The Automatic Control of Naval Boilers

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In conjunction with industry, the Royal Navy has for some time been developing systems for fully automatic control of ships' main boilers. The first fully automatic boilers used at sea in one of H.M. Ships were in H.M.S. *Tiger,* using a spill burning system with Admiralty suspended flame wide range registers fitted to Admiralty 3 drum type boilers. Various limitations in the design of the fuel system, the combustion control system and the method of boiler water level regulation became apparent during the sea trials. This paper describes the trials, the analysis of the trials records and the ensuing development work on a modern frigate boiler shore installation at the Admiralty Fuel Experimental Station, Haslar.

The design of systems rather than components is dealt with, since the latter were mainly standard commercial items. The various factors which influence the design and operation of a fully automatic boiler with a spill burning system are considered from a practical standpoint, and the results obtained on the frigate boiler after development are compared with those of the original trials in H.M.S. *Tiger.*

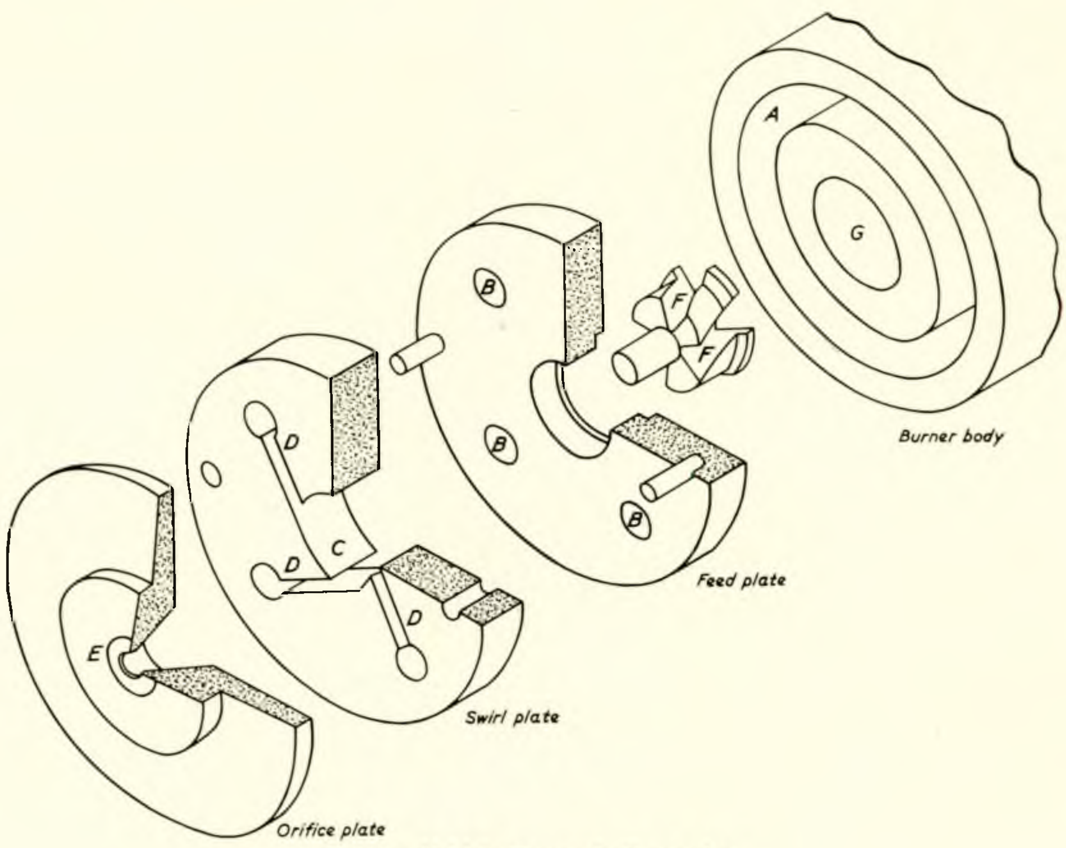

FIG. 1—*H.M.S.* Tiger—*Spill atomizer*

INTRODUCTION

The Reasons for Fitting Spill Burning Systems

The objectives in the case of H.M.S. *Tiger* were that the boilers should be capable of remote operation over the whole range from main steaming standby condition to full power. It was thought that a spill burning system combined with the Admiralty suspended flame wide range register could enable the necessary turndown to be achieved and that, with little additional complication, fully automatic control could be provided. It was felt that burners which remain in use at all times when the boilers are in use suffer less from defects. such as burning or carboning, than those which have to be

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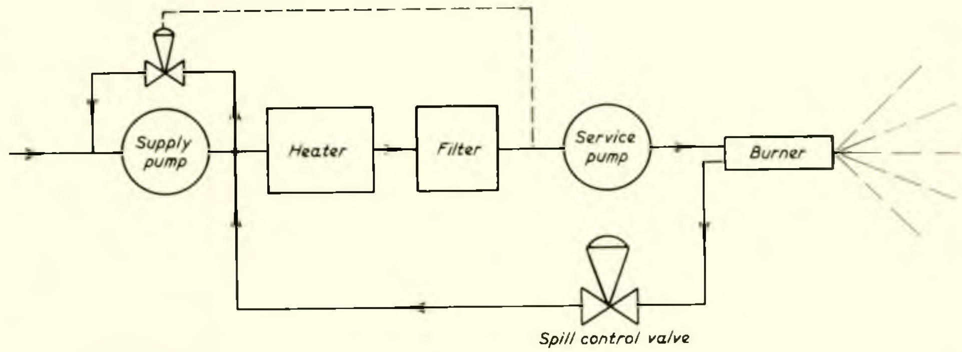

FIG. 2—*The basic spill system*

shut off and relit frequently, and freedom from defects is essential in an automatic system. It is important to note here that the proportion of time spent manœuvring in a naval vessel is considerably higher than in the average merchant vessel, and the rates of manœuvring are frequently higher.

The Basic Spill System

Fig. 1 shows the type of spill atomizer fitted in H.M.S. *Tiger.* Oil enters through the outer tube in the burner body A and passes through the feed plate holes B. It then enters the swirl chamber C *via* the tangential slots D in the swirl plate. Some of the oil is then sprayed into the furnace *via* the final orifice E, the remainder passing through the helical slots F in the pintle and away through the central hole G in the burner body. The quantity of oil spilled through G depends upon the opening of the spill control valve which is fitted downstream of G (see Fig. 2).

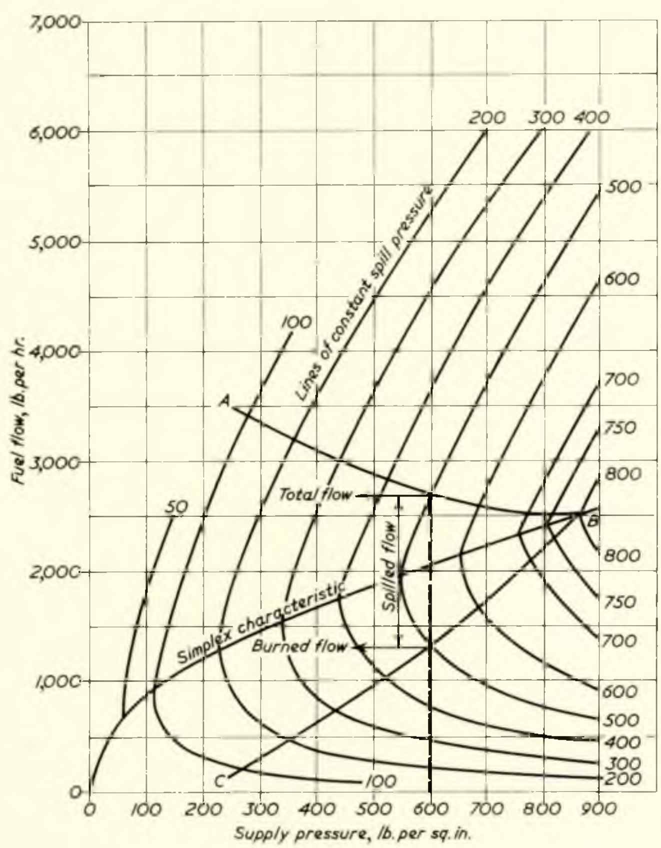

FIG. 3—*Characteristic of spill atomizer in H.M.S.* Tiger

A high turndown can be achieved because a high flow rate, and hence a high swirl velocity, is maintained in the swirl chamber even when the sprayed flow is low. The excess fuel leaving the atomizer is "spilled" back to pump suction.

A diagrammatic view of the basic spill system as fitted in H.M.S. *Tiger* is shown in Fig. 2. The supply pump delivers oil at low pressure (25lb./sq. in.) to the service pump suction *via* the heater and filter. The service pump discharges at high pressure (850lb./sq. in. maximum). Of the total oil supplied to the atomizer by the service pump, a proportion is returned to the supply pump discharge *via* the spill valve. Thus at full power the spill valve will be shut, all the fuel which is supplied being burnt; at lower powers, the spill valve will be open. The wider open the spill valve, the greater will be the spilled flow and the less the burned flow.

The characteristic of the atomizer used is shown in Fig. 3 and the line A-B shows the total fuel requirement on a base of supply pressure to achieve the burned fuel characteristic C-B (the reasons for the selection of the latter are discussed in appendix 1). In the original system in H.M.S. *Tiger,* the line A-B was achieved by using the naturally drooping characteristic of a screw type positive displacement pump governed at constant speed; thus it was thought that only the spill valve position needed to be altered to change the fuel input to the boiler, provided the number of burners or pumps in use per boiler was not changed.

The Fuel System in H.M.S. Tiger

The complete fuel system of H.M.S. *Tiger* is shown diagramatically in Fig. 4 and consists of two 2-stage pumps, each of which is capable of supplying either or both boilers at full power through common heaters and filters. One pump is run at a time, the other normally being left in a standby state. Arrangements are fitted for the remote operation of the pump turbine stop valves so that the standby pump may be started in the event of a defect in the other. The two boilers are normally operated as one, as are the two spill valves which can be joined together.

The Original Control System in H.M.S. Tiger

Fig. 5 shows the pneumatically operated combustion control system originally fitted in H.M.S. *Tiger.* This very simple system consisted basically of programmed blower control and spill valve openings giving the required air fuel ratio at any boiler output. The operating signal to the blower control and spill valves was taken either from the steam pressure controller or from a servo/manual control. The two blowers were operated by separate sequential nozzle control valves, positioned simultaneously by a common air motor. The programming of blower control and spill valve openings was intended to be achieved by profiling cams in the positioners of the two valve operators concerned. Automatic control of fuel temperature was also fitted. Boiler feed regulation was by a conventional single element level control actuated by feed pressure. The system components are all shockproof

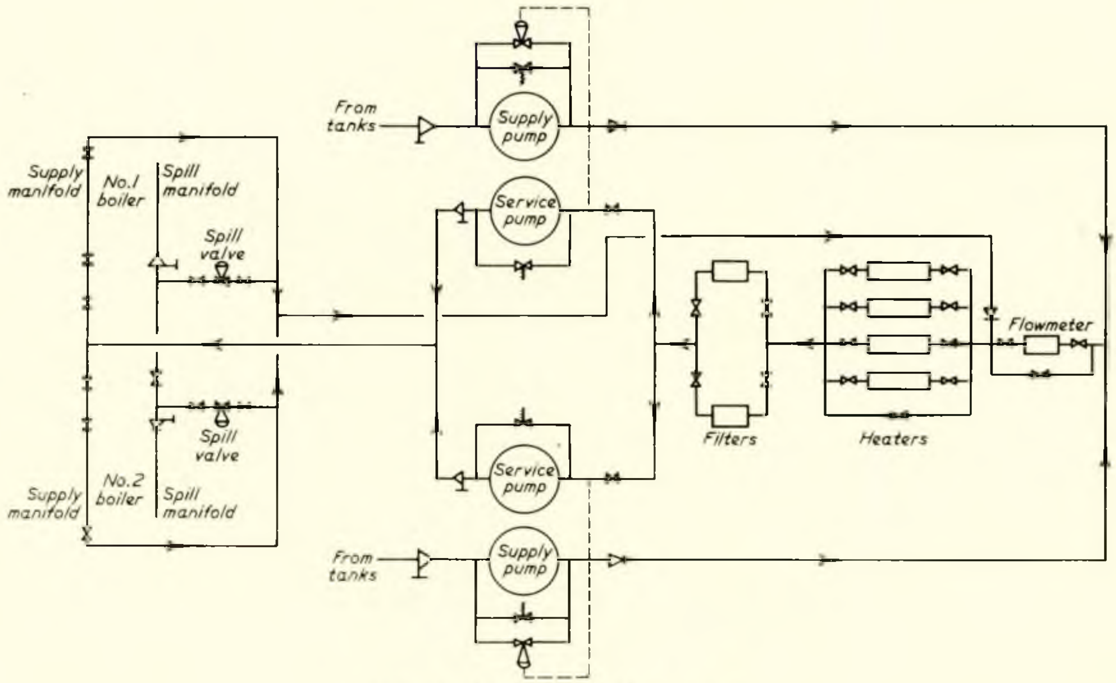

FIG. 4—*H.M.S.* Tiger *Fuel system*

and have shown themselves very trouble free when provided with clean oil-free air.

SEA TRIALS IN H.M.S. "TIGER"

Trials Under Steady Steaming Conditions

The boilers were steamed at selected different powers and sets of readings taken of the data relating to fuel and air requirements. This was done partly to prove the combustion satisfactory over the whole range and partly to obtain the information necessary to repeat these readings automatically. The fuel temperature control was satisfactory from the first and was left in "automatic". The dotted lines in Fig. 6 show the results obtained in terms of register draught loss, and it will be seen that the clear funnel range at low boiler outputs was extremely narrow. This was due to the use of fixed area registers, resulting in very low air velocities at low fuel rates with attendant loss of flame stability.

The air/fuel ratio relay was now adjusted to give the required register draught losses at minimum and maximum spill valve positions. Due to the unsatisfactory characteristics of the blower nozzle control valves, it was found that the slight mechanical backlash existing in the valves was sufficient to cause a large hysteresis effect in blower speed, and hence air flow. The effect of this upon register draught loss, which is a function of airflow per register, is shown in full line in Fig. 6. It was obvious, therefore, that it would prove impossible to keep the funnel clear when operating at low boiler powers in automatic control. This is, of course, no reflection upon the valves, but merely illustrates the danger of the use of valves not specifically designed for automatic control.

Another equally disturbing effect of the backlash was mis-matching of the speeds of the two blowers for a given valve operator position. This from time to time caused one or other of the blowers to reduce speed to the extent that a dangerously low lubricating oil pressure occurred. Adjustment of the low speed stop on the valve positioner to cure

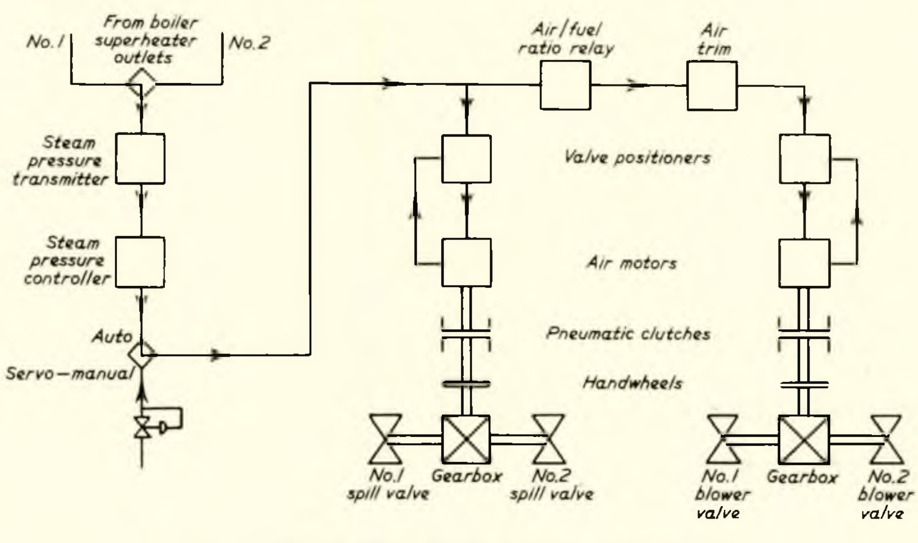

FIG. 5—*H.M.S.* Tiger *Original boiler control system*

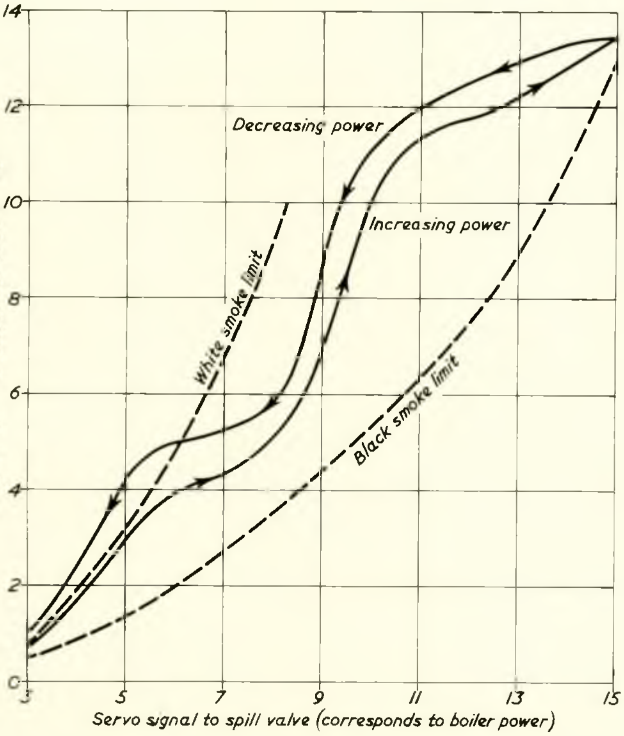

FIG. 6—*H.M.S.* Tiger—*Register draught loss in automatic control*

this either resulted in too high or too low a minimum speed.

Divergence from the Designed Supply/Spill Pressure Relationship

Early in the sea trials several limitations of the system were found. The worst of these was that large departures from the designed burned flow characteristic C-B in Fig. 3 were taking place in the following circumstances:

a) A change in the number of burners in use without attendant change in pump speed.
b) A change in pump speed without an appropriate change in the number of pumps or burners in use.
c) A change in the number of pumps in use per boiler, e.g. when changing over pumps or boilers.
d) A change in pump condition, e.g. due to wear or leakage through a relief valve.
e) External leakage, e.g. through a recirculating valve.
f) Change of fuel temperature, which changed the fuel viscosity and hence the internal leakage rate of the pump.

As a result of these departures, it was not certain at any time whether the maximum or minimum designed fuel rate would be available without the necessity for manual adjustment. It was, therefore, concluded that it was operationally undesirable to rely upon the pump characteristic at constant speed to maintain the burners on their designed characteristic.

Lack of time in H.M.S. *Tiger* at this stage, however, prevented remedial action and the trials continued with the object of adjusting the existing system to its best advantage and evaluating it further, despite its now obvious limitations.

Pump Change-over and Changing the Number of Burners in Use

It had been hoped that pump change-over from the remote control position would be a simple matter; in fact, it proved almost impossible. It was obviously essential to start the standby pump and wait for a few minutes to observe steady conditions before stopping the running pump. In practice these steady conditions were rarely achieved.

Referring to Fig. 7, and considering a particular case: Assume the boilers are steaming in automatic control with the fuel pump at steady r.p.m. on characteristic ST, and that all burners are in use at 2,000lb./hr. output each (operating point A). The corresponding burned flow characteristic is RT. If the standby pump is now started and run in parallel with the already running pump, the combined characteristic from the two pumps is UV, and the corresponding burned flow characteristic now WX. It can be seen that it is impossible to achieve 2,000lb./hr. burned flow on this new characteristic unless the supply pressure lifts the relief valve and allows the burner to work at constant pressure from X to Y. The high pressure relief is not a control valve, and the supply pressure will be anything but steady; the air/fuel ratio will also be very inaccurate, since the boiler automatic control will have opened the spill valve to maintain the 2,000lb./hr. burned flow required, and the blowers are programmed with spill valve position.

Considering the two conditions:

	Operating point A	Operating point Y
Supplied flow lb./hr./burner	2,530 (B)	5,000 (V)
Burned flow lb./hr./burner	2,000 (A)	2,000 (Y)
Spilled flow lb./hr./burner	530 (B-A)	875 (Z-Y)
Relieved flow lb./hr./burner	0	2,125 (V-Z)
Spill pressure lb./sq. in. ...	680	750

Assuming that the spill valve opening at operating point A was ϕ, then the spill valve opening required at operating point Y is approximately $\frac{\phi 875}{530}\sqrt{\frac{680-40}{750-40}} = 1{\cdot}57\phi$ where 40lb./sq. in. is the back pressure on the spill valve.

Hence if the original blower valve opening was θ, the new opening will be $\frac{\theta}{1{\cdot}57}$ and insufficient air will be provided for the burned flow of 2,000lb./hr. which is unaltered.

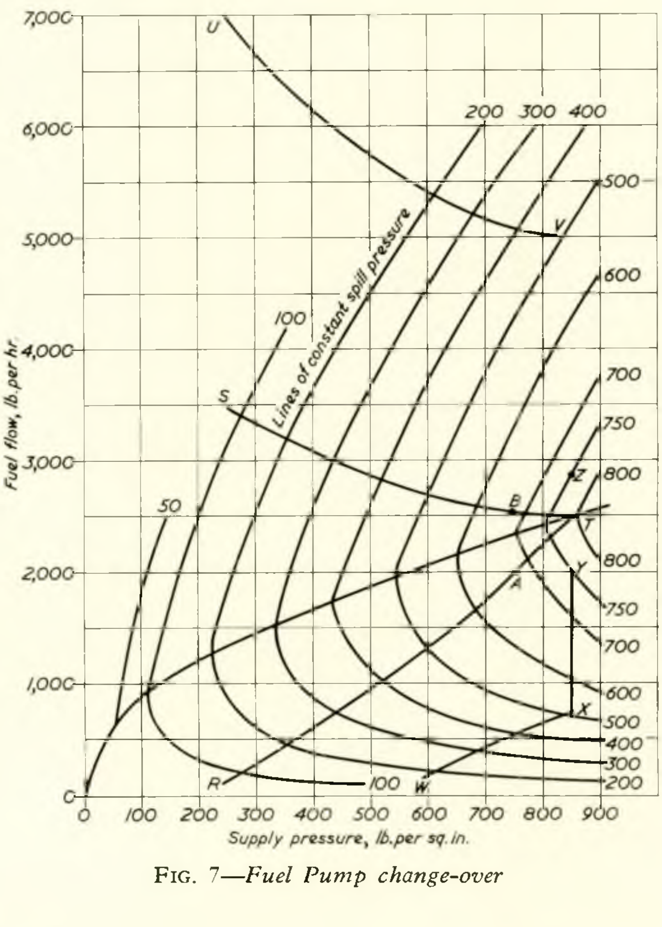

FIG. 7—*Fuel Pump change-over*

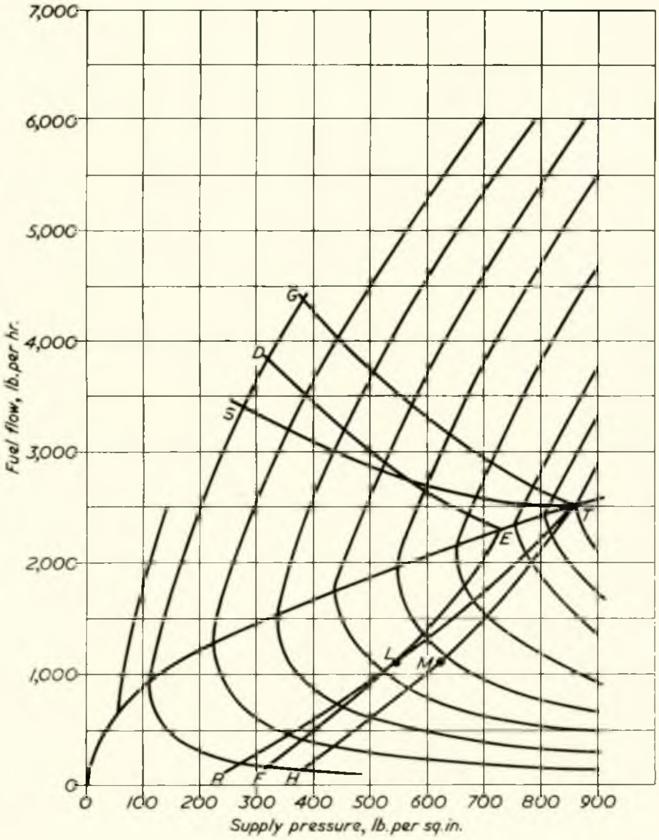

FIG. 8—*Effect of changing pump speed*

Changing the numbers of burners in use per pump has an exactly similar effect as changing the number of pumps per burner.

Selection of the Correct Pump Speed

Referring to Fig. 8, ST is the designed pump characteristic and RT the corresponding burned flow characteristic. Suppose that for some reason (e.g. increased internal leakage due to wear, external leakage through the relief valve, reduced viscosity due to too high fuel burning temperature) the pump characteristic steepens. If it is desired to steam at, say, 1,160lb./hr. per burner, the pump speed can be adjusted to give the characteristic DE in order that the operating point lies on the correct characteristic at L. Since the burner is now operating on the incorrect characteristic FE, if the spill valve is now closed the maximum fuel input obtainable is 2,300lb./hr. at point E. In order that full power (2,500lb./hr.) may be obtained, the pump speed must be increased until the new characteristic is GT with corresponding burned flow characteristic HT. If when running on the characteristic HT it is required to steam at 1,160lb./hr./burner, the spill valve must be adjusted until the operating point is M. It can be shown that if the spill valve opening at L is ϕ, the required opening at M is $1{\cdot}2\phi$ for the same burned flow. If the blower valve opening at L was θ, it will become $0{\cdot}83\theta$ at M for the same burned flow, and hence black smoke will be made at M.

Minimum Output Limiting Stop

The spilled flow required for maximum turndown is dependent upon the fuel pump characteristic and the number of burners in use per pump. Both these are variables, and it is therefore impossible to fit a stop which will prevent the automatic control gear, or for that matter a human operator, from calling for a burned flow per register below the minimum at which satisfactory combustion may be expected.

Response with Reduced Number of Boilers

It is common practice in naval vessels on passage to steam with reduced numbers of boilers in use to improve economy and reduce the number of watchkeepers required. With only one boiler in use, the rate of response of the steam pressure control in H.M.S. *Tiger* is exactly half what it is with two. Thus the deviation of steam pressure for a given load change is doubled and a reduction in desired steam pressure is necessary to ensure that safety valves are not lifted. This means that full boiler pressure is not available in automatic control with reduced numbers of boilers in use.

Lifting of Safety Valves

When a boiler safety valve lifts it does not close again until the steam pressure has fallen below normal. If a boiler is steaming in automatic control, and due to a particularly violent engine movement the safety valves are lifted, the drop in boiler steam pressure will cause the fuel to increase to its maximum input. This may effectively prevent the boiler pressure from falling far enough to re-seat the safety valves. This can only be overcome in automatic control by reducing the desired steam pressure well below the safety valve re-seating pressure. This problem is, of course, inherent in automatic combustion control systems and is not confined to H.M.S. *Tiger*. In designing a boiler for automatic control, account must be taken of this fact and the design pressure for the drum (and hence safety valve setting pressure) increased accordingly.

Dynamic Response Trials

Although there were obviously defects in the system, trials were continued to obtain information regarding its dynamic characteristics. It was soon found that the rate of response of airflow was not fast enough to match the rate of fuel change when manœuvring rapidly. While it was appreciated that the open loop system used for controlling the air would not give the fastest possible response, it was obvious that there were other factors involved. For instance, it was noticed that the fuel pump speed was departing considerably from its desired value during load changes. It was therefore decided to fit continuous pen recorders to investigate the performance of both the pumps and blowers more fully.

The following parameters were recorded:

Actual supply pressure
Actual spill pressure
Blower r.p.m. (an electrical signal proportional to r.p.m.).
Percentage funnel obscuration (an electrical signal from a photo-electric cell proportional to obscuration).

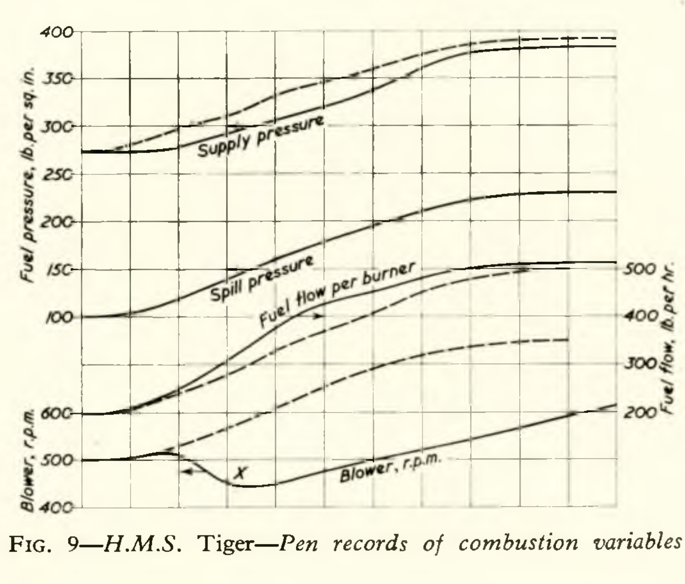

FIG. 9—*H.M.S.* Tiger—*Pen records of combustion variables*

In addition it was possible to record any three pneumatic signals.

A series of records was taken, using in each case the same load change, making an adjustment to one of the variables in the control system between each run. In this way, optimum settings were quickly found for variables such as proportional band and integral action time of the steam pressure controller. With these optimum settings applied, the load changes were increased with the object of proving that the ship could carry out, in full automatic control with a clear funnel, the most severe engine movements which might normally be expected. As the severity of the load change was increased, it became obvious from the pen records that the blower r.p.m. which initially started to increase in step with the fuel flow, hesitated and sometimes decreased sharply during the load increases (see Fig. 9). Due presumably to damping of the instruments, this decrease could not be detected in the blower tachometers. The fall was originally thought to be due to mechanical backlash in the blower control valves, but it eventually became clear that it was associated with a rise in the auxiliary exhaust pressure. This rise was occurring due to the rapid reduction in feeding rate of the boiler caused by the violent rise in burned fuel rate which was taking place early in the load change. When the back pressure on the blower turbines rose, their available heat drops fell and the blowers slowed down. While nothing could be done immediately to prevent this exhaust pressure rise, which was accentuated by the condenser dump valves being unable to cope with the extra exhaust steam, it was appreciated that changing the steam pressure controller sensing point from the superheater outlet to the steam drum might improve the situation by making the load change less rapid. On the main engine throttles being opened, the pressure at superheater outlet was instantaneously reduced owing to the suddenly increased pressure drop across the superheater. Thus abrupt and, in fact, almost step action was taken by the steam pressure controller to increase the fuel flow to the boiler (see Fig. 10).

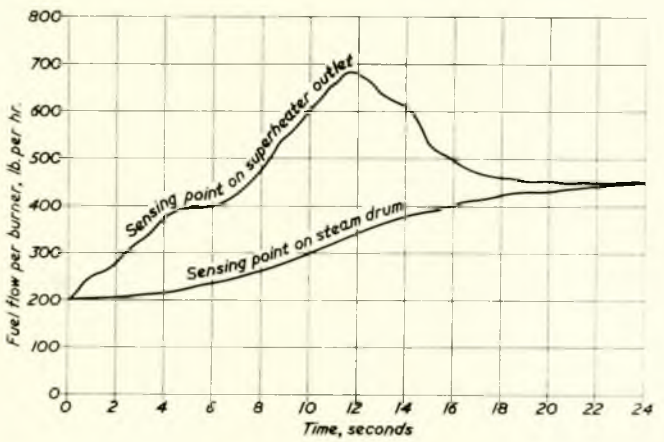

FIG. 10—*H.M.S.* Tiger—*effect of changing sensing points*

A pen recording of an exactly similar load change but with the steam pressure sensing point transferred to the steam drum is shown on the same figure. Undoubtedly the superheater outlet sensing point gave a very fast and almost derivative response. This was not necessarily a desirable feature, as steam pressure control was found to be the least difficult problem; matching of air to fuel was much more critical.

Analysis of Dynamic Response Trial Records

More detailed analysis of the pen recordings after the trials revealed a further source of trouble. Fig. 9 shows in full line the recorded supply and spill pressure, deduced burned flow and the recorded blower r.p.m. The dotted lines indicate what the supply pressure, and consequently the fuel rate would have been had the pump remained upon its desired characteristic. The shift from this desired characteristic was due to the pump governor allowing too large variations of pump r.p.m. during the load change, with the result that the supply pressure did not match the spill pressure. At the point of maximum divergence, the actual burned fuel rate per register exceeded the desired rate by 60lb./hr., i.e. 20 per cent of the total load change. This error, added to an already rapid increase in burned fuel rate due to sensing steam pressure at the superheater outlet, caused a rapid rise in boiler water level. This in its turn caused the boiler feed regulator to shut, and when feed flow ceased in the feed heaters (the major users of auxiliary exhaust) the exhaust pressure rose. This back pressure, applied to the blower turbines, caused the reduction in blower r.p.m. shown at X in Fig. 9, with inevitable heavy black smoke and pulsation. The rise in exhaust pressure is also partially responsible for the failure of the fuel pump governor to maintain the correct speed.

FURTHER TRIALS AND DEVELOPMENT ASHORE

Description of the Admiralty Fuel Experimental Station Test Boiler

The boiler is a modern frigate design of the two drum type with superheat temperature controllable by means of dampers which can restrict or augment the gas flow over the superheater. Registers of the Admiralty suspended flame type are fitted, while the fuel system is basically as shown in Fig. 2. The pneumatic control system originally fitted to this boiler was similar to that of H.M.S. *Tiger* although supplied by another manufacturer. It differed, however, in that closed loop blower control was fitted, with register draught loss being used to meter the air, and the feed regulator was of the three element pneumatic type. The automatic control of superheat was by pneumatic operation of the dampers. In order to programme the air and fuel flow, a measurement of burned fuel flow was required. Since direct measurement of this quantity is not easily achieved in a spill system, the total and spilled flows were measured in flowmeters, and were subtracted to give burned flow. This entailed the subtraction of one large quantity from another of the same order of magnitude, and errors inevitably would have resulted; these would have been greatest when the burned flow was least and hence the air/fuel ratio most critical.

Development of the T.B.S. Spill Control System*

Until this time, three methods of spill control were common:

a) Constant speed as in H.M.S. *Tiger*.
b) Constant supply pressure.
c) Constant supply/spill pressure differential.

For the wide range systems in H.M. ships, both the latter two methods were impossible. With the atomizers then available, constant differential could not give the required turn down inside a reasonable pressure range, while the constant supply pressure system would have required enormous pumps to deliver the large quantities involved in producing low burned flows (See Appendix 1).

For the reasons explained earlier, the constant speed pump had also proved unsatisfactory and a new method of spill control was therefore needed.

Ideally this was required to be independent of the number of burners in use per pump in order that pumps or boilers could be run parallel when changing over, without manual adjustments to the pump speed being necessary. Furthermore, deviations from the chosen burned flow characteristic were required to be small in order that the correct air/fuel ratio could be maintained.

To be independent of the number of burners in use, it is evident that whatever quantities relating to the fuel are programmed, these must be common to both pump and burner on the supply side and burner and spill valve on the spill side. The only alternative is a complicated system of dividing measured and programmed quantities by the number of burners in use. The obvious choice is to match the supply and spill pressures, and investigation of not only those fitted in H.M.S.

* The letters TBS merely stand for the names of the inventors.

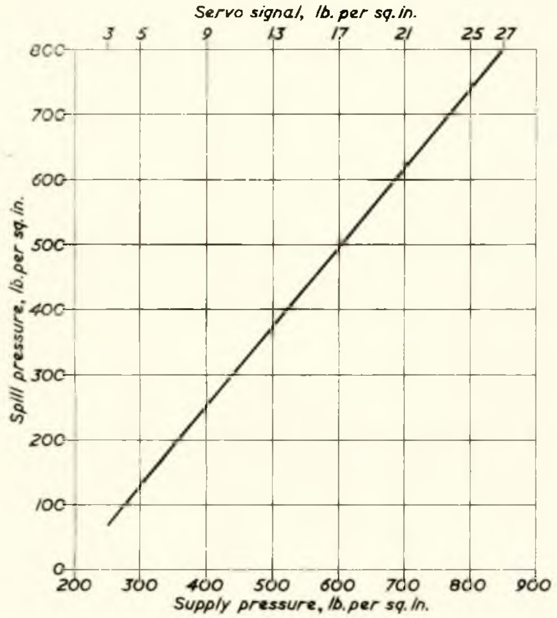

FIG. 11—*Designed supply/spill pressure relationship for TBS*

Tiger but also other atomizers revealed that it would be possible to use a straight line relationship between supply and spill pressures, the slope of this line varying according to atomizer size and the turn down required. The suitable straight line for H.M.S. *Tiger* is shown in Fig. 11, this giving the identical burned flow characteristic C-B shown in Fig. 3. To achieve this required relationship, a control system known as TBS was devised, and was tested at the Admiralty Fuel Experimental Station, Haslar.

In order to control the supply pressure it was necessary either to control the pump speed or, since the pump was of the positive displacement type, to run it at constant speed and to return part of its discharge to suction. The latter possibility was not adopted since it involved controlling the relieved quantity between 0 and 40,000lb./hr. in a twelve burner installation and this was not considered as simple a control problem as altering pump power by controlling the steam supply to the pump turbine. It was originally thought that the necessity to change the pump speed would introduce an unacceptable lag, but as it is only on much reduced numbers of burner that the pump speed is required to alter appreciably over the burner output range this fear was unfounded.

Description of the TBS Spill Control System (See Fig. 12)

The TBS spill control system consists of two separate pressure control loops, one for the supply pressure and one for the spill, each loop being fed with the same desired value servo air signal. The supply pressure is governed by its controller which positions the F.F.O. pump turbine steam valve so that the output from the supply pressure transmitter equals the incoming servo signal. Similarly, the spill pressure is governed by its controller which positions the spill valve so that the output from the spill pressure transmitter equals the same incoming servo signal. Referring now to Fig. 11, it will be seen that if the incoming servo signal is, for example, 15lb./sq. in., the supply pressure will control at 550lb./sq. in. while the spill pressure controls at 435lb./sq. in.

Load limiting relays are fitted which prevent the incoming servo signal to the two controllers from exceeding 27lb./sq. in. or falling below 3lb./sq. in. This limits the maximum and minimum controlled pressures and hence burned flows.

The incoming signal to the two controllers may either be manually controlled by means of a pressure reducing valve or be taken from the steam pressure controller output, when the boiler will be in fully automatic control.

The practical advantages of TBS over the original *Tiger* system are:

1) The burners remain on their desired characteristic during boiler load changes, thus easing the problem of matching the fuel to the air.
2) Changing the number of burners in use has no effect upon the output of the others, since the supply and spill pressures are unchanged.
3) Pump speed is automatically selected for any given boiler power and is automatically compensated for internal or external pump leakage, exhaust steam pressure changes, fuel viscosity, etc.
4) Output limiting stops are possible.
5) A pneumatic signal is now available which is roughly

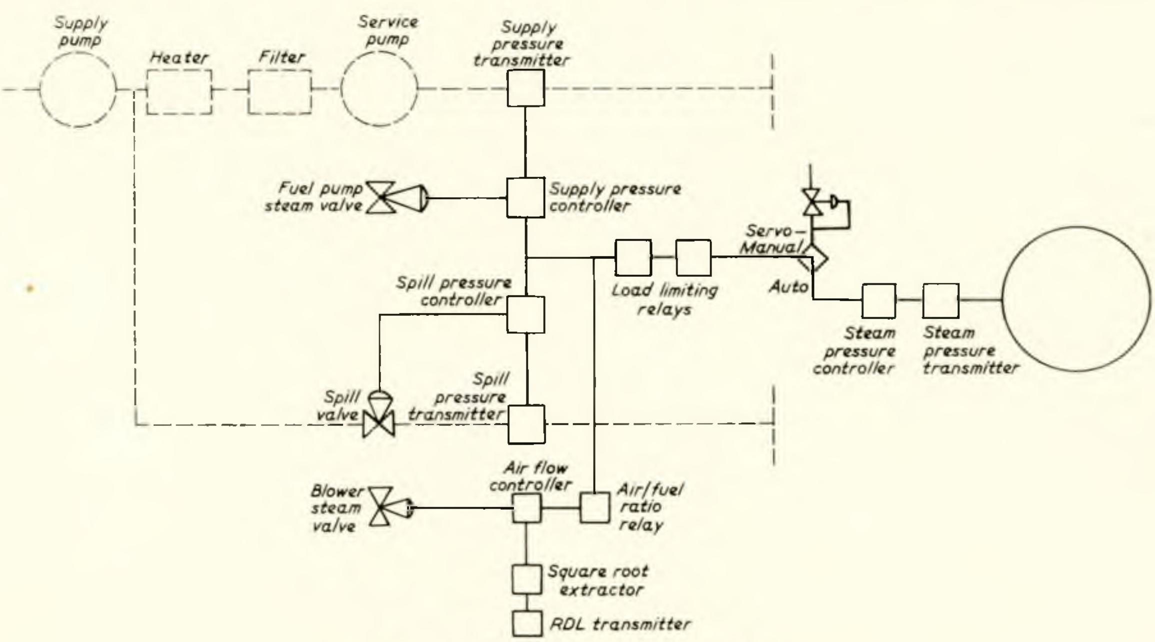

FIG. 12—*TBS Spill Control System*

linear with burned flow per register and the significance of this will be seen when the closed loop air control is discussed.

The criteria adopted for measuring the success of the TBS system were firstly, that the system must be stable over its whole range of operation and secondly, that for any reasonable change of boiler power the maximum variation from the desired burned flow characteristic must be ±20lb./hr./burner. On the A.F.E.S. test boiler it proved possible to change the boiler load by 50 per cent full power in five seconds without exceeding this error, while the system was stable except when operating at very low boiler outputs on few burners. This instability was traced to the supply pressure loop and can be cured by cracking open the recirculating valve, thus giving the pump turbine more work to do and the turbine control valve more steam to pass. Very accurate control of the steam supply to the pump turbine is, of course, necessary and this demands accurate sizing and positioning of the valve which must be sited as close to the turbine as possible. In recent installations it has been the practice to order such control valves with sets of inserts of different sizes, in order that the smallest permitting the maximum steam flow can be used. This method has been made necessary by the difficulty in obtaining accurate information about the required steam flows early enough for valve ordering purposes. The correct valve size having been fitted, it merely remains to adjust the two controllers to give accurate tracking of the supply and spill pressures. A useful check during this tuning process can be obtained by continuously recording the supply and spill pressure transmitter pneumatic outputs, since these should always be equal if the system is correctly tuned. Alternatively, if these outputs are subtracted in a relay, the output from that relay should be constant (corresponding to zero difference) if the system is correctly tuned. Thus if this output is recorded, the result should be a straight line.

Development of Combustion Air Control

Some thought was first given to the best method of achieving the required head/flow relationships at various powers. These can be achieved in the following ways:

a) Blower speed control over the whole range.
b) Running the blower at constant speed or a speed slightly in excess of that actually required and blowing off the excess quantity to atmosphere.
c) As for b), but throttling the blower discharge to achieve the desired conditions.

The most economical of the above methods is a) since both the others involve wasted work in the blower. Furthermore, the adoption of c) involves careful design of the blowers to avoid running them too near their surge line. It was therefore decided to throttle the steam input to the blower turbine on the test boiler at A.F.E.S., but not to use the sequential nozzle valves. Subsequent results at A.F.E.S. have fully justified this decision.

It was also considered that closed loop air control could give a faster response than that achieved with the open loop

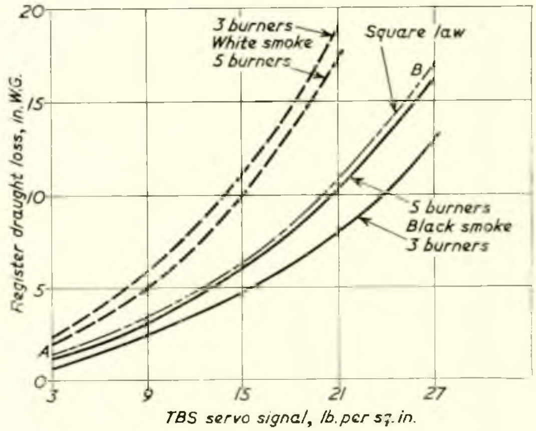

FIG. 13—*A.F.E.S. test boiler smoke limits*

system in H.M.S. *Tiger*. Thus the closed loop air control system shown in Fig. 12 was adopted. While the use of register draught loss as a measure of airflow per register had been contemplated for some time, the registers in the spill system were working over a very large turndown. A series of trials was therefore carried out on the A.F.E.S. test boiler to determine whether the draught loss was substantially the same for a given burned flow per register, regardless of the number of burners in use. The results are shown in Fig. 13 and it will be seen that, although the clear funnel band width and position does vary with the number of burners in use, it is nevertheless possible to draw a line which conforms to a part of a square law A-B and will maintain the funnel clear; the base is steam pressure controller output, which is roughly linear with burned flow per register.

It was found that while the decision to use register draught loss as a feed back was fully justified, the trimming arrangements were not sufficiently flexible since they altered the slope of the register draught loss/burned flow characteristic. The system shown in Fig. 14 was therefore devised and although this has never been used at A.F.E.S., results from a prototype system in H.M.S. *Lion* (sister ship to H.M.S. *Tiger*) are most satisfactory. A pen recording from the latter ship is shown in Fig. 15 and comparison of this with the original results of H.M.S. *Tiger* in Fig. 9 reveals the magnitude of the improvements obtained.

The trim control in Fig. 14 merely adjusts the square law vertically upwards or downwards. Trimming only needs to be carried out on changing the number of burners in use, and then only if it is desired to reduce the excess air to the absolute minimum to improve economy.

The air flow/register draught loss relationship is unaffected by boiler fouling and once the required square law is selected and set during initial trials no subsequent adjustments

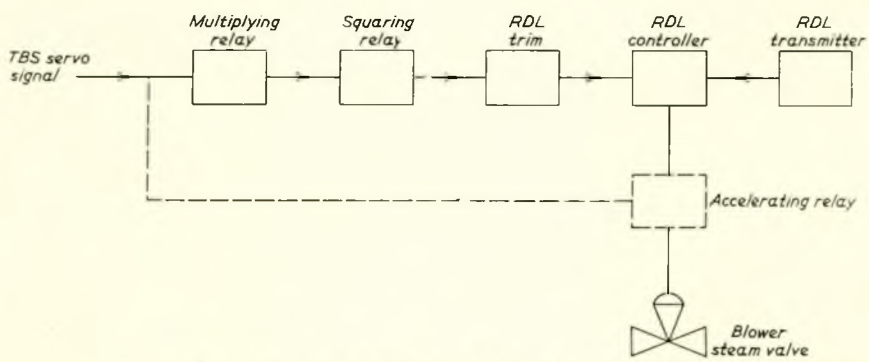

FIG. 14—*H.M.S.* Lion—*Improved air control*

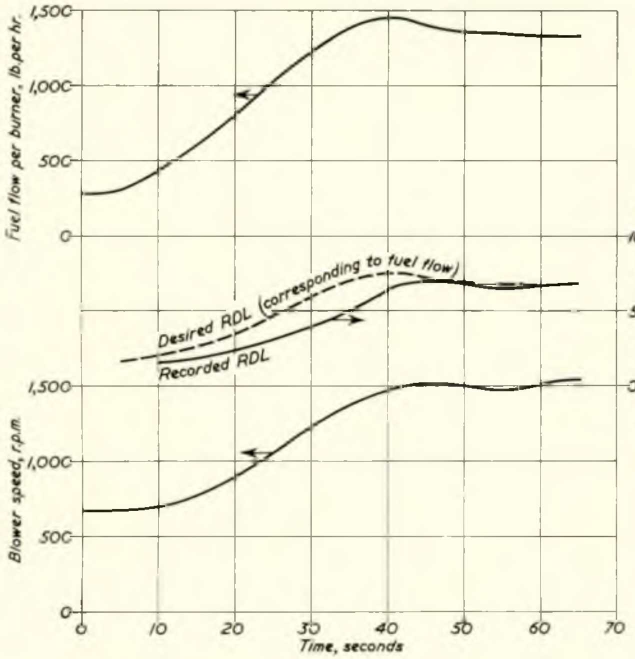

FIG. 15—*H.M.S.* Lion—*blower control performance*

should be necessary. It is considered important that no means of adjusting the square law other than vertical trim should be available to the operator, since complete recalibration is necessary if the law is altered.

The desired air flow servo signal is taken from the same source as the desired supply/spill pressure signal for two reasons:

a) The load limiting relays are available to prevent the register draught loss from exceeding or falling below its prescribed limits.

b) It provides a much steadier desired value signal than would, for instance, actual supply pressure, i.e. the number of loops in series is kept to a minimum.

FEED REGULATION

Consideration of Conventional Boiler Feed Regulators

The undesirable effects upon the combustion control system in H.M.S. *Tiger* of a conventional boiler water level regulator have already been described. Although these effects could be reduced by the use of TBS spill control and a fast

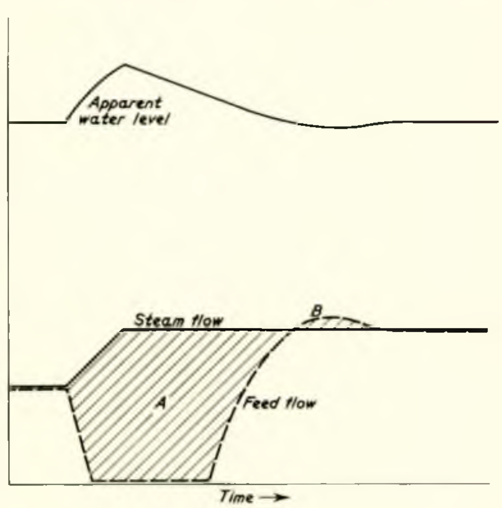

FIG. 16—*Performance of single element feed regulator*

closed air loop, boiler water level was still liable to impose the limit on the rate of manœuvring. This was the case, even with the three element feed regulator fitted to the A.F.E.S. test boiler, and during fast load changes the water frequently disappeared from the gauge glass.

The single element water level regulator senses water level in the steam drum. It has two fundamental disadvantages:

a) Instability can occur in certain designs of boiler due to the lag between the time feed is admitted, and the time it reaches the steam generating surfaces, thereby affecting the rate of steam take-off and also the level. (See reference.)

b) Because an increase in steam flow causes a sudden rise in the measured level, the water level regulator calls for a reduction in feed flow before it increases the feed flow to match steam flow. Consequently violent surges in feed flow occur on rapid change in power (see Fig. 16).

In naval boilers, the problem of instability is overcome by heating the incoming feed water to a temperature near the saturation temperature of the steam/water mixture in the boiler drum. This heating takes place partly in external feed heaters and partly in the boiler.

Both two and three element feed regulators have however been adopted for new construction ships in post war years with a view to eliminating the surges in feed flow which occur on change of load. The two element feed regulators used in the Royal Navy measure drum level and pressure drop across the boiler superheater, which is a function of steam flow. As steam flow increases, an increase in feed flow is called for by the steam flow element, partially offsetting the reduction in feed flow called for simultaneously by the level element.

Three element feed regulators measure drum level, and feed and steam flows. When the difference between the latter two is zero, the regulator functions as a single element type, but when steam flow changes, a corresponding initial change in feed flow will take place.

Development of the "Absolute" Boiler Feed Regulator

Referring to Fig. 17, it will be seen that if a constant

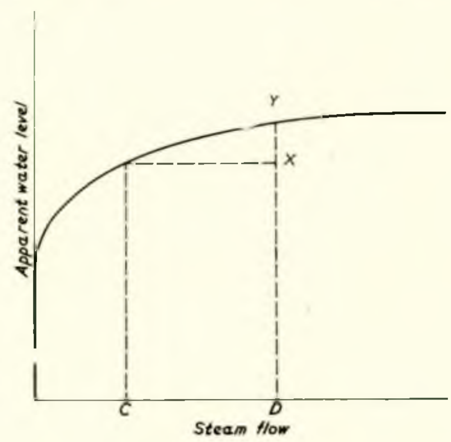

FIG. 17—*Water level/steam flow relationship for a boiler containing constant water weight*

weight of water is maintained in the boiler, the apparent water level must rise with increase of load due to the decrease in density of the steam/water mixture. Conversely, if the water level is held constant, as with a conventional single element regulator, there must be a reduction in the weight of water in the boiler with increase of load. With self acting regulators of the single element type a further reduction in the weight of water occurs due to the proportional action of the regulator. Referring to Fig. 16, it will be seen that the shaded area A minus shaded area B represents the reduction in the weight of water in the boiler which occurs on increase of

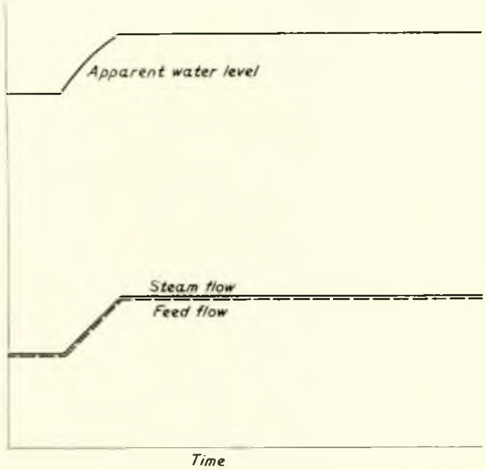

FIG. 18—*Performance of constant water weight regulator*

load. If the feed regulator were, by some means, made to maintain a constant weight of water in the boiler, it follows that feed flow must keep in step with steam flow, as shown in Fig. 18.

Consider the imaginary case of an instantaneous change in steam flow from C to D on Fig. 17. Even though the water level regulator may shut the feed valve instantaneously, the weight of water in the boiler after the change in steam flow must equal the weight before the change. Hence the water level must rise by XY. While in practice changes in steam flow cannot occur instantaneously, it also takes a positive time for the change in the weight of water to take place, particularly on an increase of power where the most that the regulator can do is to shut the feed valve. A transient rise in level approximately equal to XY must therefore occur on a rapid increase from C to D whatever type of feed regulator is fitted.

Consideration of the above, led to the suggestion that, if a boiler can accept a transient rise in level on sudden increase of power, it should be able to accept this as a programmed level when steady steaming. This could be achieved by a feed regulator sensing water weight rather than apparent level. With such a feed regulator, feed flow should in all circumstances keep in step with steam flow, as shown in Fig. 18.

Fig. 19 shows diagrammatically the arrangement of the "absolute" feed water regulator on the test boiler at A.F.E.S. Differential pressure transmitter A measures the static head of water in the boiler, and transmits a pneumatic signal proportional to this static head to controller B. Pressure reducing valve E transmits a preset signal linear with the desired value of static head to controller B. It can be shown that this static head of water is a function of the weight of water in the boiler (See Appendix 2). Controller B transmits a pneumatic signal to valve positioner C, and regulates the opening of feed valve D according to the error between the measured and desired values of static head in the boiler. The proportional band of controller B is readily adjustable and integral action can be introduced if required. Servo manual control of feed valve position is provided by pressure reducing valve F, and selector valve G.

Initial trials showed that, when the static head was maintained constant by introducing integral action in the controller, the rise in apparent level which occurred on increase of load could not be accepted in the A.F.E.S. test boiler. The remaining trials were therefore conducted using proportional action only in the controller. The static head was therefore maintained lower at high boiler outputs than at no load, by an amount corresponding to the proportional action of the controller. Various proportional action settings were tried, and some of the results are shown in Fig. 20. Considering Fig. 20(b), it will be sen that feed flow closely follows steam flow, and that the water is steady at its new level immediately the change in steam flow is complete. The apparent instability of the feed flow was due to a defect in the feed valve positioner. Integration of the pen traces of steam flow and feed flow showed that the weight of water in the boiler after the increase of steam offtake was about 50lb. more than before the change. As the proportional action of the controller required a $1\frac{1}{4}$in. fall in static head for this load change, it was apparent that the static head was not a simple function of water weight. Nevertheless it provided a very satisfactory and completely stable means of control, and enabled the water weight to be held approximately constant.

Fig. 20(a) shows a pen trace for a similar load change when the proportional action of the controller had been adjusted so that the water level was approximately constant with load. In this case the performance is more akin to that of a conventional two element regulator. The sudden reduction in feed flow experienced with a single element regulator does not occur but, because a reduced weight of water is required in the boiler with increased steam flow, feed flow necessarily lags behind steam flow and level takes a considerable time to achieve steady conditions. Integration of the pen traces of steam and feed flow show that the weight of water in the boiler is about 600lb. less after the increase of steam flow. For naval boilers which are subject to rapid manœuvring, the performance illustrated in Fig. 20(b) is preferable because steady conditions are achieved immediately. Other benefits to the

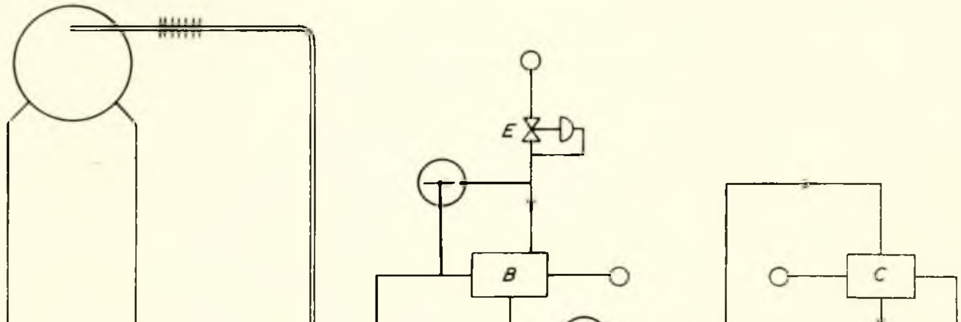

FIG. 19—*"Absolute" feed regulator*

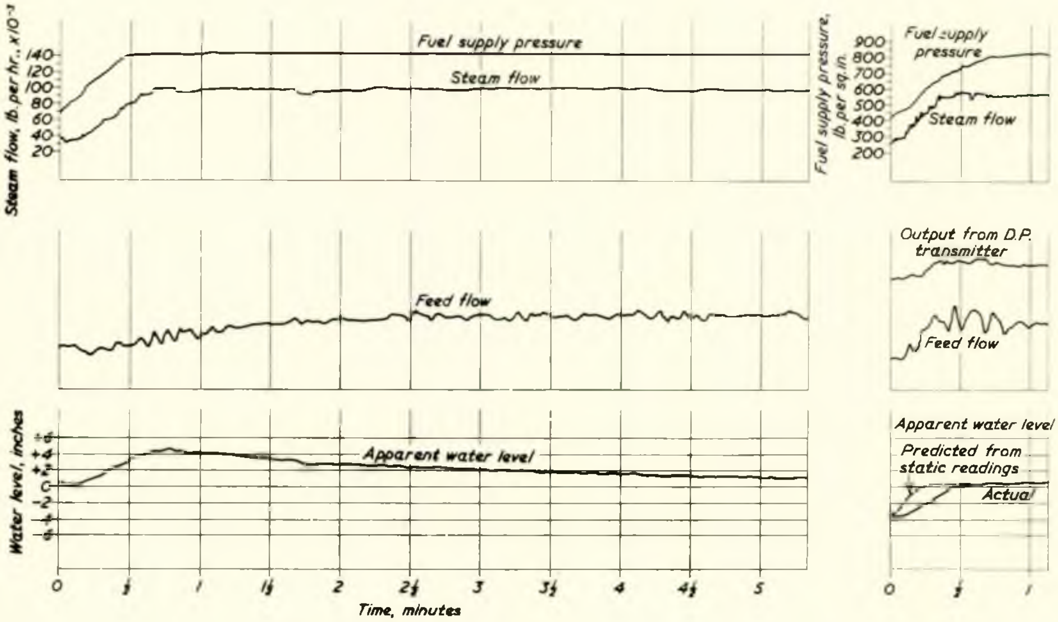

FIG. 20(a) FIG. 20(b)

FIGS. 20(a) and (b)—*Performance of "absolute" feed regulator*

performance of the plant as a whole also accrue, but discussion of these is beyond the scope of this paper.

A number of tests were carried out to prove the stability of the "absolute" feed regulator, including:

a) A sudden alteration in the desired value of static head (see Fig. 21b). It will be noted that the new conditions are achieved without overshoot.

b) A sudden alteration in the set point of the steam pressure controller (see Fig. 21a). It will be seen that despite large variations in burned fuel flow the feed regulator is virtually unaffected.

DEVELOPMENT OF AN IMPROVED STEAM PRESSURE CONTROL

The various developments discussed above had effected such an improvement in the manœuvrability of the boiler as a whole that it was now possible to consider whether an even closer control of steam pressure could be achieved. In H.M.S. *Tiger* the steam pressure sensing point was moved from the superheater outlet to the steam drum because neither the blower control, the spill burner control, nor the water level control was adequate to keep in step with the demands of the steam pressure controller. With these difficulties overcome it was decided to try once again controlling steam pressure at the superheater outlet.

Controlling at superheater outlet has the advantage that an instantaneous response is obtained due to the suddenly changed pressure drop through the superheater, whereas with drum sensing the response is a function of time and of the

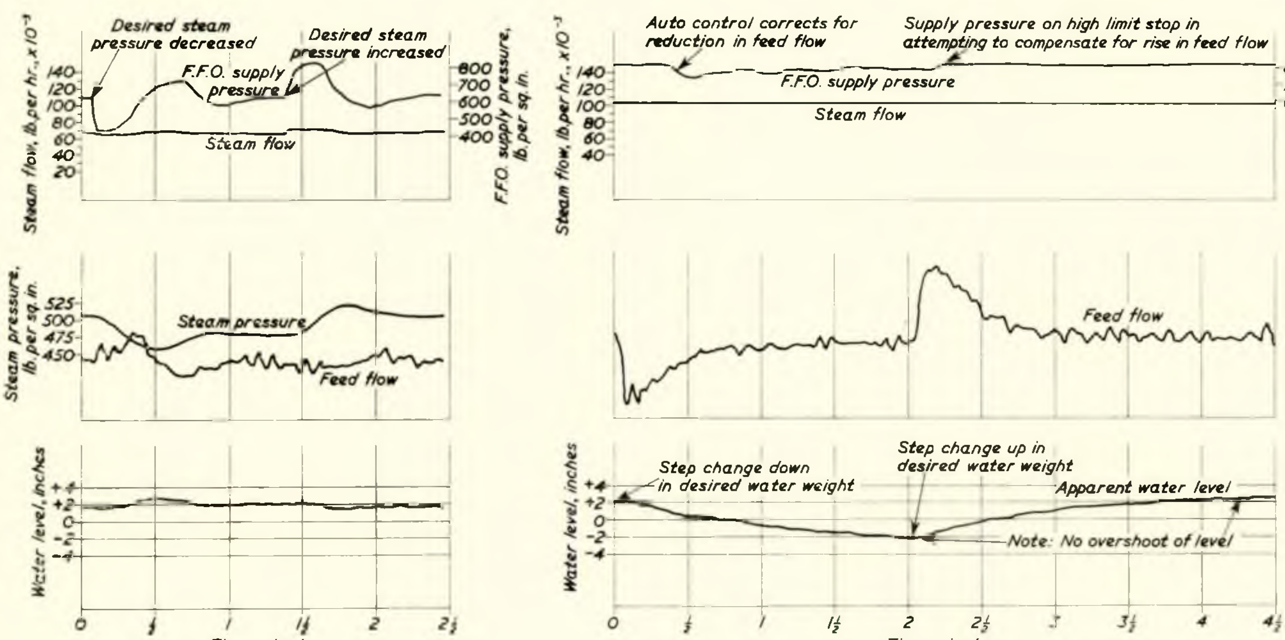

FIG. 21(a) FIG. 21(b)

FIGS. 21(a) and (b)—*Performance of "absolute" feed regulator* heat stored in the boiler. The disadvantage is that if the pressure at the superheater outlet is maintained constant the pressure in the steam drum must rise with load.

It was therefore decided to test a proportional only system in which the transmitter output is led direct to the fuel flow control system TBS and the calibration of the transmitter is arranged to give the superheater outlet pressure characteristic shown in Fig. 22. The resultant steam drum pressure

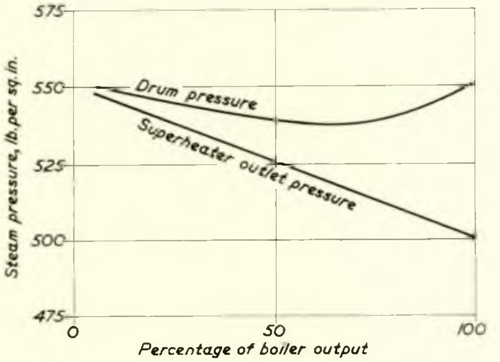

FIG. 22—*Performance of proportional steam pressure control*

for the A.F.E.S. test boiler is also shown in Fig. 22 and it will be seen that the maximum steam drum pressure drop is 12½lb./sq. in.

This type of steam pressure control has two advantages, viz:

a) Simplicity.
b) Steady conditions are achieved almost immediately the change in steam flow is complete.

Both these advantages are extremely important in naval boiler installations and the initial trials of this system are promising.

APPLICATION OF THE LESSONS LEARNED TO THE DESIGN OF A NEW CONTROL SYSTEM

Many other difficulties which were encountered during the development of a fully automatic naval boiler have not been described owing to lack of space. Some of the lessons learned, which are applicable to the design of future control systems, are however discussed below.

Lack of Design Information

Inevitably, the design of a control system must proceed concurrently with the design of the plant if a properly integrated whole is to be achieved. The control system design must therefore be based on past experience of similar plant performance rather than a full knowledge of all the component characteristics, since these are also in the design stage. Furthermore, one must accept that the control system may influence the design of the plant. It may be true to say that any system can be controlled, but heavy penalties in performance and control system complexity will frequently result if this policy is adopted.

Fortunately, because of the versatility and wide ranges of adjustment of the many excellent pneumatic instruments commercially available, the lack of knowledge which would permit controller settings to be computed is seldom an embarrassment.

Selection of Controlled Variables

In the early stages of the design, it is essential to give very careful consideration to which of the many plant variables must be controlled, and to the exact means by which they may be controlled. It is, for example, seldom acceptable to programme a valve position in order to achieve a desired pressure, since the pressure is a function of not only valve position but also pressure at valve inlet and fluid viscosity. It is preferable to measure the actual value of the controlled variable and to feed this back to the controller which will continue to adjust the valve position while there remains an error between desired and actual values of the controlled variable. Thus in the case of an automatic combustion system, it is preferable to programme air and fuel flow per register, which are the two variables primarily deciding the quality of combustion, rather than blower steam and spill valve positions. Similarly, to achieve optimum plant performance it is essential that ALL variables which have a significant effect upon plant performance are controlled in such a way that there is no undesirable reaction upon other system components. For example, it is of no use controlling the water level in a boiler to a constant value if this entails very violent surges in feed flow and, as a secondary effect, equally violent surges of exhaust steam pressure which in turn will influence fuel and air flow. In fact a very beneficial effect upon the system as a whole may result if the boiler water level is programmed so that level varies over the power range in order to reduce feed flow surges.

Stability

When the development of the fully automatic installation was in its early stages, it was thought that instability and interaction between the various control systems might be major problems, and that a fundamental investigation of plant characteristics would be essential to the development of an inherently stable boiler control. In fact, few stability problems have been encountered, and none of them has required more than simple, on the spot, investigation and deduction to solve them. In many cases it has been found unnecessary and even undesirable to tune loops as tightly as possible.

Care is, however, necessary in the design stage in matters of detail. In particular, attention must be paid to the accurate sizing and the good design of valves used for control. The use of long control leads, resulting often from the inclusion of unnecessary complication, must also be avoided.

There is nevertheless a real need for more knowledge of the dynamic characteristics of both the plant components and control equipment, but this information can only be of value in succeeding plant designs.

Control Valves

Automatic control systems demand valves specifically designed for control. The use of sequential nozzle valves, for example, for controlling a steam turbine cannot give the smooth and consistent response of a single control valve, which can be flow characterized.

Similarly, it is seldom acceptable to adapt for automatic control a valve originally designed for manual operation.

Valve Operators

In the selection of a valve operator, consideration must be given to providing sufficient accuracy, reserve of power, speed and response. An automatically controlled valve must always be capable of responding faster than the most rapid signal change from the instrument controlling it. Suitable arrangements must also be made to provide for failure of instrument or power air, or of the operator components.

In the opinion of the authors, the diaphragm operator is the simplest and most suitable means at present available of providing for these requirements.

Failing Safe

In the design stage, great care must be taken to ensure that partial or complete failure of an automatic system does not result in a dangerous situation. Discounting mechanical failure, the system may suffer failure of either instrument or power air, and whether each valve or damper fails open, set or shut must be considered for both cases. It is not necessarily correct, for example, to arrange that all components fail set. Failure of a feed regulator set, for instance, will lead to boiler burn out if the fuel flow is increased. (One might prefer to strip the turbines by arranging that the feed regulator fails open!)

Simplicity

The versatility and reliability of pneumatic control instruments is liable to lead the unwary to use complicated systems in an attempt to achieve perfection. There is, however, no point in using six instruments to achieve an accuracy of ±2 per cent if ±10 per cent would have been acceptable and achieved with one instrument.

A further important consideration is the need for the systems used to be simple enough for the watchkeepers and maintainers to understand them and to diagnose faults. This is an essential naval requirement since the manufacturer's service engineers will not necessarily be available to ships in trouble.

Overall reliability is essential in an automatic system, and therefore not only the instruments but the associated valve operators must be the most reliable possible. The authors consider that in general the fewer the moving parts the greater the reliability, and for this reason prefer diaphragm to motor operators.

Auxiliary Machinery Changeover Arrangements

The use of fully automatic control with untended boiler rooms demands a new approach to system design. The fuel system in H.M.S. *Tiger* as shown in Fig. 4 has, for example, certain disadvantages, viz.

Assume No. 1 pump unit is running and that the filter in use becomes choked. All that is known in the machinery control room is that the discharge pressure available from No. 1 pump unit is falling below the desired value. If the standby No. 2 pump unit is now started, the same choked filter will be in use.

It is considered that a better layout would have two separate pumping units comprising supply and service pumps, heater and filter, so that in the event of any trouble on one unit the other may be started with confidence.

CONCLUSIONS

The problems encountered in the initial sea trials of H.M.S. *Tiger* have been described in some detail in order to provide a background for the explanation of the ensuing developments. In reading of these difficulties it must be remembered that this was the first fully automatic wide range boiler installation at sea in one of H.M. Ships, and initial troubles were therefore to be expected.

The developments made possible by these initial trials have produced an extremely flexible boiler plant, it now being possible to increase from standby load to full power and achieve the new steady conditions within a period of a few seconds, without hazard to the boiler and with the boiler room untended.

Further development needs to be directed towards simplification, thereby making the controls even more reliable and more readily understood by their operators. The authors consider that a fully automatic wide range system using simple, self-acting controls is by no means impossible.

ACKNOWLEDGEMENTS

The authors wish to emphasize that the developments described were the result of the joint efforts of many, including other members of the Marine Engineering Division of the Admiralty, the staffs of the Admiralty Fuel Experimental Station and the Admiralty Engineering Laboratory, Associated Electrical Industries Ltd., Joseph Lucas (H. and C. E.) Ltd., and Bailey Meters and Controls Ltd.

This paper is published by permission of the Admiralty but the views expressed are those held by the authors and must not be construed as necessarily representing those of the Admiralty.

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Appendix 1

CHOICE OF BURNED FLOW CHARACTERISTIC

Small droplet size over a large turndown is effected in the spill atomizer by the supply to the atomizer of considerably larger quantities than are required to be burned. Thus high velocities exist within the swirl chamber, the air core in the atomizer orifice is large and the effective orifice size small. Study of Fig. 23 shows that a given output can be achieved by an infinite number of combinations of supply and spill pressure. With the particular atomizer used in H.M.S. *Tiger*, it had been found that the limiting supply pressure for reasonable droplet size was 250lb./sq. in. Thus the area to the left of the 250lb./sq. in. supply pressure line in Fig. 23 has been shaded. The minimum output required of the atomizer was 150lb./hr. and so the area below the 150lb./hr. line has also been shaded.

Since a maximum output of 2,500lb./hr. was required of the atomizer, the maximum operating point was chosen with the atomizer running under simplex conditions with the spill valve shut as this gives the lowest possible maximum supply pressure. The other end point for the characteristic must lie on the 150lb./hr. line, and it can be seen from the diagram that the smallest maximum pump throughput is given when the supply pressure is a minimum (i.e. 250lb./sq. in.). Thus are chosen the two end points, and any line between them which gives a reasonably steady increase in burned flow for a steady rise in supply and spill pressures will be satisfactory as the burned flow characteristic.

Constant Supply Pressure

If a constant supply pressure of 850lb./sq. in. is used with this atomizer, a total fuel input of 7,150lb./hr. is needed to achieve 150lb./hr. burned flow. This would require a very bulky pump with unacceptably large inertia.

Constant Supply/Spill Pressure Differential

Lines of constant differential are shown dotted on the figure. It is obvious at once that the slope of these lines is too small to permit the required turndown to be achieved without using an excessively high maximum supply pressure.

Constant Supply Pressure/Spill Pressure Ratio

The full line joining the two end points is such that supply pressure bears a linear relationship to spill pressure. This will meet the requirements of the atomizer and can readily be produced by a control system.

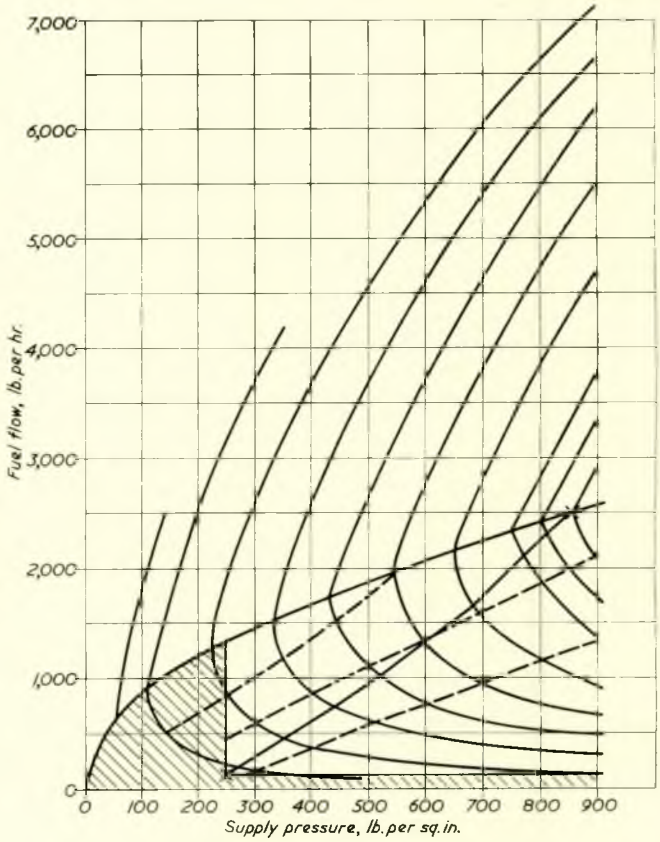


FIG. 23—*Selection of the burned fuel characteristic*

Appendix 2

MATHEMATICAL ANALYSIS OF "ABSOLUTE" FEED REGULATOR

List of Symbols (See Fig. 24)

- H_1 Total head at point (1)
- H_3 Total head at point (3)
- P_1 Static pressure at point (1)
- P_3 Static pressure at point (3)
- h_a Height of point (1) above point (3)
- h_b Height of point (5) above point (3)
- f_2 Friction loss between points (1) and (3)
- v_1 Velocity at point (1)
- v_3 Velocity at point (3)
- K, k_1 and k_2 Constants
- A_2 Mean area of downcomer (2)
- A_4 Mean area of riser (4)
- Q Weight of water in the boiler
- w_2 Mean density of water in the downcomer
- w_4 Mean density of the water/steam mixture in the riser
- w_0 Density of water at N.T.P.
- k_p Proportional band setting of controller
- M_f Feed flow expressed as a fraction of the maximum

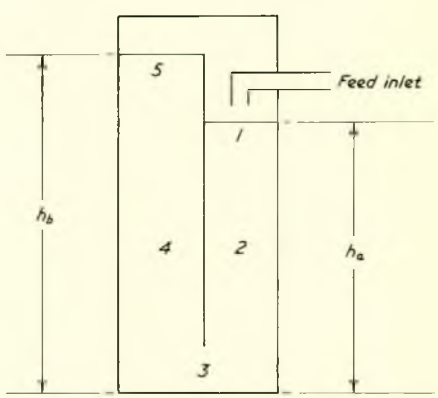


FIG. 24—*Simplified boiler*

Total head at point (1) $= \frac{v_1^2}{2g} + \frac{P_1}{w_o} + h_a = H_1$ (1)

Total head at point (3) $= \frac{v_3^2}{2g} + \frac{P_3}{w_o} + 0 = H_3$ (2)

But $H_1 = H_3 + f_2$ (3)

Therefore $\frac{v_1^2}{2g} + \frac{P_1}{w_o} + h_a = \frac{v_3^2}{2g} + \frac{P_3}{w_o} + f_2$ (4)

Hence $P_3 - P_1 = w_o \left(\frac{v_1^2 - v_3^2}{2g} + h_a - f_2\right)$ (5)

But the weight of water in the boiler, Q, is defined by

$Q = A_2 w_2 h_a + A_4 w_4 h_b$ (6)

Hence $h_a = \frac{Q - A_4 w_4 h_b}{A_2 w_2}$ (7)

But A_2, w_2, A_4, and h_b are constants.

Let $k_1 = \frac{1}{A_2 w_2}$ = a constant

$k_2 = \frac{A_4 h_b}{A_2 w_2}$ = a constant

Then $h_a = k_1 Q - k_2 w_4$ (8)

Substituting for h_a in equation (5)

$P_3 - P_1 = w_o \left(\frac{v_1^2 - v_3^2}{2g} + k_1 Q - k_2 w_4 - f_2\right)$ (9)

or $P_3 - P_1 = w_o k_1 Q - w_o \left(k_2 w_4 + f_2 - \frac{v_1^2 - v_3^2}{2g}\right)$ (10)

It will be seen that $P_3 - P_1$, the measured variable, is proportional to the weight of water in the boiler minus another term which varies with boiler load.

The controller maintains $P_3 - P_1 = K - k_c M_f$ (11)

If k_c is adjusted so that $k_c M_f = w_o \left(k_2 w_4 + f_2 - \frac{v_1^2 - v_3^2}{2g}\right)$ at both full power and standby conditions,

then $Q = \frac{K}{w_o k_1}$ = a constant at those two powers.

Discussion

Mr. I. G. Bowen said the authors had set out to give an account of the Navy's attempt to make a push-button system for Naval boilers, and he wished to compliment them on the lucidity of the paper and especially on the thorough testing of the equipment. Controls systems were often very well designed and manufactured but the dynamic response of the system could only be studied in its entirety, and the data published on that score would surely be of great value to those firms specializing in control equipment.

The paper covered work on three aspects of control, namely, steam pressure control, control of water level and air/fuel ratio control, and he proposed to make a few comments on the last of the three problems and also to pose a few questions for the authors.

Shortly after the last War the Navy had begun to examine the possibility of wide range burners. Prior to that, simple pressure jet atomizers were employed and load variation on the boiler was effected largely through change in the number of atomizers in use. Not only was an atomizer turned off on reducing load, but also its air supply. That system was just about perfect from the combustion engineer's standpoint. Each burner worked at virtually a single load and its performance could be optimized. The turn down obtainable was almost unlimited. But could such a system be made automatic and remotely controlled? There were a number of arguments against such a system: in the first place, each burner and local air damper had to have an actuator; secondly, at change of load a change of combustion gas volume occurred and that could produce some trouble especially at the lower loads, and thirdly, each burner would have to be protected from radiation when not firing, i.e. by retraction or purging or by use of a tip shut-off self cooling type of atomizer.

The case for, hinged largely on first class combustion, avoidance of smoke in the stack and excellent CO_2 control over wide range.

Those were results not to be despised and he mentioned the possibility to illustrate the fact that other burner designs might provide a better end result if control was not the only criterion.

After trying many types of wide range pressure jet atomizers the Navy seemed to favour the spill type and he agreed with that assessment. Having decided that, they then attempted to produce a combustion system in which all burners were in use at the same time with the range being obtained by use of the spill in the case of the atomizer and throttling in the case of the combustion air. Such a system sacrificed good combustion at low load for ease of control, as might be seen from Fig. 13, where the white and black smoke limits converged.

Assuming for the moment that the choice was the best compromise for a Naval ship, one wondered why such low values of minimum fuel supply pressure were chosen. The authors acknowledged a problem by saying that 250lb./sq. in. was the lowest feasible supply pressure. When one bore in mind that the range of air flow was also 13:1 the minimum value of air pressure was ½in. water gauge or less and at that condition 150lb./hr. of heavy oil had to be atomized and burned with no smoke. Why, therefore, not set the minimum supply pressure, say, at 500lb./sq. in. gauge? Referring to Fig. 3, that would entail the use of a pump capable of supplying about 5,000lb./hr. per burner which was surely better practice than sacrificing combustion efficiency or risking smoke.

In fact why not go the whole hog and control the pump at constant pressure and squeeze the maximum advantage from a spill burner? The reason given in Appendix I he found incomprehensible. There the authors said that the inertia of the pump would be too great. But surely since the pump was already running and oil was incompressible, no question of pump inertia could be involved. On the grounds of running cost one should remember that since the pump was steam driven, pump horsepower was largely recoverable in the boiler in the form of heat. He would therefore suggest that constant pressure control was well worth investigating and should give no greater difficulties than in the execution of the authors' system.

Having said that, it would be churlish not to pay tribute to the authors for the ingenuity of their TBS system. The concept of choosing a burning line along which spill and supply pressures were linearly related, was novel and resulted in great simplification.

It was only fair to point out, however, that at least one practical difficulty remained. Burners choked with dirt from time to time and that would upset the spill to supply pressure ratio as well as cause inequalities of flow. The classic system was to measure oil and air flow and through a controller set the air/fuel ratios according to a predetermined set of values. That system minimized the effects of blockage and perhaps the authors would comment on the point. He also assumed that when an atomizer was out for servicing its air register was dampered? Otherwise draught pressure control, according to the TBS system, would also be suspect.

Captain G. F. A. Trewby, R.N. (Member) congratulated the authors on setting down in a clear and factual manner the problems encountered and the achievements to date with the automatic control of Naval boilers.

He thought it might be helpful if he explained the general background to the work on automatic control of Naval boilers described in the paper.

It was stated in the introduction to the paper that Naval boilers should be capable of remote operation over their full range. That was a military requirement which could be met either by moving the watchkeepers to some remote position and providing them with gauges and remote operating valves, or by arranging for the boilers to be fully automatically controlled.

For a number of reasons it was thought that the right solution was to provide fully automatic control but that, of course, depended upon the development of a thoroughly reliable control system.

In addition to the primary military requirement it was expected that automatic control would bring other important benefits. Firstly, it should enable the number of operating personnel to be reduced, either freeing them for maintenance work or allowing the total complement of the warship to be reduced. Secondly, good automatic control should provide better and more efficient operation of the boilers with avoidance of the human errors and failings of watchkeepers which sometimes occurred in the fatiguing and very trying conditions met with in modern warships. Finally, a most important benefit was the enormous improvement in watchkeeping conditions if the operating personnel could be housed in air conditioned control rooms. Watchkeeping in warship boiler rooms with rapid changes of power continuously taking place was a very trying and fatiguing business. He thought that anyone who had had experience of watchkeeping in warship machinery spaces in the tropics in wartime would realize the enormous improvement in morale and efficiency which would be obtained if the boilers and other machinery of warships could be operated from air conditioned control rooms.

It was too early yet to say definitely how much those additional advantages will be realized; in particular the long term reliability and maintenance requirement of the automatic controls in H.M.S. *Tiger* and other ships must be proved. Results to date are, however, very promising and confidence was felt that automatic boiler control would prove, in Naval ships at least, fully justified quite apart from the purely military requirements.

The developments described in the paper covered a period of about three years. At the start of this period knowledge of the factors affecting automatic control of British Naval boilers under warship operating conditions, was scanty. A good deal had been found out the "hard way" as might be inferred from some of the difficulties in H.M.S. *Tiger* described in the paper. Perhaps it was worth stressing here that H.M.S. *Tiger* was a new ship undergoing acceptance trials of all the machinery and weapons and this did not make it easy to pursue the development of the boiler control system.

However, with the work in H.M.S. *Tiger* and developments ashore at A.F.E.S. it is now felt that a great deal of useful detail knowledge was available to guide future developments.

The development of the control system described was one of increasing complexity. The systems shown in Figs. 12 and 14 combined, were much more complex than that in Fig. 5. The authors rightly stressed the danger of over-complexity by the addition of more and more groups of "black-boxes" to overcome troublesome features. The present system was undesirably complex, but so far, the operators at sea had not complained of this. It was to be hoped that future developments would, if anything, reduce complexity.

The authors might have stressed that while the design of the system was important, so equally, was good engineering without which the most elegantly designed system would not work. They rightly mentioned that excellent designs of instruments, valve operators and positioners, etc., were available. Given a chance, these would do the job. The chance required was complete freedom from dirt, water and oil in the pipe systems and air supply; also good mounting of the elements to avoid damage of all sorts including that from external water and steam. Those, of course, were mainly matters for the shipbuilder.

On the general question of automatic control of warship machinery many people present would remember that this had first been achieved in a limited fashion, some 30 years ago, in the battleship H.M.S. *Centurion.* H.M.S. *Centurion* had been used as a target and was under the wireless control of a destroyer stationed some ten miles away.

One point which he wished to stress was that reading the paper might give the impression that the automatic control system was still in the very early experimental stages and full of trials and tribulations. The fact was that it worked, and it worked well at sea, and he thought that all concerned with the development of automatic control systems for Naval boilers could justly feel proud of their achievements to date. Perhaps the most encouraging aspect of the development was the growing enthusiasm and confidence shown in automatic boiler systems by the ships' staffs at sea, which was exemplified by the fact that in H.M.S. *Tiger* and H.M.S. *Hermes* the ships were manœuvred in and out of harbour entirely on automatic control, and complete full power trials were carried out with the machinery operating on automatic control.

COMMANDER H. E. C. HIMS, O.B.E., R.N. said the authors were to be congratulated on a most interesting account of a design problem that was not simplified in any way by what he considered to be the extreme age of the design of the machinery, the implication being that it did not lend itself to automatic control and could not be altered readily to suit the new requirements.

Having been concerned with very similar problems at Pametrada, he wished to make some remarks on the paper that he hoped would be of general interest. Referring to the air/fuel ratio part of the combustion controls he was interested to note that during the sea trials of H.M.S. *Tiger* the large hysteresis effect in air flow during changes of power was attributed to mechanical backlash in the blower turbine nozzle control valves.

During some similar trials at Pametrada the blower control system, a pneumatic one by Messrs. Bailey Meters, was operated on servo-manual and instrumented from end to end to determine the time lags due to the various links in the chain. There was undoubtedly some backlash in the nozzle control valves and the instrumentation did not separate the consequent time lag from the lag of the blower as a whole, but the backlash was not the whole story. It was found that the response of the control system up to these valves could be measured in times of the order of seconds. The time lag due to the rest of the system—the nozzle control valves and the inertia of the blower, however, mostly the latter, was of the order of tens of seconds. That feature, of course, was desirable up to a point when reducing power but completely undesirable when increasing.

From those trials the conclusion was that automatic control of such a system offered little prospect of success when manœuvring although it was quite all right for slow changes of power. It was decided that the answer lay in the provision of inlet vane control for the blowers, coupled with speed governing of the drive turbines, economy requirements being satisfied by manual control of the governor settings at the commencement of a steady run.

Such an arrangement was provided in due course in a new plant boiler, the size of which could be judged by its output—260,000lb./hr. × 1,200lb./sq. in. gauge × 1,200 deg. F. which was now in the last stages of commissioning, and it had been shown many times to be possible to take full advantage of the flexibility of the boiler by changing the evaporation rate in both directions over some 80 per cent of the range in times of the order of 12 seconds. During those changes, with the inlet vane control on the forced draught supply, there had been perfectly satisfactory results from the combustion controls and not a trace of funnel smoke. One would perhaps not expect white smoke when reducing but the vital point was that there was no black smoke when increasing. In that particular case the fuel system was rather simpler than the one described in the paper. It employed Babcock and Wilcox plunger type burners and, for control purposes, the measure of fuel burned was the pressure in the pipe leading to the burner manifold. A feature of the controls was that they functioned equally well when a burner was added or subtracted from the number alight.

On the subject of feed regulators Pametrada had had considerable experience of feed system instabilities in complete machinery installations under trial, one component often producing a hunt which took a very long time to diagnose and cure and in considering that particular boiler they had realized that there might be the same sort of trouble in the system generally if the feed regulator was subject to violent fluctuations. They had decided to do the best they could to avoid such troubles and, if they did arise, it was thought that there was enough experience available to take care of them. The point was that they were not worried about any possible effects of the feed regulator on the system; the intention was to make the feed regulator suit the boiler. Owing to good design—or possibly to good luck—they had been successful. The latter was probably nearer the mark.

The regulator had been designed on principles originating from one of the later speakers in this discussion, Mr. Morton. Therefore he would not say much about it in detail, but it appeared to overcome what had been observed to be a difficulty in feed regulators. He had observed a number of boilers in the past using two element regulators, steam flow and water level, where the manœuvring rate was limited by the water level and that when increasing power this was to a considerable extent due to the steam flow element operating as soon as the manœuvring valve started to open, thus increasing a water level already high due to ebullition. The reverse was true when reducing power.

To cure that, the inverse derivative of the steam flow had been introduced into the control system, operating only when the steam flow rate was changing. That meant that when the manœuvring valve was opened suddenly the steam flow control tried to open the feed valve but, while the steam rate was changing, the inverse derivative action closed, or tended to close the valve and it had that effect as long as the rate was changing, i.e. roughly over the period during which the manœuvring valve was being adjusted, which corresponded with the temporary increase of ebullition in the steam drum.

Similarly, on reducing power, as the water level fell due to the collapse of steam bubbles, the device tended to open the feed valve wider. So far, with rather limited trials, it had shown as much promise in practice as it did in theory.

Mr. R. H. Paddon Row (Member) said the authors were to be congratulated upon presenting a very interesting paper which indicated that the Royal Navy had decided to discard the wheel spanner and vocal control system in boiler rooms.

It was rather surprising that a positional or "open loop" control was attempted with the type of oil fuel and combustion air systems described. The limitation of that type of control system had been known for a great many years.

From page 106 it could be seen that the problem of closed exhaust pressure variation was still apparent after some 30 odd years of running ragged the nerves of engine room staff! He wondered why such a comparatively simple control and engineering problem had not yet been solved in the Royal Navy.

The control system depicted in Fig. 12 was satisfactory when the control elements did not have excessive lags. It was often necessary where fans or blowers were speed controlled to install very fast derivative action either in the controller or by means of external accelerating relays. Another method already mentioned by a previous speaker was superior, namely the one in which speed control was combined with damper control in the case of fans or speed control combined with discharge valve control in the case of pumps. That system had the disadvantage of being more costly, both in capital and operating costs, and so it had to be used with discretion.

What was termed the "absolute" feed regulator appeared to be no more than a combination of feed flow and water level control. Feed flow by measurement of the depression in a boiler was not an accurate method as the circulation in a boiler was not a constant over time. In addition to that the actual total head that was to be measured was considerably more than when measuring the level in a drum, and therefore to measure a small part of that, for instance to control the water within $\pm \frac{1}{2}$in. level was very much more difficult when there was a big head. A far better method, if it was desired to maintain a constant water weight, would be to use the normal three element control system, with the water level element having an adjustable set point re-set in accordance with feed flow to maintain a constant water weight in the boiler.

The use of a proportional controller sensing superheater outlet pressure was very common and there was no disadvantage in its use so long as the steam pressure variation with load was acceptable. The drop in superheater outlet pressure with load shown in Fig. 22 appeared to be excessive. From a turbine efficiency point of view it would be better to control the superheater outlet pressure so that it was constant or had a falling characteristic with falling load.

One could only agree wholeheartedly with the authors' sentiments expressed in the paragraph headed "Lack of Design Information". Too often a boiler installation was designed and almost built before the instruments and automatic control system was decided upon and then boiler and auxiliary plant modifications became costly.

The authors favoured diaphragm "slaves" or "operators" and it was agreed that that type was compact, and cheaper than power cylinders or rotary operators but they had severe limitations in power available and should be used only for reasonably small valves and dampers.

It was surprising that monitoring of the P.D. across the oil filters was not adopted as that type of instrumentation was an essential for the successful operation of automatic controls as operators had reasonable warning of the beginings of a system disturbance.

In conclusion he would say that simplicity was not the Shangri La of automatic control and the answer to the maintenance problem was to train operators thoroughly so that they could take an intelligent interest in maintaining and setting instruments and controls. It had always seemed to him that the Royal Navy maintained traditionally an unbalanced fear of complication with the exception of routine and that fear was becoming more pronounced with the increased rate of progress elsewhere. The application of single button start-up and loading of very large power stations was on the threshold and practically full automation had been applied to small liquid tube boilers in industrial concerns where failure of a unit might cost something like £8,000 each time it occurred. Those arrangements had proved entirely satisfactory and it seemed that this experience was not drawn upon in arranging the automatic control systems described in the paper.

Mr. A. J. Morton, B.Sc., (Associate Member) said he wished to make a quick comment about the absolute feed regulator. At first sight it rather savoured of black magic in that it seemed to confer upon its owners powers to play tunes on a boiler which ordinary people could not quite manage. It was quite well described in the paper but what was not brought out was the relationship of the regulator to the ordinary old "family favourites" with which they had been playing for years. The essential point was that the level was measured in a static tube connecting the steam space with the water drum, and the question was how was the level in the static tube related to drum level? It was depressed below drum level by an amount dependent, presumably, on steam flow. Therefore what one had was a regulator which responded to boiler drum level minus a function of steam flow. Would it not be possible to get very much the same effect with a conventional two-element regulator suitably set up? The conventional regulator would have the advantage that the level of steam flow action and water level action could be varied independently, but in the other case they were built in. It was a very neat system but he questioned whether it always gave what was wanted. It would be helpful if the authors could give a curve relating depression to boiler load.

Next, the regulator positioned the feed valve more or less direct in the hope that it would give the feed flow required. In dealing with oil fuel systems the authors had pointed out that what was really wanted was an extra loop on the end to take account of valve wear and so on. Why could that not be put on the feed regulator, making an ordinary three-element regulator?

Fig. 21 (a) showed the effect of varying the steam pressure set point. That resulted in throwing the firing rate all over the place but the water level was shown by the bottom curve and it was constant. In the paper that was taken as an indication of the excellence of the regulator, but the catch seemed to be that the steam flow also was constant as shown in the same figure, and if that was so why should the regulator be upset? It rather looked as if it was like the House of Peers in "Iolanthe"—it did nothing in particular and did it very well!

What should really be looked for in that figure was the reason why the steam flow was so constant when the firing rate was not, and it was a very interesting demonstration of the effectiveness of the boiler reserve. The boiler was probably steaming by itself, supplying a fixed steam demand, and if the firing rate was wrong there would be a rise or fall in pressure, but to a first approximation the steam flow would be constant, and this appeared to be well borne out by the figure. The effect of boiler reserve was always to maintain the total steam output of the boiler plant very nearly equal to the consumption of the main and auxiliary machinery, the pressure meanwhile rising or falling according to whether the firing rate was excessive or insufficient. To provide a real test for a feed regulator, it was necessary to alter the steam flow, and to do this with a single boiler system the setting of the turbine throttle must be altered.

When two or more boilers were steaming in parallel, their total steam output was still governed by the demand from the turbines, but could be redistributed between the boilers by altering their relative firing rates. Thus a change in firing rate on any one boiler would affect the individual steam outputs and hence the water levels of all the boilers, making heavier demands on the feed regulators than in a single boiler system.

Finally there was the question of stability. A sudden inflow of relatively cold feed to a boiler caused the absorption of heat which would otherwise have been available for steam production, and so produced much the same effect as a reduction in firing rate. In a single boiler system this did not matter much, as steam output would be unaffected and there would consequently be no sharp change in water level. If the boiler were in parallel with others, however, its steam output would fall, causing the collapse of submerged steam bubbles and hence a fall in water level. This would cause most regulators to open further and admit more cold feed. If the regulator were too sensitive (i.e. causing too great a change in feed flow for a given change in level), instability and hunting would result, yet the same regulator might be entirely satisfactory on a boiler steaming alone.

Mr. R. Barrington said that he would first like to congratulate the authors on their work and the painstaking way in which it had been written up. As one who had been privileged on occasions to assist at those sea trials, he knew a little of the great and sustained efforts which had gone into that project and could assure them that the developed system was now quite something.

If he had had any criticism it would be that the paper covered only the latter part of a development which had started much earlier, and that the advisability of producing a constant pump curve "by artificial means rather than by relying on nature" had already been suggested long before those trials had shown it to be essential.

The success of the control system depended upon the ability of the atomizers to meter fuel under a wide variety of conditions. That special type of atomizer had been developed during the earlier (or prehistoric?) stage of the project and had been later scaled down to suit the requirements of particular ships.

It had been designed to work with F.F.O. at a burning viscosity of 15 centistokes and with the following desirable requirements in mind:

1) The spilled fuel must at all times be in a fit condition to return to the input of the pump.

   Every effort was made to prevent aeration of the spill by direct entrainment at the base of the air core, and by the provision of a reverse swirler to pick up the spill with the minimum of shock and deliver it no longer spinning along the central spill tube, free from released vapour or steam.

2) The atomizer must be unchokable (or at any rate the choke must be in the right place).

   With a simplex atomizer a blockage merely results in reduced output. In the spill system a blockage in the spill return means an increase in sprayed fuel which could rise to the simplex value of the input pressure and be dangerous. The smallest passage was therefore made at the inlet slots where chokage can cause least harm.

3) It should be as viscosity unconscious as possible.

   The working volume of liquid in the atomizer has been cut to a minimum.

4) Manufacturing tolerances must be exceptionally small to enable accurate fuel metering and to avoid interaction between atomizers.

   The problem here is to ensure the matching of twelve atomizers so that the black and white smoke diagram in Fig. 13 shall have the biggest V opening to enable the automatics to work to a clear funnel line giving a reasonable CO_2.

5) Materials should have the highest possible resistance against erosion and chemical corrosion.

He thought it would be clear from Fig. 1 in the paper, how all of those desiderata had been met.

Mr. Ll. Young (Member) said that in this paper the authors had pinpointed a number of fundamental problems which confronted the manufacturer of automatic control apparatus who considered the application of equipment to a new design of boiler or boiler ancillary. The first and foremost of these problems was the practical impossibility of forecasting accurately the control characteristics of newly designed plant.

Although the subscriber was not associated with the main work which was described in the paper, he had for some years been connected with much of the work on other projects and most of the problems experienced in the trials of the plant installed in H.M.S. *Tiger* were in fact foreseen. It was at that time, however, recognized that the versatile nature of automatic control components meant that there was built into the component such means of adjustment that would meet every possible practical requirement. This meant that work could proceed with the knowledge that the re-arrangement of components or site calibration would ensure recognition of the peculiar characteristics of the various parts of the boiler plant. It was only when operational experience on the equipment had been gained, that solutions to a number of the problems became possible and the paper describes the careful work which proved necessary under operational conditions to find the simplest and most efficient manner of applying automatic control to the type of fuel burning equipment at present being used by the Admiralty.

Close control of combustion necessitated the accurate measurement of fuel and air flow. The authors have referred to the problem of ascertaining the quantity of fuel burned by measuring the difference between total flow and spill flow but it was suggested that it was just as important to measure the flow of air to the burner accurately, and a burner register was a notoriously bad measuring device, especially at low loads. Since the flow meters used for fuel oil flow were extremely accurate and consistent devices, it was most probable that air flow measurement by register draught loss would give rise to greater errors than any difference errors from the flow meters. It was interesting, however, to note that spill pressure had been found to be an accurate and consistent function of fuel burnt.

As the paper pointed out, in any automatic system of combustion control a prime requisite was that the rate of change of air flow should be equal to the rate of change of fuel flow. This requirement becomes of still greater importance in the naval boiler where very rapid and wide load variations might be required, using wide range burners. For this reason, variable speed blowers operating in conjunction with a spill system were likely to give rise to problems of control, owing to the difficulty of accelerating relatively heavy machine masses. Some amelioration of conditions will be obtained by the use of an accelerating relay.

One might have expected more emphasis to be placed on the maintenance of combustion efficiency, which appeared to be dependent on the permanency of a number of variables over a very wide range of operation. It might be considered fortunate that in the present instance a number of local closed loops loosely connected into a control system gave as results a state of combustion efficiency which was poised between black smoke and white smoke.

While the argument that the end justified the means was appreciated, it was sad that proportional control of superheater outlet pressure, which must have as many limitations as advantages, should have been selected. It meant in effect that there was one control setting only for any given boiler arrangement and that the pressure "programme" was dependent on plant design.

The authors referred to the difficulties of dealing with the response with a reduced number of boilers, and the lifting of safety valves on load change. Those, of course, were problems that had been met and dealt with elsewhere, the former being one that was to be found on every land based boiler. In both instances, however, the solution meant the fitting of more equipment and it was questionable whether it was not more realistic to instruct the watchkeeper in the use of a limited degree of automatic control equipment.

The "absolute" water level control system gave impressive results during load changes and had the merit of simplicity.

The authors implied that this system attempted to achieve a constant water weight in the boiler. It would, however, seem that as the ebullition rate changed the water level would vary widely, while constant water weight was being maintained. The calculations on page 115 would moreover indicate that factors other than water weight were involved. Could the authors give details of the range of water level variation as seen in the gauge glass? Since such variations were due to "swell", it was difficult to imagine how the type of control system could affect the momentary change in level due to variation in ebullition.

The hydrostatic measurement of the water content of a boiler, whether by conventional or absolute means, would be subject to errors due to the "attitude" of the vessel. These errors could be corrected but lead to complications. In the three element system referred to in the paper, such correction was unlikely to prove necessary since level had a relatively slow effect. With the "absolute" system the response to level errors must be fast and the system might need compensation for vessel "attitude" (pitch and roll). Such compensation would inevitably render the system relatively less sensitive to transient movements of water in the drum, thereby militating against good control.

It was not considered to be good practice to limit control action settings by means other than the plant dynamic response characteristics. In the present instance the proportional band of the level controller was determined by the necessity to meet the requirements of a "programmed" water level. This must inevitably limit system performance and affect the ability of the system to accept variation or defect in the response of auxiliaries. In the three element control system referred to the control action settings were determined entirely by the requirements of plant performance.

The authors summarized their findings under the heading of "Application of Lessons Learned". The experienced control engineer would agree with most of these conclusions. However, most would hesitate to choose a "fail" condition which was likely to lead to the wrecking of a turbine. It would generally be considered far preferable to deal with the loss of a few boiler tubes or even a boiler. The subscriber would suggest that a fail "set" condition was likely to be preferable since in most cases a continuance of steady conditions was likely to be required. This condition, with suitable warning to the watchkeeper would give time for emergency action to be taken. It was most unlikely that in the event of a choice being made to "fail" to either extreme of travel, that conditions would always be such as to make this a "safe" condition. However, there was at least one manufacturer of automatic feed water control systems who fitted a mechanical standby system which took over automatically should the basic system fail.

In their conclusions the authors suggested that a fully automatic wide range system using self-actuating control was by no means impossible. While nobody would be so rash as to deny the possibility of such a proposition, given unlimited finances, it was doubtful at the present moment whether what were still considered fundamental features of control devices could be realized in self-actuating mechanisms without heavy development expenses and high component cost, due to a limited market. The subscriber preferred to suggest that the best interests of the Admiralty would be served by using equipment corresponding as closely as possible to commercial designs, thereby taking advantage of the modern production methods which became possible owing to a much wider market availability.

In conclusion, the authors were to be congratulated upon their freshness and originality of approach. To the engineer working continually on automatic controls, one of the greatest difficulties was to approach a problem with an open mind and to avoid doing something by a particular method merely because it had been done that way in the past.

Commander R. B. Cooper, M.B.E., R.N. said the authors were to be congratulated. They had done a magnificent job in producing the paper, but in his opinion the most important part was how they had taken a particular ship operating under particular conditions with a particular type of boiler, already set down for them, and had then made it work automatically, which really brought him to the point that all equipment, if there was going to be automatic plant, should be designed from the word "go" and should include the burners, the boilers and the automatic equipment. He hoped that was fully appreciated. In order to bring that out a little more clearly he wished to ask the authors one or two questions about things which he did not think were quite clear in the paper.

For instance, in Fig. 13, it could be seen that there was a square law coming down very close to the five burners black smoke limit. Of course, it was known that the draught loss from a burner varied on the square law proportion of the output, but if full power was taken, combustion assumed to be very good and to have a small proportion of excess air, it would then be found that the draught loss on that particular curve was 18 inches or 16 inches. If they were going to turn down by nine they would get 16/80 which, of course, came to something like 8^5 and instead of that they were coming down to a draught loss of about 1½in. Therefore it was a matter of quite simple calculation, if the air/fuel ratio at full power was taken as being pretty well near the optimum, it was easy to calculate the air/fuel ratio at a 9th power, and it would be seen to be of the order of 75:1. He found that interesting because in most burners the air/fuel ratio was about 350 per cent—or perhaps he ought to say that most burners with just over 200 per cent excess air produced white smoke. Looking at the curve the difference in the black smoke curve with five and three burners could be seen. How did the authors explain that?

Was that air increased through the other burners which were not on, or through the boiler? He believed it was the former because referring back to Fig. 6 it would be seen there —and he believed that it could be assumed from the paper that the same atomizer was being used in the ship as was used at Haslar—that the draught loss through that boiler at full power was only 13in., and on the black smoke curve it came down to a figure of about ¾in. Therefore there was obviously some difference in the draught loss of that burner due to the way in which it was employed. Of course the same applied on the white smoke end because dependent upon how the air was introduced so a different white smoke point would be obtained.

It had been his experience that immediately air pressure went below 1½in. the burner lost stability and there was a tendency for the flame to become rather ragged. Also the type of boiler which the burner was applied to could make a difference because if only a small quantity of fuel was put through the burner and the air pressure could not be reduced because one was on the black smoke point, there was a tendency to blow fuel all over the boiler with, of course, rather adverse results. Had the authors steamed that boiler under conditions of low output from the burners, because the results given were taken from a boiler with a lot of brickwork in it, and when turned down that brickwork was still hot. He could see no reference to turning down on the boiler at Haslar, which was probably water walled, and therefore it would be possible to have a reasonably cool furnace on turn down.

With regard to manœuvring, he believed the general condition of manœuvring with all burners on was not intended unless there was no operator in the boiler room. He would like to know whether, when they were actually manœuvring on automatic control, they also had someone in the boiler room putting the burners on and off.

He could see that the authors had been faced with all the trouble which occurred in commerce, and of course every variable output burner suffered those troubles. In commerce there was the plunger burner which was difficult to get synchronized; they also had the steam atomized and air atomized burner, which suffered from the amount of power used, and again in commerce there was the return flow burner which he believed suffered from hunt trouble. There, of course, the problem was rather simplified by being able to use turbo machinery. Had the authors considered what might happen if ordinary electric machinery in an a.c. ship was used?

He would also be pleased to hear more from the authors about the arrangements which they had for measuring fuel as accurately as was specified in the paper.

A consideration of the boiler pressure emphasized the need for designing the whole system in one, because it looked to him as though the boiler pressure in that particular vessel was such that to be really safe it would be necessary to reduce the final steam pressure therefore reducing the output of the ship, otherwise there would be a risk of the safety valves going. Would not the authors support him in saying that a boiler and its pressure and all the other factors should be designed together? The same point applied to feed.

Finally, he would be interested to know whether the authors had any experience of efficiencies of boilers when being fed by hand and being fed automatically. The little experience which he had on the testing of boilers showed that a higher efficiency, of the order of about two per cent could be got when hand feeding a boiler as compared with the best automatic system which was available at that time, during the War. That had seemed to him to be a very odd thing.

MR. S. R. TYLER said the lecturers had found it necessary to control both inlet and spill pressure simultaneously in order

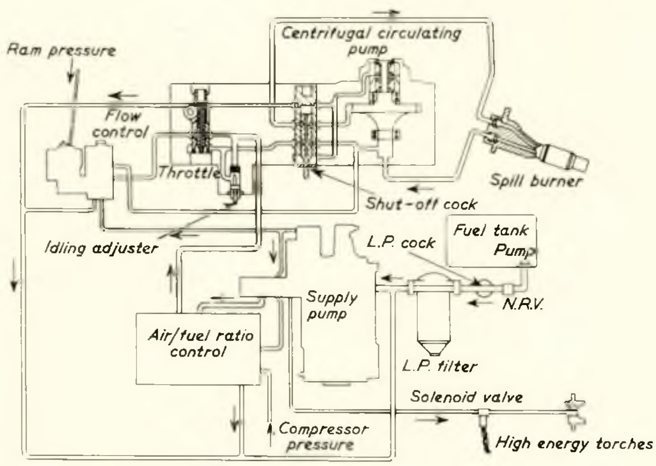


FIG. 25

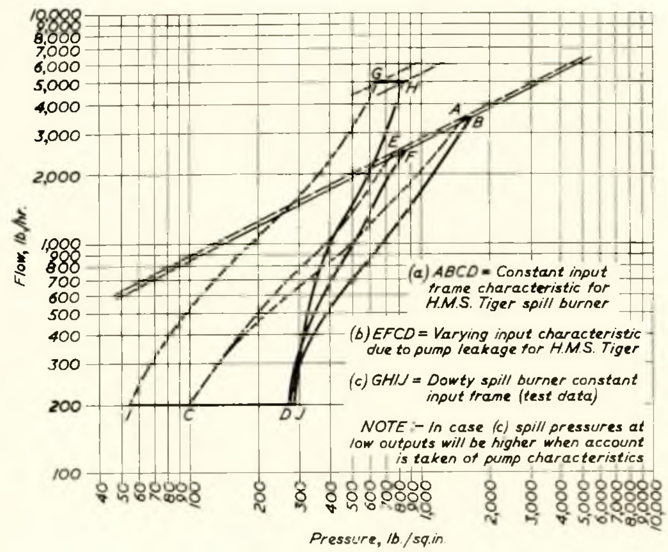


FIG. 26

to achieve the desired flow range with the particular spill nozzle, and a previous speaker had also mentioned that the problem necessitated accurate calibration, speed control, and consistency of performance of fuel pumps. It was noteworthy that a similar wide range of flow was required in the aero gas turbine and Fig. 25 showed how this was achieved by the use of a centrifugal fuel pump. If this system were applied to the marine application it would be possible to remove a burner without having to alter the pressure calibration and accurate metering could be achieved, irrespective of pump speed variations, by simultaneously changing the fuel flow prior to feeding into a centrifugal circulating pump or pumps. With such a system the flow ratio would be dependent upon the type of spill burner employed and Fig. 26 showed the relative characteristics of the nozzle described in the paper when compared with the Dowty nozzle. It would be noted that, without resorting to pressure regulation of any kind, a flow ratio of 25 : 1 could be achieved. Avoidance of this regulation control simplified the equipment and in consequence could improve the overall reliability, and transitional difficulties of introducing standby pumps no longer arose.

REAR-ADMIRAL SIR ALEX MCGLASHAN, K.B.E., C.B., D.S.O. said that as one who had been out of touch with the detailed design of Naval Boilers for some years he had been fascinated by the paper. That fascination had been somewhat tinged with nostalgia. Some people present might remember that just before the last War two German merchant ships were put into service running to the Far East, which had automatic boiler control. As a result a great deal was said in the technical press about them and the Admiralty boiler designers were under severe pressure at that time to adopt automatic boiler control. For a good many of the technical reasons which had been brought out by the authors in their paper, and also because it was not a very suitable time, while re-arming, to indulge in that sort of work, it was decided that it should not be done for the time being.

Having said that, he wished to cast one or two doubts on some of the statements which had been made, rather more from the military point of view than any other. In the first place, in one of the concluding paragraphs of the paper the authors stated that the developments made possible by the initial trials had produced an extremely flexible boiler plant, it now being possible to increase from standby load to full power and achieve the new steady conditions within a period of a few seconds, without hazard to the boiler and with the boiler room untended. He would first like to ask, was that really necessary? If there was increased flexibility was it possible to do anything with it? Would the turbines nowadays take it? Was the automatic control of super-heat temperature sufficiently good to protect the turbines under those violent changes of conditions?

The second question he wished to put to the authors related to manning the boiler room. There was a good deal of talk both ways about that but he could not see any clear recommendation by the authors, and that really did not surprise him. However, the authors had said that the use of fully automatic control with untended boiler rooms demanded a new approach, and they had themselves mentioned some of the things which could go wrong in a boiler room, such as choked filters, but they had not mentioned such things as joints blowing. One of the earlier speakers in the discussion had mentioned the military advantage of having no watch-keeper in the boiler room but he wondered if that was wholly justified.

Lastly, he would suggest to the authors that it might help the industry to help them in the future if they had said a little more about why they had discarded other forms of automatic control and banked wholly on a pneumatic system.

Mr. P. L. Cowper-Coles congratulated the authors on their paper and the very hard work which must have gone into achieving these results and compiling them in such excellent form.

He wished to ask the authors to elaborate upon the change-over from local to remote control with particular reference to the advantages of a system in which local handwheel control was transferred directly to remote automatic control, as compared with a system having local handwheel control, local servo manual control, and remote automatic and/or servo control. Those features bore a direct relationship to the advantages of rotary as compared with diaphragm type operators; the former offering very great advantages in ease of change-over from handwheel control and in providing centralized floor plate handwheel operation.

Commander R. M. Inches, R.N. said that in his present job he was concerned with everything relating to boilers in H.M. ships and therefore he was fairly closely concerned with the question of automatic boiler control. However his interest in general had been in the overall behaviour rather than in details, and his remarks would be based accordingly.

In the first place, he was very satisfied with the present stage of the automatic controls for operating Naval boilers. He included the word "Naval" because the problems were peculiar (and he thought the authors had not brought this out). Anything additional that was proposed for inclusion in a warship was going to be fought against. One had to justify fully every single additional item that was put in a ship, for very good reasons: it was additional weight, it took up additional space and it was an additional maintenance load. None of those could be afforded. The trend in warships, particularly since the last War, had been to cut down the machinery space to the absolute bone and beyond. That had been brought out in a paper presented to the Institute sometime previously, but he wished to reiterate that when considering the Naval approach to engineering in all its aspects that was very vital, and it was an aspect which other people fortunately could neglect. Therefore the automatic equipment had had to be restricted as far as possible. Within those terms he thought it worked very well.

It had been produced at the same time—if anything later than—some other complex equipment, namely wide range combustion equipment. There the authors had to some extent made the point, but in his opinion not clearly enough, that to the Navy "wide range" meant something which to the automatic control people first of all meant something impossible. They had laughed when the Navy had said that it would be necessary to achieve a 15:1 turndown. They had helped to achieve it in the end but there was no question of looking round and finding something ready-made, and it was to the authors' great credit that they had taken a vital part in that development. They had been assisted in that by the third member of TBS—Mr. Strong—who had done a lot of the analytical work, the analyses of systems, and so on, which also had to be associated in it. Just when this analysis was done, before or after, was a matter of luck. If it had to be done after it usually cost more but the information could be used later, as the authors had mentioned.

Reference had been made to the fact that it was difficult to suit a control system to an existing plant. In his view, that ought to be remembered very carefully because, if it was not, there was the certainty of a disappointment with the performance of the controls initially. He knew a number of cases where that disappointment had led to the dropping of automatic control. It was very sad but it was inevitable if the thing was to be expected to work first time on an *ad hoc* approach.

He thought the authors had not made the point that the part of their paper relating to feed control was on a somewhat different basis from that relating to combustion control. The absolute feed regulator was, in his view, much more of an experimental device than the remainder of the equipment talked about in the paper. He wished to mention that briefly because the authors' statement did not make it clear and several of the previous speakers had brought out the point that it actually was not proved. The behaviour of that piece of equipment at sea could not be predicted and therefore it did not entirely fit into the picture that automatic controls could completely take charge of steaming a ship, even when manœuvring. That statement therefore did not apply to the absolute feed regulator at present, although they were hoping and working to bring it about, mainly for the reason of simplicity.

A point of detail which the authors had mentioned but which he believed needed more emphasis was the necessity for clean oil-free air in control systems. That was one of the very big obstacles to trouble-free operation, and a rather surprising one, that had been encountered. It had been found that control systems as a family had an almost unequalled ability to find oil in air which was not supposed to contain any. That ability should be applied to a better cause than creating chaos in a control system, but they had not found one yet! There was no doubt that unless clean oil-free air could be guaranteed, disappointment as regards reliability of any pneumatic control system was certain.

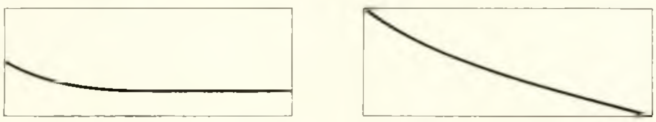
Finally, the authors' combustion air flow control used burner register draught loss as a measure. That was very neat and with a constant opening register there was no problem. However, efficiency of combustion over wide ranges of burner output would be assisted by being able to change the effective size of the throttle. That was going to remove the standard nozzle, and he would be interested to know whether the authors had any thoughts on how to then meter the air flow.

Mr. E. G. Hutchings, B.Sc. (Member) expressed the view that the paper was particularly timely when already in the United States of America there were merchant ships in which full automation had been experimented with, not only for the boiler room but the engine room as well, and he did not think it would be very long before that was seen in Europe—in fact investigations were already going on.

It was a little unfortunate that the majority of the problems which the authors had come up against were ones associated mainly with Naval applications. For example, the very wide range burner which had been developed—and it was a very wide range burner, he had seen it himself do well over 20:1 without any great difficulty—was probably not of great interest to the merchant field, due to its high cost and the high power consumption of the pumps, and there were one or two quite useful wide range atomizers on the market at the present time which had been in use for many years and which could be used quite simply on an automatic control system.

With regard to the absolute feed regulator the main reason for its development was the fact that the blowers were steam driven and not electrically driven, so that the exhaust pressure had a material effect on the automatic control. He thought that the feed regulator was a very interesting piece of equipment which had quite a lot to recommend it, and he could not agree that it was merely a three-element regulator put another way. The trouble with it was that its use was rather restricted. It had already been said that there was a very long arm on the meter element, and what happened when the ship rolled? His own opinion was that there would be the effect of a falling water level, which could be very serious. (Subsequent discussion which he has had with the authors reveals that the effect of a vessel rolling is by no means as serious as he at first thought.)

The other thing was that the regulator had been designed and proved to work in association with a stationary boiler with a not unusual but a rather special type of drum intervals, and in answer to one of the questions which had already been raised, the Y/H ratio, which was in effect the water weight against load, was in the form shown (Fig. 27(a)) and over the majority of its range it was a horizontal straight line. In the average boiler the figure was more curved (Fig. 27(b)) and if



(a) (b)

Fig. 27

one put the absolute controller on a boiler with the more normal Y/H ratio he did not think it would work.

There was some interesting formulæ given at the back of the paper, and there was a factor f_2, a friction loss between points (1) and (3), and it had been suggested that that was the factor which caused the apparent change in boiler load. Actually he rather doubted that and thought it was probably due more to the effect of the variation in the area of the risers, because the position where the water level was changing was actually in the steam drum and not in the tubes.

He wondered whether the authors had considered the use of electric instead of pneumatic controls. If full automation was wanted probably a better system could be devised, with perhaps, pneumatic operation of the individual valves but electric transmission of the impulses.

In conclusion, he thought the paper was so interesting that it would be useful to the industry as a whole if the Admiralty could find it in their hearts to enable somebody to write a complete book on what had been done, in a lot more detail.

Mr. G. J. Gollin said that the designed turndown range for this burner was from 2,500lb./hr. to 150lb./hr., i.e. 16·66 : 1. Using a fixed air register and varying the pressure at its inlet, it would be expected that the ratio of the air pressure at full load to that at the minimum load to be the square of 16·66, i.e. 277 : 1. Looking at Fig. 6 it would appear that in order to avoid white smoke the pressure must operate between 13·5in. W.G. and 1in. W.G., so that the volumetric turndown of the air was only 3·6 : 1. It was assumed that at full load the burner worked at 13 per cent CO_2, that was 20 per cent excess air, a turn down of 3·6 : 1 implied the admission of something like 455 per cent excess air. Apparently the black smoke limit was achieved with an air pressure turndown of 27 : 1 and with this too it would mean operating with 280 per cent excess air. It followed that although the system would appear to be much more flexible than those normally used for industrial purposes, the combustion efficiency at the minimum end of the scale must be rather poor. It would be illuminating if the authors could have provided CO_2 figures associated with various parts of the hysteresis curve shown in Fig. 6. Perhaps this rather low combustion efficiency at the low end of the range had the equivalent effect of increasing the turndown range from 17 : 1 to about 20 : 1.

It would be suspected that the shift in the black smoke line with the change from 5 to 3 burners was in some measure associated with the air leakage through the idle registers. In a modern boiler there might be an appreciable difference in the combustion chamber pressure according to whether 5 or 3 burners were in operation. It would be interesting to know what error would be caused by variations in combustion chamber pressure if it was assumed that the air supply to a register depended solely on the upstream air pressure.

Commander L. D. Dymoke, R.N. (Member) said his excuse for speaking was that after the captains and the kings had departed he was more or less left in the boiler room hoping that the fire would not sink. He thought the paper gave the impression that the gear did not work very well and that they would do better later on, but in fact from the practical operational point of view it worked exceedingly well. Furthermore, it was liked by all who had come into contact with it, although they had had no contact with automatic controls before. They had worked up to operating it from hand controls because they had had a good deal to do with actually commissioning it, and had been left on their own.

Two or three speakers had suggested that the controls should be electric, but that was rubbish (with due respect to the people who made electric controls), because sufficient people who understood enough about electric "black-boxery" were not available to operate the gear. It was possible to take one of the pneumatic controls to pieces without ever having seen a pamphlet about it. It was necessary only to know what it was trying to do and with average intelligence it was possible to deduce how it was supposed to do it from the pieces in front of one, and therefore what was wrong with it. Coupled with this was the fact that on occasions the thermometer read 118 deg. on the wet bulb.

Mention had been made of the difficulties of the narrow smoke-free band. They were always supposed to manœuvre with all the burners on but they had found that it looked better in Grand Harbour, Malta, if they came down to 5/6 burners per boiler. It raised the smoke-free point just a little. Normally they steamed all the time with all the burners on.

Although steaming in "auto" they had men down in the boiler room—because they were in the Navy! It was very expensive if it all blew up, and in any case the men had to be trained and to keep the place clean. The chaps were kept down there all the time, except when the fall-out conditions were being simulated that the lash-up was designed for; because with great respect it was a lash-up and was not designed from scratch. Anyway, those men down there were not taking on and off burners. They had manœuvred out of harbour on several occasions in remote control. In addition they had steamed out of Portland Harbour with the machinery spaces unmanned. He personally thought that was a very good test of the gear.

He had referred to the burners being cleaned, but they only cleaned them because they were in the Navy and it said in the book that they had got to be cleaned. It was ridiculous, because when they were taken apart they were as clean as a whistle, and there was a hiss of breath when the remark was made that it had only got a 32 "thou" passage. The thing which had wrecked the old simplex burners was a chap stuffing a pipe cleaner into them.

The derivative action in the blower control was put in after the pen traces had been taken in H.M.S. *Tiger*. It had ironed out the worst effects of the speed drop in the blowers and after that it had been possible to manœuvre quite satisfactorily. As one worked up so the manœuvres tended to become more violent because the Admiral was watching, and that kind of thing, so it really was very satisfactory, and the chaps stood back from the boiler control panel and never touched anything at all.

The most dramatic thing that had ever happened was in connexion with the seizure of two blower control valves. It was a dreadful situation because, of course, the fuel input had already increased with the increasing demands from the engines, the combustion quality was falling away, and unless the people in the machinery control room were very quick and realized what was happening, the most dramatic results followed.

One point posed by the automatic and remote control was the difficulty of diagnosis in a hurry. Picture being in a boiler room, particularly the after boiler room (where one could move 3ft. in at least three directions) and one suddenly felt the boilers pulsating. In the old days one wound up the fan hand wheel and hoped for the best, but there were more things which could now be wrong. It was all very well to say there was no need to worry about it, that it should be well maintained, that if it had proper maintenance it would not go wrong. That gear required less maintenance than any other gear, whether comparable or not as a system, had ever done before; but now and again a little bit of dirt got in, or more often particularly the lash-up controls which it was controlling gave trouble, and when that happened it was necessary to think much more quickly. He had raised his eyebrows somewhat when "an unbalanced fear of complication" had been mentioned: whether or not it was unbalanced, it was jolly real.

He was personally a little unhappy about the "absolute" boiler feed regulator and would like to suggest to the authors that in fact the controls which were organizing the combustion should be made sufficiently powerful to cope with swings in the boiler water level, although he was unable to make any quick, natty suggestions as to how it should be done.

Finally, they had done a great deal of unmanned operation. Furthermore not only with the boiler rooms and the engine rooms unmanned but completely closed down and with no ventilation whatever. That gave rise to several very real problems, the most outstanding one of all being that the boiler water level was not really known because there did not exist as yet a reliable remote-reading boiler water level indicator. It was a very unpleasant experience, trying to steam boilers remotely without knowing the water level exactly. In addition, it was impossible to nip in to the boiler room because of the very great heat. It was necessary to open the ventilation flaps and then turn on the gauge glass and have a look to see what the boiler water level was. If somebody could develop a reliable remote boiler water level indicator they would have his blessing!

Commander M. Richards, R.N. said that of the various criteria for the design of marine machinery the most important were reliability and a close second (certainly for warship machinery) was ease of operation. The first criterion seemed to have been well satisfied by the control system described in the paper and which had been installed in H.M.S. *Lion*. There had been some embarrassing moments, but those had been due to purely mechanical shortcomings and ships' officers were confident that they would not recur now that minor modifications and lubrication schedule revisions had been carried out.

Unfortunately the second criterion had not been well met. The control equipment had been developed so fast, that each progressive improvement had resulted in additional equipment having to be fitted into an already congested boiler room wherever space could be found. As a result the control panels at present fitted were far from satisfactory.

What seemed to be needed now was for someone to specify the outside of the control panel without altering the setup of the control system basically. In the particular case of H.M.S. *Lion*, they could operate in any one of four levels of control, *viz.*, auto, servo, semi-manual and manual. Those terms were of local use only and should be explained.

Auto, meant that the whole business of keeping steady boiler pressure and appropriate fuel temperature was done by the control mechanisms, the only thing left to the human operator being the selection of desired boiler pressure. Servo meant that the human operator observed the boiler pressure and adjusted the burner output and corresponding forced draught by moving a single knob to adjust the boiler pressure as required. Semi-manual meant that control air was available for operating the fuel temperature control and for regulating steam to the fuel pumps through a single knob control, but that spill valve opening and the setting of the forced draught blower steam valve must be regulated directly by hand as required. Manual meant that all the boiler control operations must be executed directly by hand, i.e. fuel pump governed speed selection, steam to fuel heaters, fuel spill valve, forced draught blower steam valve. It would not have been at all difficult to arrange a panel by which each one of those four states could be selected in turn by the movement of a master control. As it was, only one change could be so easily accomplished, *viz.*, from auto to servo. To go from servo to semi-manual required the operation of two levers and the closure of a valve, not located directly on the panel. In the early days of the commission the comparative difficulty of moving from one state to another had been a great nuisance.

It was very desirable that a control system should be self-revealing, i.e. that it should indicate to the observer when it was failing to function correctly. The system which had been described in the paper did this quite well, and if a revised control panel as had been suggested above was produced, the telltale duplex gauges that indicated signal and response, could be located on it, whereas at present they were located on two separate panels.

This general exercise in the application of human engineering principles should be extended to cover a further requirement of marine engineering equipment, *viz.*, easy accessibility for maintenance. The control panels fitted in H.M.S. *Tiger* class ships were quite good from that viewpoint but could be much improved by turning them "inside out" and "back to front". By "inside out" he meant that the various control instruments, such as controllers, transmitters, relays, etc., should be nearest to hand and pipework should be arranged so as to impede their adjustment and removal as little as possible. By "back to front" he meant that access to instruments should be from the front of the control panel and not from the back. By this means one could site panels hard up against bulkheads or backing on to other equipment without the necessity for leaving 18in. or so access space for maintenance behind the panel.

A particularly convenient setup would be a panel arranged in the form of a cabinet with a hinged front. This front could carry gauges and selector/control valves. The fixed back part of the cabinet could contain controllers, etc., of the plug-in type. Access to all instruments would then be available by opening the hinged part.

Finally, he wished to set Commander Dymoke's mind at rest. There was in existence a somewhat superior version of the remote water level reading indicators which were installed in H.M.S. *Tiger*, and they really did work. He had absolute confidence in them and he had personally managed to control the water level of two boilers from the machinery control room, using those indicators in conjunction with the remote manual feed control levers. The facility for remote feeding in H.M.S. *Lion* was also greatly improved over that in H.M.S. *Tiger* by the use of radically different feed check valves, designed for easy control of feed.

The sophisticated types of automatic feed regulator discussed in the paper and by contributors present might be desirable or even necessary with advanced boilers whose working water capacity was low compared with feed flow rate, but with the 3 drum boilers fitted in H.M.S. *Lion* (as in the majority of H.M. ships), experience with the Weir "Robot" regulators fitted had been so happy that nothing more complicated was needed.

Commander N. K. Bowers, R.N. said that he would like to discuss the use of the "fail safe" criterion in designing control systems.

As the authors had implied, for many items there could be no such thing as "failing safe" and they had quoted the outstanding example of the feed regulator. Furthermore, even if the feed regulator were designed to fail shut and at the same time designed to cut off the fuel supply to the burners, it still could not be said to fail safe because the loss of steam might well endanger the ship. Consequently one began to wonder whether the "fail safe" criterion was of much use to the designer of marine engine control gear.

He therefore wished to suggest that another principle should be adopted which could, in fact be applied to control systems generally, and that was the principle of "fail gradually".

This principle could perhaps be illustrated by taking the conventional float operated feed regulator and considering the effect of redesigning it to fail gradually. Suppose that instead of a single float, three floats were fitted in such a fashion that each float gave a percentage of the control signal to the regulator valve. Failure of one of them would result in an abnormally high or low level in the boiler and this would be noticed by the watchkeeper in the control room who could take action while the level was still in the glass. How would that affect the chances of disaster?

It would be assumed that the average rate of float failure was one per year and that all times were equally likely for failure, i.e. the likelihood of failure was not altered by flashing up, shutting down, boiler cleaning, high salinity in the boiler or any other factors. It would also be assumed that disaster would occur five minutes after failure in the case of a regulator fitted with one float, and five minutes after the third float failure in the case of a regulator with three floats.

Bearing the above assumptions in mind, the case of the regulator with the single float could first be considered. If the watchkeeper failed to observe the gauge glass for just five minutes during the steaming year, the odds against a disaster occurring during that five minutes were roughly 100,000 to one against. If on the other hand, the watchkeeper only looked at the gauge glass once an hour then the chance of disaster occurring during a steaming year were 11 to one on.

The case was now considered in which three floats would have to fail before disaster occurred. If the watchkeeper looked at the gauge glass only once an hour the odds that the disaster would occur during a full steaming year instead of being 11 to one on, were now in round figures, 100,000,000 to one against. Even if the watchkeeper looked at the glass only once a watch the odds against disaster with the three float arrangement occurring during the steaming year were still 5,000,000 to one against. With the single float device, however, the odds of disaster occurring during the steaming year if the gauge glass were only observed once a watch were 47 to one on.

The principle involved here was simply that the deliberate introduction of redundant components throughout a control system could improve reliability out of all proportion to the amount of extra equipment required.

A redundant element was not the same as a standby element. If a redundant element failed the system would continue to function but not as well as it did before and this would be observed by watchkeepers who would have time to make the necessary repairs or adjustments before disaster occurred. The trouble with standby elements was that there was nothing to tell the watchkeeper that they would work when required. Many of those present would have met auxiliary feed pumps that tripped on starting or electric lubricating oil pumps that failed to cut in when required.

It might not be necessary to have redundancy in every loop. Some loops could be made mutually redundant and it would be unnecessary, for example, to duplicate the steam flow signal in the three element regulator since the float element would do the whole job although not as well. It was of course, important that no more redundant parts should be fitted than were necessary to give the required odds against disaster.

Every additional element meant an increase of cost and an increased maintenance load. Fortunately the maintenance required by pneumatic control equipment was very slight and in comparison with some other items of marine machinery could almost be neglected. Nevertheless it was essential that the system be considered as a whole. Quite obviously it was pointless to fit several redundant elements to insure against disaster and then to feed them all with a common supply of compressed air.

Using a system with a suitable number of redundant components the odds against disaster might be even higher than they appeared from simple probability theory, since the fact that the system was functioning badly would also be noticed on gauges which had little direct connexion with the item causing the trouble, and other watchkeepers would be alerted.

The principle of introducing redundant components qualified the authors' contention that the fewer the working parts the greater the reliability. It did not contradict it because a system with a suitable number of redundant components could in fact replace watchkeepers whose complexity, cost, weight and space must be taken into account when comparing one system with another.

Correspondence

MR. R. BURROWS wished to endorse the authors' views that the control system should be designed concurrently with the plant to be controlled, and would join with them in challenging the statement that "any system could be controlled". If it was understood that by "control" it meant that the control should be within prescribed limits for a given rate and magnitude of load variation, then the plant itself must be designed with this in view. In fact, it was true to say that the quality of control which was ultimately obtained would be more closely associated with the design of the plant than the particular choice of control loops, since the limit was ultimately imposed by the inertia of the items of equipment being controlled.

It would be interesting to know whether the superheat temperature was maintained within satisfactory limits during the tests described. Given satisfactory temperature sensing apparatus, the response of the control loop was so rapid that it might be ignored, whilst the design of superheater and its associated de-superheater or by-pass system, together with the arrangement of the superheater in the boiler, would greatly affect the quality of control which could be achieved.

Whenever possible, therefore, the required performance of the boiler under the most severe conditions of manœuvring should be predicted during the design stages, to enable the best type of plant to be determined.

His company had recently tested a package watertube boiler (13,000lb./hr. evaporation at 180lb./sq. in. gauge) under conditions of rapid load changes, and whilst under automatic feed and combustion control. The results of these tests might be of some interest.

The load was increased from 30 to 100 per cent M.C.R. in five seconds, during which time combustion was held within acceptable limits and the water level surged a maximum of 3in. above normal.

In this unit combustion control was achieved by means of an air/fuel ratio controller operating the spill valve on a single spill type pressure atomizing burner and the forced draught fan damper. In this case it was obviously easier to obtain a rapid response of the combustion air, since inertia of the fan and its driving unit was not involved. However, feed water control was achieved by means of a single element level control only.

LIEUTENANT COMMANDER E. D. HOBSON, M.B.E., R.N. (Member) in a written contribution desired to congratulate the authors on the presentation of their most informative account of the evolution and co-operative development of wide range, spill burner type combustion equipment, and the ingenious and relatively simple automatice control equipment which had rendered it eminently suitable for warship applications.

He understood that certain features of these systems were the subject of British and/or foreign patents and it occurred to him that it would be valuable to those likely to be interested in the application of those developments if the authors made reference to this aspect.

He observed that, in the Naval systems described, steam turbines were used to drive the two-stage supply and service pumps and that this factor, together with the combined characteristics of turbine and pump selected, permitted controlled speed and consequently output variation to be effected by variation of the steam supply to the turbine. It occurred to him that many potential users of spill type combustion equipment would prefer to adopt constant speed a.c. motor drive for the pumps and he requested the authors to confirm the practicability of this method of drive and to suggest means of achieving the desired controlled variation in pump output over the range of burner operation, particularly when changing over from one pumping unit to another.

He was interested to note that automatic control of fuel temperature had been satisfactory from the outset and could confidently be left to the automatic equipment. This was presumed to be primarily attributable to the fact that the heater oil throughput at the lower fractions of burner output was always in excess of that which takes place at maximum fuel consumption, thereby not only permitting the simplest form of such control equipment but also overcoming the necessity in the past for frequent cleaning of oil fuel heaters in which the flow corresponded with burner output.

He observed that the developments described had rendered it possible for H.M.S. *Tiger* to increase from standby load to full power or *vice versa* with all burners in use and the boiler room unattended. He would be very interested to hear if readings of percentage CO_2 were obtained after settled conditions were achieved at various fractions of main shaft power over this wide range, as an indication of the standard of combustion achieved. He noted that the TBS system could cope with reduced numbers of burners provided the register draught loss trim control was applied. He would be interested to learn, if available, the improvements accruing at reduced powers from a reduction in the number of burners in use, should operational conditions permit an appropriate delay in the availability of full power.

A further point arose in connexion with Fig. 8. Deterioration of pump performance was assumed to require a pump characteristic G.T. to obtain full burner output. While it was appreciated that this was no more than an example of the conditions which might arise in such circumstances, it did, in fact, constitute a deterioration of volumetric efficiency at full burner output of over 50 per cent. In other words, the pump speed would require to be increased accordingly as would the power input. Nevertheless, unless special provision for these requirements was incorporated in the design of pump and prime mover, it would appear that the ability of the control system to compensate for such deterioration would be nullified. It would thus appear that the maximum permissible level of pump deterioration would require to be settled and allowed for in the design stages and unless relatively small would impose an unacceptable penalty in the design.

LIEUTENANT COMMANDER C. H. HUMBY, R.N. (Member) had been closely associated with the development described and with sea trials of recent Naval ships using wide range combustion systems. He wished to confine his remarks to the spill system and to associated control problems.

The modulation of a bank of registers of Admiralty type through a wide range of output at maximum efficiency was dependent on careful matching of air and oil supplies. This had been clearly demonstrated during trials in H.M.S. *Tiger* and later ships. In one boiler room where air supplies to individual registers were not uniform the average CO_2 content for a clear funnel in the uptake gases was about 13 per cent, whereas in the other boiler room where the air supply was more uniform, the figure was above 14 per cent. In another ship fitted with the same combustion equipment but having a still more uniform air distribution the average for all boilers over a 6 hr. trial was above 15 per cent.

As the output of a spill atomizer, operating in a furnace under near atmospheric conditions, was dependent on the differences between the supply and spill pressures the maintenance of these at the required values was most important. The spill atomizer was fairly sensitive to small variations in pressure in either the supply or spill lines but this was not of significance if all burners altered in the same manner. In order to obtain the lowest air/fuel ratios it was thus of importance to ensure that the burners were correctly matched. This required a high degree of precision in manufacture coupled with careful maintenance. The design of the fuel system should ensure that pressure drops from the manifolds to the atomizers were uniform and could not be changed by mistakes in installation or by poor maintenance or operation.

In order to avoid smoke and obtain efficient trouble-free combustion any form of control had to be set up using the onset of smoke as a guide. One or two registers having a significantly higher oil output or less air supply when related to the remainder could raise the effective average air/fuel ratio at which the equipment had to be adjusted and thus lead to considerable loss of boiler efficiency.

Authors' Reply

The authors would like to express their gratitude to all those who took part in the discussion, whether verbally or in written contributions. In view of the large number of contributions to the discussion, they hoped that it would not offend if they answered under subject headings rather than by giving separate answers. Some of the questions asked were answered by later contributors to the discussion and the authors had not covered the ground again.

The Objectives

The authors would like to thank Captain Trewby and Commander Inches for their useful surveys of the Admiralty background to automatic controls. It was, of course, outside their terms of reference to make any recommendations either within Admiralty or in this paper regarding the desirability of untended boiler rooms. This requirement, as described by Captain Trewby, was military and had to be met. The authors did however, maintain that if it was a requirement to use a ship occasionally with untended boiler rooms, it would be folly to attempt to achieve this with a control system which was only used on those few occasions. Nothing in a ship deteriorated so quickly as an unused machine or system. It must, however, be accepted that if automatic controls were used exclusively deterioration of watchkeepers would occur. It was appreciated by the Admiralty that fully automatic light-up, running and shut-down of the boiler installation was now possible, but there was no military requirement for this at present and the additional complications were not justified in ships which were already very complicated. The Admiralty certainly had no unbalanced fear of complication; far from it, for their ships were much more complicated in general than were those of the Merchant Service.

Combustion Quality

Many contributors commented on the poor combustion quality which occurred at low burned fuel rates. In this respect the conclusions of Mr. Gollin and Commander Cooper were quite correct and Fig. 28 showed the order of air/fuel ratio figures which obtain in H.M.S. *Tiger*. This inevitably bad combustion at low fuel rates was something which was suffered in order to achieve the military objective. Combustion quality at high fuel rates was as good or better than that which could be obtained in other designs of register. Under auxiliary steaming conditions and for steady peace-time cruising at sea one would reduce the number of burners in use and this would improve the combustion and the boiler room efficiency as a whole. It was partly to enable the number of burners in use to be reduced when required that the TBS system was devised.

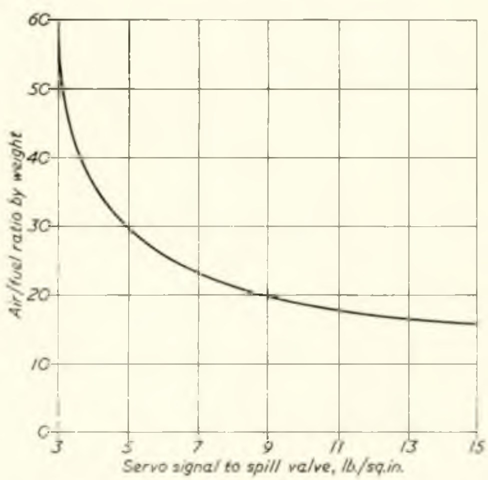


FIG. 28—*Approximate air/fuel ratios in H.M.S.* Tiger

Several contributors also mentioned the effect of idle burners. Fig. 29 showed the relationship between register draught loss and air flow on a register which, although not of the same size as that used in H.M.S. *Tiger*, was similar in arrangement; and it would be seen that the leakage through the closed register was approximately one seventh of that through the open register. This accounted for the very much reduced register draught loss which was required on one burner when achieving a burned fuel rate of 2,500lb./hr. per burner as compared with that necessary when all burners were in use, since the air entering the furnace through the closed registers was used for combustion by virtue of the recirculatory pattern of the gases within the furnace. This leakage was designed into the register for cooling purposes.

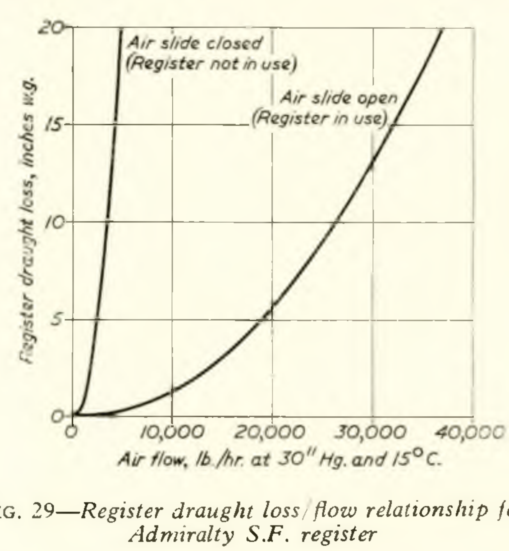


FIG. 29—*Register draught loss/flow relationship for Admiralty S.F. register*

It was not possible to answer quantitatively Mr. Gollin's question regarding the influence of furnace pressure, because the A.F.E.S. test boiler was subjected to varying furnace pressure depending upon the superheater damper position and the latter depended in turn upon the air/fuel ratio. However, the table below showed what might be expected, assuming

(i) that furnace pressure at full power is, say, 7in. and varies as the square of boiler output, and

(ii) that the shut registers pass 1/7th of the quantity

of those in use for the same register draught loss, and
(iii) the same air/fuel ratio obtains in each case

No. of burners in use	Output per burner lb./hr.	Per cent boiler output	Furnace press in W.G.	Required register draught loss W.G.	Required air box press
5	2,500	100	7	13	20
3	2,500	60	2·5	10·8	13·3

Thus air box pressure, if used as a parameter for control purposes, would result in more excess air on reduced number of burners than did the use of register draught loss.

The high quality of combustion achieved at high fuel rates had been due in large measure to the performance of the atomizers designed by Mr. Barrington. With this standard of atomizer, it had always been possible to deduce with confidence the burned flow rate, provided the supply and spill pressures at the atomizers had been known. It was of particular advantage in automatic installations to have large clearances in the atomizers in order that blockages did not, in general, occur. Cleaning, as Commander Dymoke remarked, was almost a thing of the past. The authors, however, agreed with Lieutenant Commander Humby's remarks regarding the matching of air and fuel in individual registers. The paper, due to lack of space, might have given the impression that no combustion troubles were met. Although not numerous, the problems which were encountered were symptomatically baffling and Lieutenant Commander Humby's painstaking work in diagnosing and finally solving them could well form the subject of a separate paper.

It was agreed with Commander Cooper that the design of boiler in which given combustion equipment was used could considerably influence the quality of combustion. In particular, the amount of brickwork might have a significant effect. Results now being obtained upon a new boiler design with very little brickwork did however indicate that the Admiralty suspended flame register was giving very good results despite this lack of brickwork, and it was believed that the small droplet size used contributed to this success. There was undoubtedly room for much research in this field, and it was hoped that register design could be improved sufficiently to reduce the excess air required at maximum turn-down to a reasonable figure, possibly by means of some form of variable area device.

In answer to Mr. Tyler, the authors made the point in their Appendix I that this particular Lucas atomizer could not be used with constant differential between supply and spill pressure. It so happened that, by virtue of the configuration of typical spill atomizer calibration curves, constant differential between supply and spill pressure roughly corresponded to constant total flow per burner. The authors would prefer to run an atomizer under conditions of constant differential since this would ensure that burners could be brought in and out of action without affecting the other burners in the installation. If flow per installation is controlled, either directly or indirectly (e.g. by using the characteristic of a centrifugal circulating pump), then inevitably if a burner was taken out of use the others would shift to a different characteristic. Furthermore, in a large installation the use of a constant differential pressure across the circulating pump would not necessarily result in constant differential across the atomizers.

Fuel and Air Systems

Although 250lb./sq. in. was probably the pressure at which the droplet size from the particular atomizers used was getting undesirably large, Admiralty experience so far was that the cone angle of spray and the mixing of the air with the fuel in the register were the major problems and imposed the limit on maximum turn-down. The investigation of precisely what features did limit the possible turn-down would however be continued. If constant supply pressure were to be used, one would unfortunately have to accept an even larger variation in cone angle with output than with the present system. There was the further difficulty that with very large turn-downs, as Mr. Bowen pointed out, the pump horsepower was converted into heat. This might not, however, be recoverable in the boiler as it might be necessary to cool the spilled oil to avoid cavitation of the service pump. With a constant pressure system, it was of course necessary to run the pump at vastly varying speeds and this introduced an inertia problem since the pump should be accelerated and decelerated. With the existing system, it was fortunate that the pump ran at sensibly constant speed and thus only the oil and the steam supplied to the pump must be accelerated.

In reply to Mr. Paddon-Row, the filter pressure drop was measured in all ships but it had not so far been incorporated into automatic control systems as a safety device. In fact, the system of supply and spill pressure control adopted was independent of the pressure drop across the furnace fuel oil filters so long as the pump could still manage to get fuel through them.

It was agreed with Mr. Hobson that in the design stage, it should be agreed what maximum permissible level of plant deterioration should be legislated for. At the same time, it was emphasized that the example he picked from the paper, in referring to Fig. 8, did not necessarily relate to deterioration in the pump; the steepening characteristic could be produced by many external causes, some of which were listed in the paragraph in the paper headed "Selection of the Correct Pump Speed". It was important in all installations that the size of the auxiliary machinery and the power of the auxiliaries be kept to a minimum. It was particularly important that this be so in systems which were designed for automatic operation, since the size of the auxiliary and the power absorbed by that auxiliary could influence the speed of response which could be achieved. Even an over size control valve could be a serious matter for a control system working over a wide range. It was therefore of particular importance in new installations, particularly where high fuel pump pressures and high air pressures were involved, that the margins be trimmed to the minimum possible necessary for deterioration in service.

It had been found to date that the Admiralty suspended flame register, being manufactured to fairly close tolerances, could effectively be used as an orifice and did not appreciably deteriorate in service.

In reply to Commander Inches, if a variable area register were produced it would be necessary to programme both register draught loss and register area with fuel flow per register. Purely from a control point of view, this should present no difficulty, but problems might arise in ensuring that the blower was maintained on a stable part of its characteristic under all conditions of operation.

Auto-Control

Several contributors asked about the use of electrically driven auxiliaries. Dealing first with the fuel pump, the authors saw no objection provided infinitely variable speed was available in the case of positive displacement pumps. This was difficult to achieve with a.c. and for this reason they felt that the use of a constant speed V.S.G. type pump might be preferable, achieving the required variations in output by means of the swash plate control. The authors believed that it was impracticable to use a constant speed positive displacement type of pump and to bypass surplus oil back to suction, since the bypass valve would be required to have a range which was far in excess of any which could be provided by a normal control valve and would also be required to meter very accurately over its whole range. It should be noted here that such a relief valve would have to deal not only with normal spilled flow but also with the excess flow which was available when reduced numbers of burners were in use. Thus the range over which it would have to operate was liable to be very large indeed.

In the case of blowers for use with very wide range combustion equipment, there was no doubt that a constant speed blower was out of the question. The problem of designing the blower to achieve stability was severe enough without using dampers or vanes and thereby aggravating the problem. Dampering inevitably meant that the blower was operating nearer its surge line than it would otherwise need to do. It was agreed of course, that damper control had the advantage of being easily designed for very rapid response, but to avoid surge problems the dampers should be of the bypass type. Naval experience, however, suggested that adequate response rates could be achieved with the use of variable speed blowers. It should be noted in connexion with the blower control system that the accelerating relay shown in Fig. 14 was included merely to overcome the unsatisfactory characteristic of the blower steam control valve. It was not a necessary fitting in a properly designed system and, in fact, was not fitted in new Naval designs.

There was no doubt that the size of blower used could play an important part in the installation. If it was over size, it would not only reduce the overall plant efficiency, but might also adversely affect the response of the control system, and for this reason great care should be taken in preparation of a specification for the blower. At the same time, it was of course realized that there was nothing more distressing than finding that a ship would not achieve her designed full power because the blower was too small. This whole problem was one which was worthy of further consideration.

Answering Mr. Paddon-Row's point regarding steam pressure control, the authors felt that for Naval boilers the use of a system which controlled the superheater outlet pressure constant was basically unsound. Such a system entailed a change in steam drum pressure with changes in load. Using constant superheater outlet pressure it was not only necessary to keep the fuel flow in step with steam flow, but to provide a temporary change in fuel input to compensate for the change in enthalpy of the steam water mixture in the drum which occurred with load. From the boiler point of view, therefore, the authors preferred to control the steam drum pressure constant; for stability reasons however, it was not practicable to control it within the close limits required using proportional action only in the steam drum pressure controller. Integral and derivative actions were normally provided in this controller to eliminate proportional offset, but in applications where rapid manœuvring was a requirement, the integral action could not be made sufficiently fast to eliminate the proportional offset while actually manœuvring. Thus they believed it preferable to control steam drum pressure by using the superheater pressure drop to offset the proportional droop of a superheater outlet pressure controller. The authors agreed with Mr. Paddon-Row that a superheater outlet pressure arranged to fall with reducing load would be ideal for plant efficiency. Efficiency of the plant, however, was not an over-riding consideration in Naval installations and when manœuvring rapidly there was no doubt that it was preferable to maintain a high superheater outlet pressure. On the other hand, when steady steaming under peace-time conditions, or when auxiliary steaming, it was perfectly possible to reduce the set point of the steam pressure controller to any desired value.

Some speakers had asked whether control systems other than pneumatic had been considered for Naval use. In fact, both electric and oil operated systems were considered, but pneumatic systems were selected because it was felt that they best met the Naval requirements for shock and vibration resistance, resistance to high temperature, resistance to high humidity and so on. In addition, a very wide range of pneumatic control equipment was already available commercially. As Mr. Young pointed out, their versatility enabled system design faults to be remedied during the early operational days of those systems. Self-acting controls were also considered but were not adopted because they needed to be expressly designed for a given job. The authors believed, however, that now the difficulties of the wide range spill system were reasonably well understood, it should be possible to design and make a reasonably cheap and reliable self-acting system.

To answer Mr. Cowper-Coles, the Admiralty had followed industry in incorporating servo manual control of the system in addition to automatic control. In some cases, servo manual control had been provided from two watchkeeping positions. This had led, in the authors' views, to unnecessary complications and they would have preferred to see a system designed for fully automatic control with hand control as the only alternative. The simplicity and natural fast action of diaphragm operators led the authors to prefer them for use in automatic systems. It was agreed with Mr. Cowper-Coles, however, that the rotary operator had advantages over the diaphragm type in respect of ease of change-over from hand to auto control. Much of the difficulty in changing from hand to auto control resulted from the use of integral action in the controller and this was one of the reasons why the authors had suggested in the paper that integral action should be eliminated where possible. In addition, the authors felt that if the system was as simple as possible it would be reliable and some difficulty in change-over arrangements therefore acceptable since such arrangements would only rarely be needed. For pure remote operation, for which there was a great demand in Naval vessels, the rotary operator won hands down.

In reply to Mr. Paddon-Row, the authors would like to state that the exhaust pressure in H.M.S. *Tiger* was, in fact, controlled and was very satisfactory. The variations in exhaust pressure in the boiler room were due to the fact that the sensing point for the exhaust pressure control system was sited near the evaporating plant in the engine room at some distance from the boiler room; hence it was necessary to accept variation of exhaust pressure in the boiler room due to pressure drops in the exhaust lines. Reference to a Mollier chart would show that a small change in exhaust pressure could have a large effect upon the power of the impulse type auxiliary turbine used. As stated in the paper, the major difficulty with this system was that the condenser dump valves were designed for steady steaming conditions and could not take the entire output of exhaust steam when the feed heater, which under steady conditions was the major user of the exhaust steam, was not condensing steam due to the feed regulator being closed.

In answer to Admiral MacGlashan, the authors mentioned in the paper that valve operators should always be capable of responding faster than the most rapid signal change. This principle also applied to the design of the system as a whole. The system must be capable of responding faster than any disturbance injected into it, e.g. the available rate of change of fuel input to the boilers must be as great or greater than the maximum rate of change of steam offtake.

Mr. Burrows asked about the control of superheat temperature. In the case of H.M.S. *Tiger,* the boiler was designed with a natural superheat characteristic and no control was therefore fitted. In the case of the A.F.E.S. test boiler automatic control by means of dampers was incorporated and no difficulties had been experienced with this system.

While the authors agreed with Commander Bowers in principle, they were not sure that in practice his proposals would be as satisfactory as he suggested. There was no doubt that watchkeepers in ships with automatic control were a little frightened at the complexity of the gear and the authors felt that anything that could be done to simplify the gear was worthwhile. For this reason they would not favour the introduction of additional equipment. If trouble was experienced through lack of reliability of the simple systems now being fitted, it would then be desirable to consider whether Commander Bower's proposals should be implemented.

In connexion with Mr. Hutchings' remarks on full automation, it was interesting to note that the stage had now been reached in the Royal Navy where a closed loop based on the main propeller shafting revolutions per minute could easily be fitted, the control for these merely being on the bridge in the form of a small handle which pointed to the desired revolutions. The rest of the system, including the engines and boilers, could be completely automatic. In conclusion, it was worthy of note that the Americans were currently considering whether unmanned ships could successfully steam across the Atlantic, merely being met with a crew near the harbour entrance.

In reply to Commander Richards' remarks regarding the layout of the combustion control, it was interesting to consider the time scale of the development. H.M.S. *Tiger* first went to sea in January 1959 and the defects in the system were realized then. After she was commissioned there was a period allotted during May 1959 to investigate the deficiencies a little further, and the spill control system which was fitted in H.M.S. *Hermes* not only had to be developed but to be produced and installed before the autumn of 1959. Thus the modifications could not necessarily be made in the best way and it had been impossible to give the attention to detailed design which Commander Richards regretted.

Feed Regulation

The whole question of feed regulation hinged on what was required of the regulator. If a constant apparent water level as indicated by a gauge glass was demanded, regardless of any undesirable effects on the systems as a whole, this could most conveniently be achieved by a conventional single element regulator. The object of the absolute regulator was to ensure that the requirements of the system as a whole were met, and to achieve this emphasis was placed upon the maintenance of a constant weight of water in the boiler as opposed to the constant volume which was achieved by conventional regulators. The single element level controller, in attempting to achieve constant volume in the boiler, might produce conditions which result in instability. This had necessitated the development of the two and three element types. The authors believed that the approach of industry in developing these two and three element regulators was inherently sound, but they considered that the absolute regulator offered a simpler solution to the problem. On the other hand, a feed regulator such as Commander Hims and Mr. Morton proposed would be even more prone to instability than the single element regulator.

The authors feared that, in attempting to explain the essential differences between the performance of the absolute regulator and that of a single element level controller, they may have failed adequately to describe the extremely simple basic conception of the absolute regulator. It was a normal feed regulator in which the lower sensing point was taken from the bottom of the water drum instead of the bottom of the steam drum. Any conventional feed regulator such as a float operated type or a thermo-hydraulic variety could be arranged to function in this way. For this reason, the authors could not understand why Mr. Llewellyn Young and Mr. Hutchings should consider the absolute feed regulator more susceptible to roll and pitch than other types. Moreover, feed regulators employing differential pressure devices were already performing satisfactorily at sea.

In reply to Mr. Hutchings, the authors would expect the absolute feed regulator to be more easily applied to a boiler having the second depression characteristic drawn by him, since a more linear rise in level with load would be obtained. They would also expect improved stability. The authors had attempted in Appendix II to show that $(P_3 - P_1)$ was not a simple function of water weight in the boiler but was also affected by the velocity and friction effects of steam/water mixture circulating in the boiler. The way in which the absolute feed regulator might be adjusted to offset the effects of friction and velocity was also explained. The authors realized that Appendix II was an over simplification of the problem but included it merely to amplify their verbal description of the absolute regulator.

It had been suggested that the absolute feed regulator was an open loop control of apparent water level. This it certainly was but at the same time it was a closed loop control of $(P_3 - P_1)$ which, it was shown, was a function of the weight of water in the boiler.

The authors were of the opinion that the weight of water in the boiler might be more important than the water level indicated in the gauge glass. They believed that, in general, provided the water level was held within the limits of the gauge glass under all conditions the requirements of the boiler were met, and that a feed regulator which achieved this and at the same time maintained a stable and consistent control of feed flow had advantages over one which attempted to maintain a constant indicated level.

The authors agreed in general with Mr. Morton's suggestion that it was bad practice to use a controller in which the requirements for programming the apparent water level determined the proportional band setting of that controller. The use of such bad practice might lead to errors, but if these errors were so small as to be acceptable then the authors felt that the practice was justified if it resulted in a worthwhile simplification. In applying the absolute regulator to particular installations, the errors might be unacceptably large and in this case resort to two or three element systems would be necessary.

Mr. Morton suggested that the fact that the absolute feed regulator maintained a closer control on water level under conditions of rapid manœuvring than normal feed controllers was due to some form of black magic. The authors would not care to discount this possibility, but believed that it was more likely to be due to normal hydraulic and thermodynamic phenomena. They were still gathering evidence but believed that under conditions of very rapid increase of boiler output, the temporary fall in steam drum pressure might, in certain types of boiler, result in boiling taking place in the downcomers unless feed flow was maintained roughly equal to steam flow. Boiling off in the downcomers could conceivably result in a large surge of apparent water level. In boilers fitted with simple level controllers, the feed valve would shut thereby further aggravating the situation.

In the paper, the authors avoided reference to the other advantages of a feed regulator which maintained approximately constant water weight in the boiler, since this was outside the scope of the paper. It appeared from the discussion that brief mention of those might be helpful. Those advantages derived from the fact that feed flow would equal steam flow and surges of water in and out of the main feed tank on change of power were avoided. Evidence was available that the majority of oxygen entering the feed system gained access by way of the main feed tank. A de-aerator was frequently necessary if the oxygen content of the feed entering the boiler was to be maintained within acceptable limits. If surges were avoided, water need only flow from the feed tank to make up losses from the system. The main feed tank was therefore no longer required within the feed circuit and the feed system became truly closed.

In answer to Commander Cooper, the authors had no evidence of changes in boiler efficiency with change of feeding arrangements.

Mr. Morton asked why, since the water level remained constant during the trial which was recorded in Fig. 21(a), the regulator should be upset. The absolute regulator did not, however, control water level but a function of water weight. This function contained terms dependent upon circulation ratio (see Appendix II) and it was necessary to prove that these terms did not overide the water weight term during violent changes of boiler pressure and firing rate. During this trial the regulator, in doing nothing, showed its merit in that, like the noble statesmen in the House of Peers, "it did not itch to interfere with matters which it did not understand". The real test for the feed regulator called for by Mr. Morton was considered adequately covered by the trial record shown in Fig. 20(b).

Conclusion

In reply to Mr. Hobson, the authors felt it inappropriate in a paper of this nature to include a list of relevant patents, quite apart from the obvious danger that they might offend by accidental omissions.

The authors, in setting down a factual account of development work had hoped also to provoke a useful discussion. The number of contributors was most gratifying and the authors hoped that the contributors had enjoyed the argument as much as they had.

Annual Dinner

The Fifty-eighth Annual Dinner of the Institute was held at Grosvenor House, Park Lane, London, W.1, on Friday, 10th March 1961 and was attended by 1,270 members and guests.

The President, The Right Honourable The Viscount Simon, C.M.G., was in the Chair.

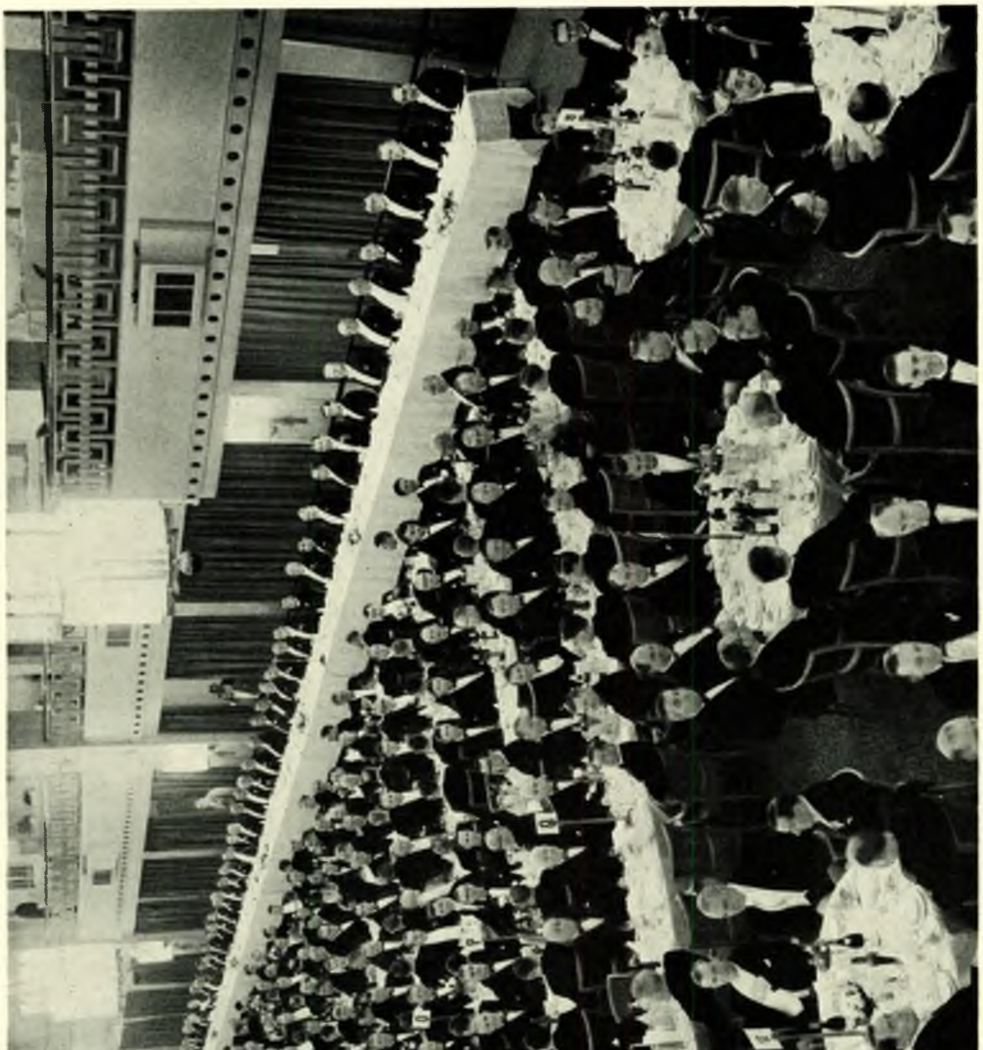
The official guests included: His Excellency Monsieur Gunnar Hagglof, The Swedish Ambassador; His Excellency Señor Don Victor Santa Cruz, The Chilean Ambassador; The Right Honourable The Lord Carrington, P.C., K.C.M.G., M.C., The First Lord of the Admiralty; Sir Gilmour Jenkins, K.C.B., K.B.E., M.C., Past President; Sir James Dunnett, K.C.B., C.M.G., Permanent Secretary to the Ministry of Transport; Sir Victor Shepheard, K.C.B., Director, The British Shipbuilding Research Association; Sir James Milne, Chairman, The British Shipbuilding Research Association; Sir Kenneth Pelly, M.C., Chairman Lloyd's Register of Shipping; Colonel T. Eustace Smith, C.B.E., T.D., D.L., President, The Shipbuilding Conference; W. Errington Keville, Esq., C.B.E., President, The Chamber of Shipping; H. A. J. Silley, Esq., C.B.E., Past President; Rear-Admiral N. Gayler, U.S.N., United States Naval Attaché; E. L. Denny, Esq., B.Sc., Past President; C. C. Pounder, Esq., The President-elect; W. R. Harvey, Esq., O.B.E., Chairman of Council; W. G. Agnew, Esq., C.V.O., Clerk of The Privy Council; D. C. Haselgrove, Esq., Under Secretary, Ministry of Transport; Eng. Capt. W. A. Graham, O.B.E., R.N.R. (Honorary Member); Stewart Hogg, Esq., O.B.E., Chairman, Social Events Committee; Commodore J. Plunkett-Cole, R.A.N.; Commodore A. G. Boulton, D.S.C., C.D., R.C.N.; H. N. Pemberton, Esq., Denny Gold Medallist 1960; The Reverend Maurice Dean, B.A., R.N.V.R., The Rector, St. Olave's, Hart Street, London, E.C.3; J. H. Pitchford, Esq., M.A., Vice-President, The Institution of Mechanical Engineers; Captain F. N. F. Johnson, R.N.Z.N.; Captain J. D. Mody, I.N.; John Brown, Esq., President, The Institution of Engineers and Shipbuilders in Scotland; Dr. W. A. Macfarlane, C.B.E., B.A., B.Sc., President, The Institute of Fuel; Commander F. J. R. King, R.N., Acting Captain-Superintendent, H.M.S. *Worcester;* Eng. Cdr. W. R. Sinclair, B.Eng., R.A.N., President, The Institute of Refrigeration; Lieut. G. A. Zaidi, P.N.; J. B. Woodeson, Esq., O.B.E. President, The North East Coast Institution of Engineers and Shipbuilders; W. A. Parker, Esq., President, The Diesel Engineers and Users Association; H. E. Robson, Esq., Assistant Secretary, Ministry of Transport; Lieut. Cdr. (E) P. C. Preston-Whyte, S.A.N.; H. O. A. Scullard, Esq., President, The Society of Consulting Marine Engineers and Ship Surveyors; T. W. D. Abell, Esq., Chairman, The Scottish Section; J. R. Cotterill, Esq., J.P., Immediate Past Chairman, The West Midlands Section; W. E. B. Dainton, Esq., Chairman, The Devon and Cornwall Section; S. H. Dunlop, Esq., Chairman, The North East Coast Section; R. N. Newton, Esq., R.C.N.C., Chairman, The Southern Joint Branch, R.I.N.A. and I.Mar.E.; J. C. Proudfoot, Esq., Chairman, The North Midlands Section; B. Taylor, Esq., B.Sc., Chairman, The Kingston upon Hull and Humber Area Section; D. S. Tod, Esq., Immediate Past Chairman, The Merseyside and North Western Section; Capt. A. D. Duckworth, R.N., Secretary, The Royal Institution of Naval Architects; T. S. Nicol, Esq., Secretary, The North East Coast Institution of Engineers and Shipbuilders; A. P. Quarrell, Esq., Secretary, The Diesel Engineers and Users Association; R. W. Reynolds-Davies, Esq., O.B.E., B.Sc., Secretary, The Institute of Fuel; Victor Wilkins, Esq., F.R.I.B.A.; J. D. C. Stone, Esq., F.C.A.

The Loyal Toasts, proposed by the Chairman, having been honoured, His Excellency Monsieur Gunnar Hagglof (The Swedish Ambassador) proposed the toast of "The Royal and Merchant Navies of the British Commonwealth".

He said: It is indeed a great honour to have been asked to propose the toast of "The Royal and Merchant Navies of the British Commonwealth". I suppose it has happened to all of you that when you have received an honour you sit down and wonder why it has happened to you, and I confess that I have thought about it on this occasion. I have pondered a bit and I have come to a certain conclusion which I am not going to conceal from you. In its long and glorious history the Royal Navy has, I believe, fought in battle almost every navy in the world—from the Dutch and the French, to the Chinese, and the Polynesian, and so on—but it has never fought the Swedish Navy! (*Laughter.*) That is certainly a strange oversight by the British Navy. (*Laughter.*)

I think it is worthwhile looking a little bit closer at it. My country is nowadays known as a country of neutrality and of peace, but it is a fact that in its history Sweden has had centuries of almost uninterrupted warfare, and I think that Sweden has fought every country in Northern Europe, except Finland. That is easy to explain: Finland belonged to Sweden. (*Laughter.*) So there is only one exception and that exception is England, the United Kingdom. That is the only exception. We have a treaty of friendship which was signed and sealed in 1654 and it is still to this very day in full force. (*Hear, hear and applause.*)

We are very proud of this fact, but I should not conceal from you that there have been moments of tension, and even one moment of great danger, when we were saved by the wisdom of a British Admiral. It happened in this way, if I may take you back to the Napoleonic Wars, when Sweden was in a very bad situation, having been attacked by Russia. We lost Finland for ever and then we were threatened by France. Napoleon threatened us with invasion unless we declared war on England. After a great deal of waiting and threats from Napoleon the Swedish Government issued a formal declaration of war, and then everything was dependent on the question whether the British Government, the Admiralty and the Naval Commanders would understand that this declaration was only a formal one. (*Laughter.*) A British fleet of some considerable strength was sent towards Sweden, and when this fleet arrived outside Gothenburg, the big port on the western coast of Sweden, (*Laughter*) they sighted the first Swedish ship. It was a small vessel. Of course, that was rather a tense moment, but the Admiral, in his wisdom, decided to wait. It turned out that the vessel had no guns and was not armed at all. If it was armed it was armed by a very great many invitation cards, addressed to the Admiral and the officers and the men, to come to a reception organized by the City of Gothenburg, and to a dance afterwards. (*Laughter.*) There was a critical moment. The Admiral hesitated, and then he



Annual Dinner, 1961

The Right Honourable The Lord Carrington, P.C., K.C.M.G., M.C. (First Lord of the Admiralty), Sir Gilmour Jenkins, K.C.B., K.B.E., M.C. (Past President) and His Excellency Señor Don Victor Santa Cruz (The Chilean Ambassador)

Sir Kenneth Pelly, M.C. (Chairman, Lloyd's Register of Shipping), The Right Honourable The Viscount Simon, C.M.G. (The President) and Mr. W. R. Harvey, O.B.E. (Chairman of Council) accepted the invitation, and so it came about that the British fleet anchored outside Gothenburg and the officers and men went dancing. According to tradition—and who would try to deny such a pleasant tradition?—it is said that the dancing went on for three nights and three days! And that is the only action in the only war we have had with England. (*Laughter and applause.*)

To my country, as to so many other countries, the Royal Navy has for centuries been one of the main factors in our national life. It is nowadays almost forgotten that Great Britain—in the words of one of your great historians—sought the balance of power in the Baltic almost as assiduously as she sought balance in Western Europe. For more than 200 years the Royal Navy was as familiar with the Baltic as it was with the Mediterranean and later on with the Atlantic and the South Seas. Indeed, as has been observed, the first global armed force in the history of the world has been the Royal Navy, and this fact was at the very basis of the whole nineteenth century, and I think it is of some considerable importance also today.

When we were at school I think we were all sometimes rather irritated by what we had to learn of Latin eloquence and Latin quotations. I remember my own feelings of protest when I was told in Latin: *Navigare necesse est, vivere non est necesse*—To navigate is necessary but it is not to live. I was a boy at the time and, like all Swedish boys, I was rather fond of sailing in sailing ships outside Stockholm, but even then I found this saying rather difficult. If it had been said, "To sail is to live", then I think that every Britisher or Swede, or anybody born at the sea and used to the sea would agree, because to all of us who live near the sea, with the waves in our eyes and in our ears, it is obvious that the sea is our lifeline, and that the Merchant Navy is one of our national necessities.

The British Merchant Navy has been the leader in the establishment of the shipping of the free world, and we smaller shipping nations have followed your Merchant Navy. Today I think it is of the very greatest importance that all the shipping nations are able to co-operate with Great Britain in this utterly important task of establishing really equal and really fair conditions for shipping all over the world. I do think that this is of the very greatest importance, even if it happens all too often that our efforts in this direction are overshadowed by events which receive much more publicity. (*Hear, hear.*)

I hope that this struggle of so many of us in favour of free shipping will continue, in spite of all the difficulties, because this struggle is really of the greatest importance, not only to the shipping nations but to all the nations, and really to all of us who care for international co-operation. (*Applause.*)

The sea is the element which unites the continents, and it is with this idea of union and of co-operation that I beg to propose the toast of "The Royal and Merchant Navies of the British Commonwealth". (*Applause.*)

The Right Honourable The Lord Carrington, P.C., K.C.M.G., M.C. (The First Lord of the Admiralty), responded and proposed the toast of "The Institute of Marine Engineers".

He said: May I first of all, on behalf of all of you present here this evening, thank the Swedish Ambassador for the very witty and generous way in which he has proposed this toast. (*Hear, hear and applause.*) He comes, of course, as he has reminded us, from a country with a very long tradition of seafaring, and not unconnected with the history of this country; and today, as in the past—as those better able to judge than I can vouch for—the Royal Swedish Navy is a formidable modern fighting force. It is all the more flattering, therefore, that the representative of Sweden should have proposed this toast in the terms that he has done, and we are honoured, too, because you, Sir, are the most senior of all diplomatic representatives in London. (*Applause.*)

About five years ago, to my intense surprise and astonishment, I woke up one morning to find myself a diplomat. I know that many of you present may not know what discipline and authority a Doyen of the Diplomatic Corps wields, and with what wisdom and sagacity he controls the affairs of his less experienced colleagues. Although he is exceptionally well fitted to propose this toast, I regret that I am almost totally unqualified to respond to it, except in so far as I have the honour to be the political head of the Royal Navy. To my great shame I did not serve in the Royal Navy during the war, and in fact—I think I ought to say this in a whisper—I was a reguliar soldier! (*Laughter.*) My only excuse is that at the age of 13 I tried to get into the Navy but I was turned down because I was short-sighted. I do not know whether I should have passed the Admiralty interview board. (*Laughter.*) I had not much difficulty in passing the Army interview board. (*Laughter.*) I was only asked two questions. The first one was whether I hunted and fished and shot. The second one—this was about 1937—was who were the people fighting at that time in Palestine. You will be pleased to hear that I got 95 marks out of 100. If I had said that it was the Arabs and Jews and not the Arabs and Egyptians I feel I would have got 100 marks. (*Laughter.*)

Nevertheless, I am faced with the difficult task of responding adequately both for the Royal Navy and for the Merchant Navy. I have had the honour to be First Lord of the Admiralty now for something like eighteen months, and I am beginning to know a little more about the Navy than I did before. To my shame, when I first went to the Admiralty I thought that a White Ensign was a very pale subaltern in the Brigade of Guards. (*Laughter.*) And I am still very conscious of my ignorance, particularly since my only experience of the Royal Navy during the war was when I was from time to time a most unwilling passenger being ferried from one comparatively safe place to another a good deal less agreeable; not, I hasten to say, that it was not done with the greatest friendliness and courtesy.

It is, however, quite clear even to me that the toasts of "The Royal and Merchant Navies" go hand in hand, both in peace and in war. I was very much reminded of this only a day or two ago when I visited the Royal Fleet Auxiliaries at Rosyth. These are the ships of the Navy's merchant fleet which enable it to be mobile and to operate away from its fixed bases, ships which are manned by men of the Merchant Service, replenishment ships and tankers of the fleet train, without which our fleets would not be so versatile or so flexible, and without which they would be seriously handicapped. What is true of the Royal Navy is even truer of the people of this country, whose food and raw materials, whose necessities and whose luxuries are all supplied by the courtesy of the Merchant Navy. (*Hear, hear and applause.*) In return, the Royal Navy gives protection to the merchant fleet, making sure that our ships are free to go about their lawful business on the seas, and coming to the rescue in times of difficulty. In war, when so many merchant seamen put on the uniform of the Royal Navy, the fusion of the two Services is complete.

Now, my Lord Chairman, there are many people who say that, with the advent of the nuclear bomb, all this has changed; that there is no role for the Navy, and that with the first exchange of nuclear bombs—should it ever come to that—there will be nothing left of these islands to supply. There are some, on the other hand, who say that these weapons will never be used, and that if there is a war it will be a conventional one. There are others who say that a limited war is possible. Yet another faction thinks that it is possible to fight a war with small nuclear weapons which will not escalate into a big war. On matters of defence, as those of you who listened to or read the defence debate in the House of Commons last week—or can hear if you come to the House of Lords next week—will realize, there are as many differences of opinion as there are Members of Parliament. (*Laughter.*) Not one of us can say with certainty that he is right. We have got to weigh up what evidence there is and then make up our minds as to the balance of probability. So I think it is the duty of the Royal Navy to be so versatile and so mobile, so technically proficient and so up to date that, together with our allies, we can cope with any likely eventuality. (*Hear, hear.*)

The Merchant Navy can rest assured that, in combination with those allies and with our steadily improving techniques in anti-submarine warfare—in which I believe we are second to none—we shall do our best to ensure our supplies in this country and to protect our merchant ships if ever war should come again.

Now I turn to the second part of my duty, which is to propose the toast of "The Institute of Marine Engineers". I remember once attending a very rowdy debate in the House of Representatives in Canberra. Everybody had become rather upset, and finally one Opposition Member shouted across the floor to a Minister, "The Rt. Hon. gentleman has got the brains of a Merino", and there was uproar and everybody shouted "Withdraw". Nobody could hear himself speak for at least ten minutes, and finally this Opposition Member got very quietly to his feet again and said, "Mr. Speaker, I withdraw. The Rt. Hon. gentleman has not got the brains of a Merino." (*Laughter.*)

I feel in that condition, because I am even more unfitted to propose the second toast than I was to answer the first. To have been a regular soldier is bad enough, but to have had also a classical education makes one feel, to say the least of it, hardly the person to propose this toast. I am one of those unfortunate people to whom the whole of the world open to a scientist and an engineer is closed. To me, unlike the engineer with his magic touch for machinery, the malice of inanimate metal knows no bounds. Although I served in a regiment which was converted to a tank battalion and a great deal of money was spent in teaching me how the horrible thing worked, and although I understood the theory perfectly, as soon as I tried to translate it into practice the carburettors and the coils and the filters and the clutches and the gear boxes all became hostile, malignant and incomprehensible. Luckily for the future of this country, I am becoming very rapidly an anachronism. (*Laughter.*)

I remember that in the days of sail, before the advent of steam, the United States Merchant Fleet was the fastest and the most efficient in the world, and the design of their ships was a very great deal better than ours. It was the ingenuity of our engineers at the time of introduction of steam which brought to this country the dominance which we enjoyed for so long. Perhaps—who knows?—we are on the threshold of another revolution as the first nuclear powered ships are being built. I know that there are a great many who say that it will be a long time before nuclear power is economic. As you know, the possibilities of building a British nuclear powered merchant ship are being considered at this moment by the Ministry of Transport. Whatever may be the outcome of that—and no doubt there are a great many things to be said on both sides—I hope that you and the marine engineering industry will never lose sight of the tremendous possibilities for this country, both commercially and in prestige, of being in the forefront of all new developments. (*Applause.*) We must not forget the advantages which, in their far-sightedness, our ancestors have given to us, and on whose dividends we still live. At a time when the ship and shipbuilding and to a lesser extent the marine engineering industry are having their difficulties, this is perhaps the moment when new ideas, boldness, and taking a risk or two, may be the most rewarding course. (*Hear, hear.*)

I believe that we in the Royal Navy have at any rate in one respect made a bold experiment, this is in the development of a gas turbine to act as a booster with our steam turbine machinery. We in the Navy regard this as a very significant development. It will be a major step forward for the captains of our frigates in the future to be able, at a moment's notice, to switch in an extra 7,000 or 8,000 horsepower. So we are watching its progress, not exactly with trepidation but with some anxiety; so much so that the Controller of the Royal Navy, Admiral Sir Peter Reid, himself attended the sea trials of H.M.S. *Ashanti* the other day. It is the first of our ships to be powered with this machinery. He tells me that there was a good deal of tension as he pressed the button to run up the gas turbine and cut it into the steam turbine—the first time this has ever been done—and I am happy to tell you that all went exactly according to plan. There is much more to be done in the way of testing and trials and we are greatly hoping that the good start made will be maintained. Perhaps I might be allowed to say that I have never ceased to marvel at the ingenuity of the designers who managed to put so much equipment into so small a space, and I have boundless admiration for those who live their lives in engine rooms.

The other day I went on what can only be described as a pot-holing expedition in the Persian Gulf. When I finally got to the bottom I was told by the engineer on duty that the temperature was over 120 deg., and I had absolutely no difficulty in believing him at all. (*Laughter.*) I hasten to add that this was not one of our newer ships.

I know that one of the subjects to which you all give a very great deal of attention is the training of new young engineers. Only last month your President attended the annual prize giving at the Poplar Technical College—an act which shows the interest that your Institute has in the Merchant Navy. The worth of a ship's engineer has always been acknowledged, and it is underlined, I think, by the present grave shortage. I believe that the Merchant Navy engineer is so valuable ashore that once he has gained his certificate it is difficult to get him to sea. On the other hand, the flow is not all one way, and I am told that during the last year 605 out of 772 second class certificates went to former apprentices from the marine engineering or shipbuilding industries. I am sure that this interchange is of great benefit to both sides. (*Applause.*)

Thanks to the efforts of the marine engineering industry the ships of the Royal Navy go faster and further than ever before. Thanks to the marine engineering industry we are able in this country to build merchant ships the performance and capabilities of which are second to none. We who are connected with the Royal and Merchant Navies are grateful to you. We wish you every success, and we will do what we can to help you in your most important task.

I ask you to rise and drink with me the toast of "The Institute of Marine Engineers". (*Applause.*)

The PRESIDENT, in response, said: I have an idea that at this moment there are passing through the minds of the members of the Institute here gathered two thoughts: one, that I should adequately thank Lord Carrington for his speech; and, two, that after I have done that, whatever else I have to say should be as short as possible. (*Laughter.*) You see, I got an immediate response! I shall do my best to satisfy you, but I have duties to perform.

First of all, to thank Lord Carrington, he gave us a most interesting and encouraging speech, and he proposed the health of the Institute in terms which I think we all enjoyed and which we all very greatly appreciate. We do thank him most warmly for sparing part of his busy life to come to this dinner, and then on top of that for giving us that excellent speech. (*Applause.*)

I know that you will be wanting to get on with the real business of the evening, which is to enable people to meet their old friends and chat about old times, and it is for that reason that we do not have at the dinner a formal toast to "The Guests", but I think it would be your wish that I should extend a very warm welcome to all those who have come as our guests this evening. (*Hear, hear.*) It is not my desire to mention them all by name, and although I know that is usually the prelude to having them all mentioned by name, that will not happen today, but I would be failing in my duty if I did not extend a special welcome to His Excellency the Swedish Ambassador, (*applause*) who gave us such a very interesting speech, with a new light on history, I think—at least, it was quite new to me, and quite delightful. He also gave us that wonderful tang of the sea which we all so greatly enjoyed.

We extend also a very warm welcome to His Excellency the Ambassador for Chile, who has honoured us by being our guest this evening. (*Applause.*)

Our other guests are most of them in one way or another connected with the marine engineering business or with shipping, and I am sure that they will not mind if I lump them all together. They are all old friends and we are delighted to see them here. (*Applause.*)

I shall break my rule and mention one in particular, because I think it gives us very great pleasure to have with us again the Chairman of Lloyd's Register, on whom Her Majesty the Queen conferred the honour of Knighthood since we last met him. (*Applause.*)

Now, if our guests will forgive me, on this occasion—which is one of the very few occasions when the President has an opportunity of speaking to a large gathering of members of the Institute—I have a certain amount of domestic business to which I would like to refer. First of all, I think it is not only encouraging, it is really stimulating, to know that in the last year, 1960, we topped the record for new members in the year: 1,325 new members—almost as many as there are sitting in this room tonight. Let me emphasize, for the sake of the guests—I think the members know it—that that is done, of course, without the slightest lowering of the standards we require for membership. It is easy enough to get members if you compel them to come in, but we make it jolly difficult, and yet that is the number who joined last year. The result is that for the first time the total membership of the Institute has topped 14,000. (*Applause.*)

During the year we have had a number of interesting developments. It would be invidious to say which is the most interesting, and I take them in the order they came to my notice. First of all, we have established a Division—that is the broadest grouping—in Canada. The Canadian Division now comprises five sections, stretching from the Atlantic coast, a section based on Ottawa and St. Lawrence, a section based on the Great Lakes, and two sections on the West Coast, one representing the mainland, Vancouver, section and one representing Vancouver Island; so we have five flourishing sections in Canada, grouped together as a Division. They are undoubtedly making tremendous progress there and are adding great strength and authority to the work of the Institute. (*Applause.*)

Then we have a most interesting development. A section has been started on the eastern seaboard of the United States—the first section of membership outside the Commonwealth. This has been started in New York and it has been extended to cover the whole of the eastern seaboard. I had the great pleasure last June of taking lunch with what was then the Interim Committee, and I found them to be as keen a body of engineers as one could find anywhere. Soon after I left, the section was duly launched, and is now on the way to becoming another flourishing child of this Institute. (*Applause.*)

In this country we have also had some developments. A new section has been started in an area which is described as the North Midlands and is based upon Sheffield. It covers, I understand, the West Riding of Yorkshire and the counties of Nottinghamshire and Derbyshire, the West Riding having previously been associated with Kingston upon Hull, but I am told—I hope that this is no reflection on British Railways—that it is easier to get from the West Riding to Sheffield than it is to Kingston upon Hull. The result of the change is, I think, that more members from that area will be able to attend. (*Applause.*)

Speaking of the Midlands, I would like to say that one of the great pleasures of a President (he has many) is being able to go round the country and visit the sections. I was, quite frankly, brought up as a shipowner, thinking of the sea as being the place where marine engineering was carried on, and I was quite surprised when I went to Birmingham, to visit the West Midlands Section, and found such an enormous number of members and such tremendous keenness. I discovered what is probably known to a lot of you but perhaps not to all: that a great deal of marine engineering work is being done in the inland engineering factories. I think it is a matter of great interest to us that the Institute should have these branches now in the West Midlands and in the North Midlands, and the old East Midlands Section which is now to be called the Kingston upon Hull and Humber Area Section.

A new section has also been started in Devon and Cornwall, with headquarters at Plymouth, and although it is only very recent there is every sign that it is going to expand and develop, and I am sure it will.

We do not create these new sections just for the sake of proliferating sections. We create them when there is a sufficient amount of support. Your Council feels—and I am sure they are dead right—that the work of the Institute is far more effective when it is sectionalized in this way, and when the greatest possible number of members can take an active part in attending meetings and discussions on papers. That is the object of creating all these sections, so that many people who could not spare the time to come to London and have a night out—or perhaps their employers could not spare the time!—can meet and read and discuss papers in centres which are more easily accessible to them. (*Applause.*)

In addition to this, our good Secretary has recently made a visit to India and to Pakistan, and we have great developments in view there. That, I am sure, will be welcome news to all of us, because we want to see the influence and the activities of the Institute spread as far and wide as we can. There are already two sections in India, and a section in Karachi, but proposals are on foot to expand the work there and to make certain alterations in the set-up which the Council will discuss in due course.

All this work is spreading the influence and the usefulness of the Institute, and I would like to take this opportunity at this point of telling you all how indebted you ought to be and how indebted I, as your President, am to the Council and to the Secretary for the work that they do. (*Hear, hear and applause.*)

Now we do not want the Institute to stand still, and indeed I am quite sure it is one of the things it will not do, to stand still. You may like me to say a few words about some of the aims for the future. First of all, the Council has planned and arranged to hold an International Conference in the year 1962. It was hoped to have one some little while ago but circumstances were not entirely suitable at that time, and so 1962 has been chosen for an International Conference in London, where we hope to have delegates from all parts of the world interested in marine engineering. I am very happy to tell you that for that year we have been greatly honoured by His Royal Highness Prince Philip, the Duke of Edinburgh, agreeing to accept the Presidency for the year. (*Applause.*) It will, I am quite sure, add great lustre to the proceedings of the International Conference.

That, of course, is merely one project. It is an important project but it will come and it will go. What are we going to do generally? The Institute is enlarging. How are we going to enlarge its activities? This is a matter to which the Council have given, naturally, a great deal of attention. They have before them at present no definite proposal, and in any case it would be quite improper for a President—and a lay President at that—to say anything about that in an authoritative way; but I am able to say this. The way people's minds are working is that the real and important function of the Institute is to develop the education and training of marine engineers, a matter to which the First Lord has already referred. It is quite clear to me that in the next decade—because it is going to take quite a long time to develop these things—we shall see great developments in this direction.

Every year marine engineering becomes a more complicated affair as greater complications are introduced into ships and the standards we require of the marine engineer grow higher. And remember that we do not want him to have qualifications that are merely just sufficient to do his job. We want to see that marine engineering is a profession of which everybody can be proud and which can stand comparison with any other branch of engineering in the country or anywhere in the world. Just how this is to be done is a matter on which there will be a great deal of discussion, and I am sure the Council will be wise—I know they will be wise—to take a good deal of advice from outside, and particularly from educational authorities and others, and also from business and industrial quarters, as to which is the best way to advance.

One suggestion is that the Institute should sponsor a College of Marine Engineering, taking students up to University standard. I would be the last person to raise any objection to that, but I am going to be bold, as a layman, in throwing out this thought: that basically the problems of marine engineering are the broad problems of engineering applied to a particular field, and I am a little doubtful myself whether the best way to train marine engineers is to make them specialize in what may be called marine engineering too early in their lives. I myself feel—and I offer this thought most hesitantly because I may have my head cut off by the Chairman of Council—that if we have a certain amount of money that we are prepared to spend on a development of this kind, we might do better to sponsor the study of marine engineering in existing institutions alongside other disciplines—not only engineering but other disciplines, too—and then to provide in addition for practical training in marine engineering as a separate project.

These are not matters on which anybody ought at this stage to pontificate—least of all the President—and I hope you do not think that I am. I am merely throwing out this idea because I think we ought to discuss these matters among ourselves during the next year or two.

Whatever we do, it is of tremendous importance that we should advance the technical ability of the marine engineer. I am not decrying in any way his present technical ability, but he is facing constantly new problems and new challenges. We do not know how soon it will be that the use of nuclear power will be extended to merchant ships. It will not be next year and I do not think it will be in five years' time, but, looking ahead, we have to be prepared for engineers to be trained for much more difficult techniques than those to which they have been used in the past.

Having said that, I would just like to say this one thing to those of you who have read the papers that have been given on this subject during the last year. I think you will agree with me that enormous progress has been made in the last three or four years by marine engineers, clearly showing that they have acquired a very great deal of knowledge about this subject, even though they have not yet had practical experience of it.

I will not keep you any longer. I will only conclude by thanking you all for coming to this dinner, and again I would thank Lord Carrington for proposing the toast so very charmingly, and His Excellency for his most interesting speech at the beginning of the evening. (*Applause.*)

The proceedings then terminated.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting held at the Memorial Building on Tuesday, 22nd November 1960

An Ordinary Meeting was held by the Institute on Tuesday, 22nd November 1960 at 5.30 p.m., when a paper entitled "The Automatic Control of Naval Boilers" by Commander J. P. H. Brown, R.N. (Member) and Lieutenant Commander W. J. R. Thomas, R.N., A.M.I.Mech.E., was presented by the authors and discussed.

Mr. W. R. Harvey (Chairman of Council) was in the Chair and 157 members and visitors were present.

In the discussion that followed seventeen speakers took part.

A vote of thanks to the authors, proposed by the Chairman was enthusiastically received. The meeting ended at 8.15 p.m.

Section Meetings

South Wales

A meeting of the South Wales Section was held on Thursday, 2nd March 1961 at 7.0 p.m. at the South Wales Institute of Engineers, Park Place, Cardiff. A paper entitled "Welding in Marine Engineering", by Mr. J. A. Dorrat was read by the author and well received by an audience of fifty members and visitors. The interesting and informative lecture was followed by a full and lively discussion.

Mr. Berridge, local Honorary Secretary of the Institute of Welding Engineers, proposed a vote of thanks to Mr. Dorrat which was seconded by Mr. R. F. Munro, Assistant Honorary Secretary of the Section and unanimously acclaimed.

The lecture was repeated by Mr. Dorrat at Swansea on Friday, 3rd. March 1961, and was attended by forty-two members and visitors. An informal discussion followed and the appreciation of all present was shown to Mr. Dorrat to whom a vote of thanks was proposed by Mr. Morgan, Assistant Honorary Secretary, the Institute of Welding Engineers and seconded by Mr. R. G. Turnbull.

West of England

An Ordinary Meeting of the West of England Section was held at Smith's Assembly Rooms, Bath, on Monday, 13th March, at 7.30 p.m. Captain W. R. Stewart, R.N. (Vice-Chairman of the Section) presided and there was an audience of eighteen, including the Local Vice-President, Mr. D. W. Gelling.

In opening the proceedings, Captain Stewart said that it was his very sad duty to inform the meeting of the sudden death of the Section's Chairman, Mr. W. John, M.B.E., at his home on Sunday, 5th March.

The meeting then stood for a few moments in silence in tribute to the late Chairman.

The Vice-Chairman then introduced Mr. F. H. Aldred, B.A., and Mr. N. W. Hinchliffe, B.Sc., who presented their paper entitled "General Developments in Ceramics for Marine Engineering". The paper was illustrated by numerous lantern slides and also with sample products. Six speakers took part in the discussion that followed.

A vote of thanks to the authors, proposed by the Vice-Chairman was accorded with acclamation. The meeting ended at 9.15 p.m.

West Midlands

A meeting of the West Midlands Section was held at the Engineering Centre, Birmingham, at 7.0 p.m. on Thursday, 16th March 1961, when a paper entitled "Heat Exchangers—Design Aspects to Avoid Corrosion" was read by the author Mr. G. Page, B.Sc.

Mr. H. E. Upton, O.B.E., Chairman of the Section presided at the meeting which was attended by forty-two members and guests. With the aid of colour slides, Mr. Page emphasized the precautions and points to beconsidered in preventing corrosion.

The various types of construction was also discussed together with the relevant features influencing the individual designs and the points which were to be avoided in using such constructions for various duties. Particular attention was also paid to the methods of cleaning, etc. In addition to the colour slides, Mr. Page exhibited various specimens suitably sectioned, showing the different forms of corrosion in the individual components of the designs.

The discussion which followed was opened by Dr. Gilbert, all questions being ably dealt with by the lecturer.

On behalf of the members and guests present the Chairman thanked the speaker for a most interesting paper.

The meeting closed at 9 p.m.

Election of Members

Elected 10th April 1961

MEMBERS

Kshetra Basi Bisoi, Lieut., I.N.
Hugh Brady
Anthony James Brearley
Lionel Casey
Peter Brown Davison, Eng. Lieut., R.N.
Thomas Dawson
Donald David Dick
Robert Hugh Gault
Francis Oswald Howat
Robert H. Imlah
Gerard McGahan
Frank Senior Milsom
Michael Joseph Moyle, M.B.E.
Jorge Dos Santos Pereira
Robert Stewart Skinner
William Hunter Spensley
James Ross Thomson
Peter Welsh
Stanley Graham Wilkinson

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Raymond Choy
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Antony Graham Collis
John Riley Fothergill
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Ambrose U. D. Iwunze
Thomas Alexander Landels
Walter John Lightfoot
Graham Harrington Matthews
Sean Glenville O'Connell
Mel E. Okafor
David Michael Oxley
Phillip Douglas Shimmin
Ian Stewart Smith
James Smith
Gopinath Sudhir
Bernard Webb
Antony Herbert Willis

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Charles Hunter Green Edwards
Peter John Farren
Arthur John Hulley
Burgess Ian Oakley
Anthony Melvyn Whatmough
Howard Lambton Wilkinson
Allan Willis

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John Alwyn Babbs
Ronald Francis Coghill
Louis Gordon Lowe
Stanley McGuire
Norman Leathley Ramsey
William Renell Seward
Norman Stanley Swindells

TRANSFER FROM ASSOCIATE TO MEMBER

Bernard Allen
Johannes Christoffel Gysbers
Austin Lawrence Jemmett
Ronald H. Peacock
Frederic George Righton, Cdr., R.N.

TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER

William Arthur Riseborough, Eng. Lieut., R.N.

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER

John Reekie Buchan
George Albert Burdon
James Raymond Clarke
Geoffrey Joseph Dixon
Thomas Orr Leith
Ian Herbert Livingstone
Derek George Orchard
Raman Somasundaran Pillai, Lieut., I.N.
John Spice
Abdul Haseeb Syed

TRANSFER FROM STUDENT TO GRADUATE

Frank Clark
Robert David Cowin
Peter Alexander Milne, Ph.D., B.Sc.(Hons.)(Durham)
Iain Leonard Bentley Moffatt
David Morter
Zafar A. Siddiqi

TRANSFER FROM PROBATIONER STUDENT TO GRADUATE

Gordon Whalley
Alan Arthur Charles Brewster

TRANSFER FROM PROBATIONER STUDENT TO STUDENT

Anthony Alfred Askew
David Davenport
Norman Davies
Thomas Anthony Edwards
John Philip Field
Ian Edward Cameron Gilg
Richard James Harrop
Camilo Heng
John Michael Jennings
William Robert Oswald Mann
Alexander William Stevenson
David Weston

OBITUARY

WILLIAM JOHN (Member 16101) was born on 14th May 1899 and served his apprenticeship with Cammell Laird and Co. Ltd., Birkenhead. He was educated at the Liverpool Collegiate School. During the First World War, Mr. John went overseas with the Liverpool Scottish and was demobilized in 1919. In 1920 he joined Elders and Fyffes Ltd. as a junior engineer in their steamship *Barranca,* and served in ten ships of that firm until October 1940, when his vessel, the *Mopan* was sunk by the raider, *Admiral Scheer*. He was on board this German battleship as a prisoner when the *Jervis Bay* and her convoy were destroyed. He was interned in the German prison camps Marlag and Milag Nord, and in September 1941 started classes among the prisoners for various subjects, the most important for him being those covering the deck and engine room Certificate examinations. The German Government allowed the use of a complete barrack block and Mr. John was able to obtain technical books through the Bodleian Library, Oxford. The International Red Cross forwarded First and Second Class examination papers to this country, and, with the exception of the verbals, many candidates were able to resume their careers upon cessation of hostilities without having wasted the years of captivity. Mr. John was awarded the M.B.E. and this decoration was one of the best deserved of the war. He rejoined Elders and Fyffes and in 1945 was appointed chief engineer of m.s. *Nicoya.* In 1950 he came ashore as assistant superintendent engineer with responsibilities covering Avonmouth and Southampton.

Mr. John was elected a Member of the Institute in 1955, and from the inception of the West of England Section of the Institute, he took an active part as a member, then on the committee and finally as chairman which office he held for three years. His fourth term of office had just begun, when he died quite suddenly in his garden at home on Sunday, 5th March 1961. He had a high regard for his profession, and three days before his death he presided at a metallurgy lecture sponsored by the Institute at the City of Bath Technical College. He had also addressed Bristol Grammar School senior forms and had arranged similar lectures at Bath Grammar School and Bristol Careers Conference. Public functions which he inaugurated included dinner-dances, cocktail parties and outings to Hinkley Point Atomic Power Station. He leaves a widow, a son and daughter, both married, as well as a host of friends in shipping circles. He will be remembered as a man of tremendous calm in times of crisis and also for the loyal and devoted support he gave to the Institute, particularly in the West of England Section.

The above appreciation of the late Mr. W. John, M.B.E., Chairman of the West of England Section, has been contributed by Mr. D. W. Gelling (Local Vice-President, Bristol) and colleagues in Elders and Fyffes Ltd.

ERIC SOUTH FIELDER (Member 6931) died last December following a tragic car accident in which he received fatal injuries. Born in Sydney, New South Wales, in 1891, Mr. Fielder served his apprenticeship with the Clyde Engineering Co. Ltd. He then served for three years in merchant vessels and during the First World War he was serving as fifth engineer in the *Clan Davidson* when she was sunk in the Indian Ocean in 1917. Seven weeks after the sinking, Mr. Fielder was again serving at sea, this time on the *Marathon.* In 1921 he joined the Royal Fleet Auxiliary and served continually in this branch of the services for the next 30 years. Until the outbreak of World War II he served in Chinese waters, making steady progress through the various grades. In March 1930 he obtained his First Class Board of Trade Certificate and returned immediately to the East, remaining there until 1939, when, as chief engineer of the R.F.A. *Olcades,* he was sent from Trincomalee, assigned for station duties with the East Indies Squadron. In November 1944 he was chief engineer of the R.F.A. *Belgol.*

After the war he continued in the service, chiefly in the South Pacific, until 1951. He then retired to Cairns in North Queensland where he became interested in the local natural history, and joined the North Queensland Naturalists' Club, taking charge of the library and the Flecker Herbarium and, two years ago, became secretary. The club became a full time occupation with him and he gave willingly and generously of his time and abilities to its interests. Children will cherish happy memories of field days at Mount Mulligan and Chillagoe with Mr. Fielder who provided transport and all amenities. Mr. Fielder was also very active in Church, club and charitable work and, though he did not practise Freemasonry at Cairns, his diaries revealed that he had not been inactive in its cause during his business life.

He was elected a Member of the Institute in 1931 and was also a Member of the Australasian Institute of Marine and Power Engineers and of the Marine Engineers Association. His friends brought his body to Cairns, where he will long be remembered.