been included to show the scope of the subject.

HUNTING THE HUNT

One of the most tiresome faults in the system is a hunt in one or more of the loops. Apart from being theoretically unsatisfactory, and giving rise to higher wear rates in linkages and machinery, it is wearing for the watchkeepers. The hunt can be a symptom of any of a large number of faults. Like any other fault on the system it is perhaps most likely to be caused by a mechanical defect. Here one should mention the possibility of interaction of other outside systems on the boiler control system. An example of this was a sticky feed pump governor; this caused the feed pump to hunt, which in turn put the hunt into the exhaust pressure (also automatically controlled by a separate system), thence causing the boiler-room auxiliaries to hunt, which the control system tried to correct. So one defective governor had the whole unit sighing like an exhausted grampus!

Tracking down the offending component is often a tedious affair, since the chicken-egg phenomenon frequently applies. Does the machine hunt, causing the control system to hunt in an attempt to compensate, or is the hunt induced by a fault in the system? The rapidity of movement and displacement of the relevant gauges often make it impossible for the eye to discern the nigger in the woodpile, and a multiple pen-recorder (not carried in ships) may be the only way of pin-pointing the offender.

MAINTENANCE AND REPAIR POLICY

The policy for control systems is that repair by replacement of the whole components (e.g., a controller complete) is to be carried out; indeed, individual spare parts cannot be obtained from S.P.D.C. While this sometimes saves time, it has certain disadvantages. If a component fails, it often fails for a very simple reason; for instance, a split 0-seal or a worn needle valve. For his own satisfaction the maintainer generally attempts to trace the specific defect and, once found it would be a simple matter to rectify. This policy therefore seems to involve an unnecessary amount of traffic in whole components between the manufacturer and S.P.D.C., and between S.P.D.C. and the Fleet.* In this context, more comprehensive manufacturers' handbooks and ship's drawings would be welcomed.†

SUMMARY

A point of view coming from the Fleet will necessarily be somewhat out of date with the latest ideas and practice at Headquarters. Doubtless much of the experience gained in these early control systems has influenced training methods and the design and operation of subsequent installations. Nevertheless it is felt that the following points may continue to be relevant:

(*i*) A detailed knowledge of the 'mechanical' side of the plant is essential to the understanding of control problems.

(*ii*) The system is an aid to the watchkeeper; his responsibilities remain unchanged and he must always be in control.

Departmental Notes:

*Defective instruments returned to S.P.D.C. are refitted by the Instrument Workshop in H.M. Dockyard, Devonport.

†B.R. 3204 (for A.E.I. instruments) will include data for the checking of instruments.

(*iii*) Unless he has serious reasons to doubt its efficiency, the watchkeeper should not 'tweak' the system.
(*iv*) Control systems may often be a minor part of a warship's machinery. They must be allotted priorities accordingly.
(*v*) Mechanical faults are more probable than pneumatic ones.
(*vi*) Good instrumentation is vital.
(*vii*) S.P.D.C. supply of individual spare parts and more comprehensive literature would be welcomed.
(*viii*) More emphasis should be placed on logic and practical principles in training. Thought might be given to the inclusion of 'Control' in the Boiler-Room Watchkeeping Certificate.

References:
1. D. J. Strong, R.N.S.S., 'Principles of Automatic Boiler Control', *Journal of Naval Engineering*, Vol. 12, No. 1.
2. Lt.-Cdr. W. J. R. Thomas, R.N., 'Wide-Range Fuel Systems for Naval Boilers', *Journal of Naval Engineering*, Vol. 12, No. 1.
3. Cdr. J. I. Ferrier, R.N., 'Design of Machinery for Automatic Control', *Journal of Naval Engineering*, Vol. 13, No. 3.

Departmental Comment

The author's experience should be of assistance to other engineer officers facing the same problems. The points made are in general supported by other reports from sea, and action is being taken on such items as handbooks, etc.

Lieutenant Middleton's attitude towards 'tweaking' or 'fiddling' is fully supported. The majority of defects occur in the process and the altering of controller settings and adjustments to cover up these defects is not recommended. The best policy is to keep the instruments standard with their original settings on, then search out the defect. The instrument most liable to damage is the supply transmitter as it is subjected to high pressure surges when the pump is started. Action is in hand to produce modified transmitters with pressure snubbers on the input connections to the Bowden tube to eliminate this problem.

The policy of unit replacement is necessary for several reasons but principally because of the need to keep instruments standard. A specialized instrument mechanic and extensive test equipment is required to rebuild an instrument and fully check its performance.