Prototype Trials of a Naval Boiler at the Admiralty Fuel Experimental Station, Haslar

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It has long been naval practice to test prototype boilers ashore, and this was considered particularly important for the boiler designed for the Guided Missile Destroyers, of which H.M.S. *Devonshire* is the first of class. Its steam conditions, at 700lb./sq. in. and 950 deg. F. (510 deg. C.), were to be the highest yet used in naval service, and the installation was to have an ambitious fully automatic system of control. The boiler design, the shore installation of the boiler and its associated auxiliaries and the instrumentation used are described in the paper, and some of the more interesting aspects of the trials are discussed.

INTRODUCTION

Early in the design of the Royal Navy's first Guided Missile Destroyer, it was decided that shore testing of the prototype boiler and its major auxiliaries would be prudent in view of the advanced nature of the plant. Not only were the steam conditions the highest yet to be used in the Service, but most of the auxiliaries were of new design and the automatic controls were the most comprehensive yet to be fitted to a naval boiler.

The broad objects of the trials were:

a) to prove the reliability of the boiler installation as a whole;
b) to determine the various settings required for the automatic controls;
c) to establish as far as possible the static and dynamic characteristics of all the components of the installation, checking that the requirements had been met and providing a fund of information to be used in future designs;
d) to train the operators for all new ships fitted with similar controls. This commitment has grown steadily as more ships have been built, and has materially contributed to the success at sea of the new and complex controls systems.

In 1957, approval was received for work to start on the building of the prototype installation at the Admiralty Fuel Experimental Station, Haslar, Gosport, where fuel, feed and cooling water, and a condensing plant were already available. The plant was built by J. I. Thornycroft Ltd., and was officially commissioned by Rear-Admiral W. F. B. Lane, C.B., D.S.C., then Director of Marine Engineering at the Admiralty, in December 1960.

THE BOILER AND INSTALLATION

The Admiralty Fuel Experimental Station, Haslar

Almost every type of combustion equipment used at sea by the Royal Navy was designed and developed at this establishment and the records there make interesting reading, describing the progress made through the century in the combustion equipment of boilers. The horizons of the station have widened recently to include the testing of prototype boilers and auxiliary machinery, and the development of automatic control systems for boilers, to mention but two of its new tasks. It is bounded on one side by Haslar Creek, from which is drawn the cooling water needed for the plant which condenses the steam produced by the experimental boilers before its return to the feed tanks.

The staff at the station is drawn partly from the Royal Naval Scientific Service and is partly naval, in the hope that the joint product will be both theoretically sound and sufficiently robust to be "stoker proof".

Description of the Boiler

Fig. 1 shows a cutaway drawing of the boiler, which was designed by Babcock and Wilcox Ltd. It is of their "selectable superheat" type, in which the gases leave the furnace through two parallel paths, that at the rear containing the superheater. The flow is proportioned between them by dampers fitted in both, between the generator tubes and the economizer. Lucas spill burners in Admiralty Suspended Flame Registers provide the main combustion fuel, while a small pilot burner maintains a flame in the furnace independent of the main fuel supply, to guarantee re-ignition should a temporary fuel failure occur when steaming in automatic control with the boiler room unmanned. The main design features of the boiler are as follows:

Dimensions (measured across the air casing)

Length	15ft. 9in.
Breadth	20ft. 1in.
Height	23ft. 3in.

Weight

Approximately 56 tons.

Steam Conditions

700lb./sq. in. and 950 deg. F. (510 deg. C.).

Steam and Water Pressure Drops at Full Power

Economizer inlet pressure	720lb./sq. in.
Steam drum pressure	700lb./sq. in.
Superheater outlet pressure	650lb./sq. in.

Heating Surfaces

Projected radiant heating surface	261 sq. ft.
Furnace volume	496 cu. ft.
Furnace length	7ft. 6½in.
Superheater surface	975 sq. ft.
Economizer surface	4,646 sq. ft.
Water wall surface	177 sq. ft.

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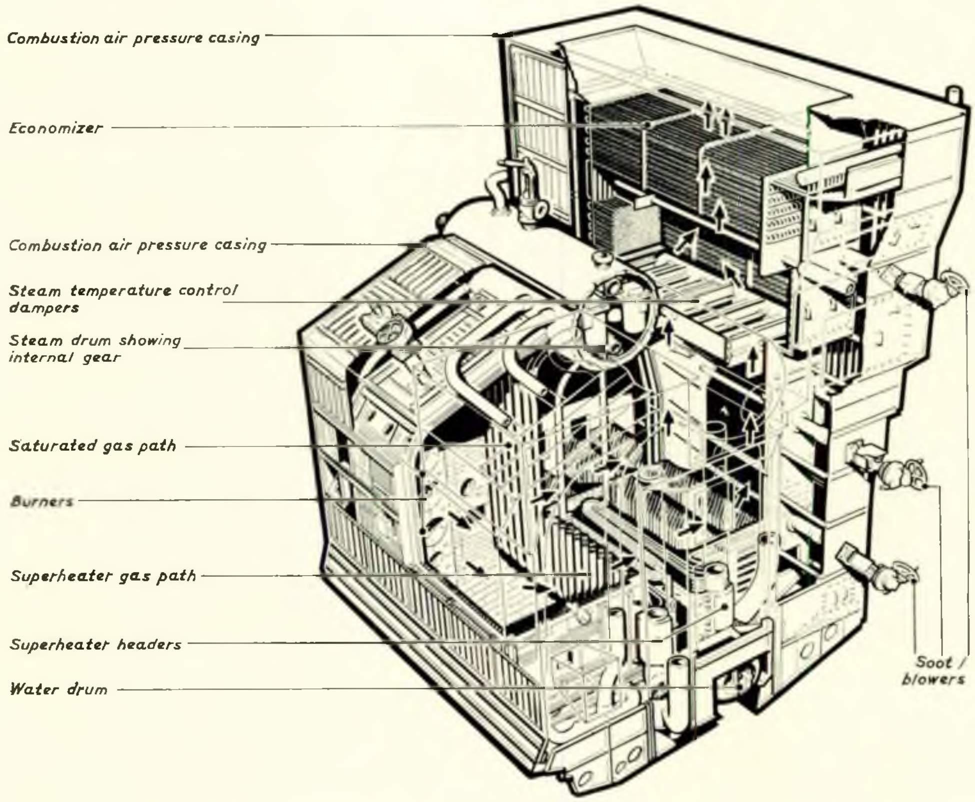

FIG. 1—*Rear cutaway view of Guided Missile Destroyer boiler*

The boiler gas casing is surrounded by a pressure case, all the casings being of welded stainless steel. Enveloping the pressure case is a suction box, from which the main blowers take their air supply. Thus piercing of the suction box, when steaming through nuclear fall out, should merely cause the blowers to evacuate the machinery space outside the boiler box and contamination of the space should not occur. In the ships, two boilers are fitted side by side in a common suction box, the layout of the machinery being fully described in reference 2.

The Shore Installation

It was originally intended to make the shore suction box

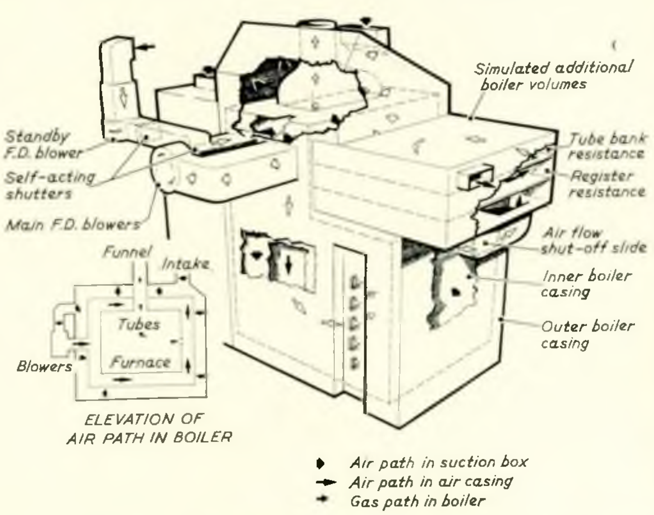

FIG. 2—*Arrangement of boiler air boxes in the shore installation*

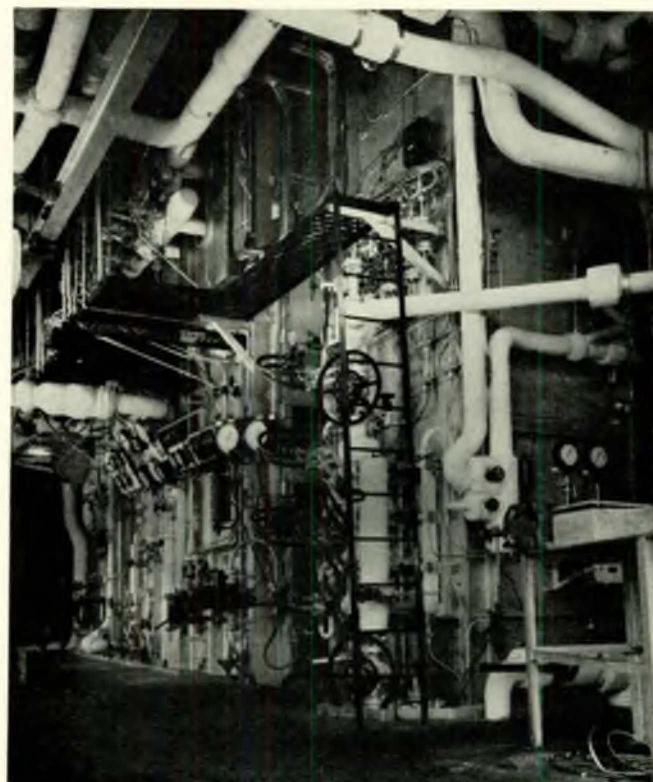

FIG. 3—*General view of the boiler room*

the same size as that fitted in the ships, with one real and one dummy boiler in it, so that the dynamic performance of the blowers could be assessed accurately. Finally, however, only half the suction box was built, but with an additional section containing the same volume of air as would have been contained in the other half. Similarly, a further box was fitted having the same volume as was occupied by the air and gas in the pressure case, furnace, tube banks and uptakes of the second boiler. Thus it was possible to add the additional capacities necessary to simulate steaming in the "one blower, two boiler" condition. The arrangement of the boxes in the shore installation is shown in Fig. 2.

The main furnace fuel oil pump, the main blower, the main feed pump and the servo air compressor fitted at the Admiralty Experimental Station are all identical to those fitted in the ships, but the main extraction pump and the standby auxiliaries are simply suitable ones which were available. The de-aerator is similar, although not identical, to that used in the ships. In laying out the auxiliaries in the boiler room, it was attempted to have the access to all as good as possible, but there was an overriding requirement to keep the pipe lengths roughly the same as those in the ships, because extra capacity and distance velocity lags could affect the performance of the automatic controls. Fig. 3 shows a general view of the boiler room.

FIG. 4—*The Control Room at A.F.E.S.*

CONTROLS AND INSTRUMENTATION

The Control Room and General Instrumentation

The control room is shown in Fig. 4, and it was made large enough to contain not only all the normal operational controls and instruments, but also most of the very comprehensive set of instruments necessary for recording the characteristics of the boiler and its auxiliaries. Amongst the latter were included some 80 pressure gauges, 13 continuous multi-point pen recorders for pressures, temperatures and flow rates, and 40 manometers showing the gas and air pressures. Four Mono and two Orsat gas analysis sets enabled flue gases from any of 16 sampling points to be analysed. The conductivity of continuous samples of condensed steam from the superheater outlet could be measured to determine the carry-over of dissolved solids from the steam drum. Just outside the control room were a further ten continuous multi-point recorders connected to the thermocouples in the superheater tubes which are described later.

The pneumatic control system for the boiler is basically as shown in Fig. 5, and its development is fully described in reference 1. A large number of tee-pieces were provided in the control system pipework with suitable stop valves and connexions so that the air pressure at any of these points could be recorded if needed. These proved invaluable during the trials, as air pressures, which ranged between 3 and 27lb./sq. in. and were proportional to almost every quantity in the boiler system, were available to record at a few minutes notice.

Two furnace fuel oil tanks were fitted on separate weigh bridges to permit accurate checks on fuel consumptions during the trials.

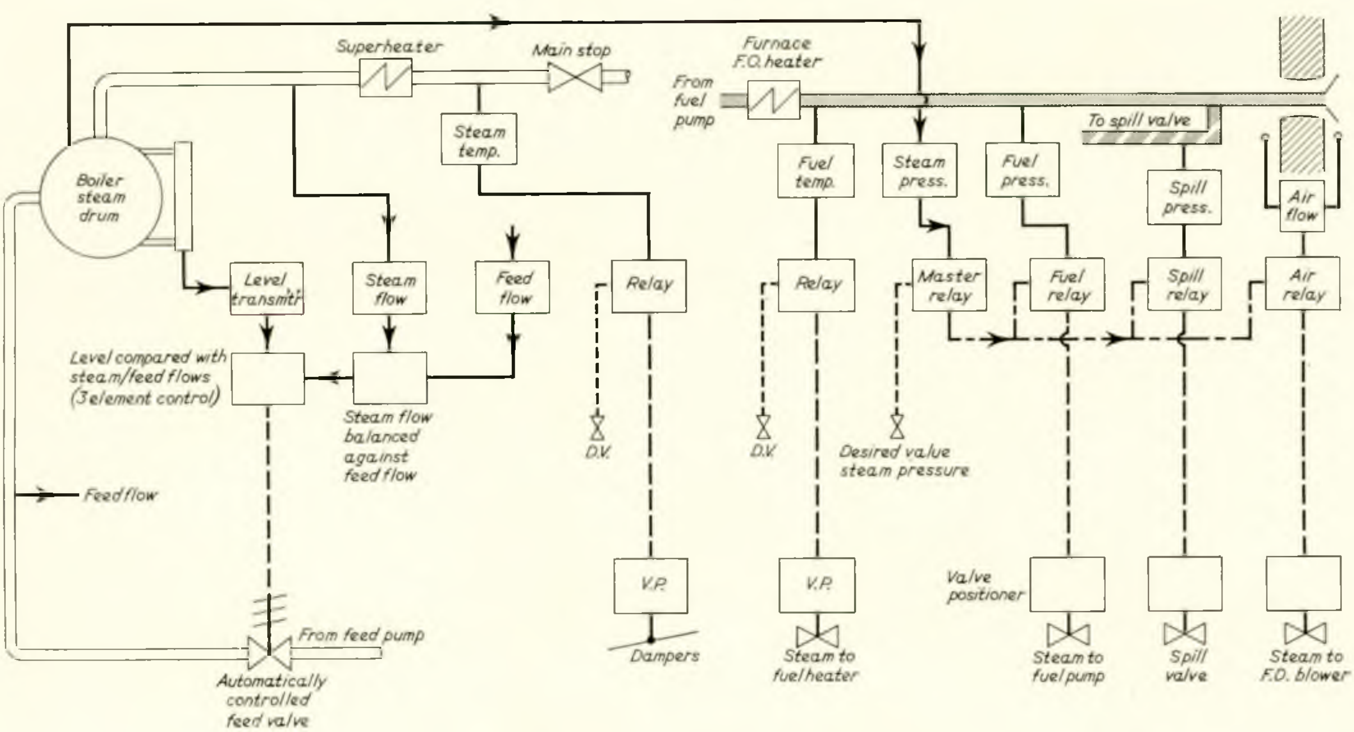

FIG. 5—*Schematic layout of the control room*

Instrumentation of the Superheater

The superheater tubes are of 2¼ per cent chromium and 1 per cent molybdenum steel, which is the best available below the austenitic range. It was appreciated that during very rapid manœuvring at maximum superheat temperature—950 deg. F. (510 deg. C.)—the tube metal temperature would almost certainly rise to values near the limit for this material. It was therefore decided to fit an extensive array of thermocouples in the superheater to give as complete a picture as possible of the heat transfer. Approximately 200 thermocouples were fitted to record the tube metal temperatures and a further 80 to record the steam temperatures at various points in the superheater. Provision was made in the gas casings for the insertion of aspirating thermocouples to record the gas temperatures. Fig. 6 shows the method used for measuring the tube metal temperatures, and it will be seen that it is similar to that shown in Fig. 45 of reference 3. All the superheater

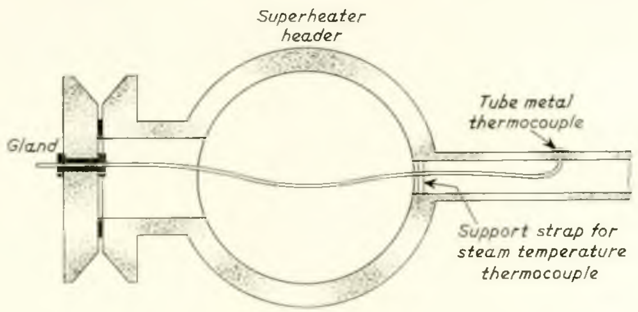

FIG. 6—*Method of measuring tube metal temperatures*

thermocouples were installed by Babcock and Wilcox Ltd. during the manufacture of the superheater at their Renfrew works. The Pyrotenax cables were brought out through small glands in flanges bolted to additional stubs which had been welded to the superheater headers, and the thermocouple outputs were displayed on continuous recorders.

The thermocouples stood up to their arduous duty well, and after more than a year of fairly intensive operation of the boiler 60 were still working, and some of these were in the last pass of the superheater. Unfortunately by April 1962 leakage of the glands, through which the cables left the superheater headers, had become such a problem that it was reluctantly decided to cut all the cables and blank the glands, because the latter were so close together and numerous that repair was impossible.

THE BOILER PROVING TRIALS

General Performance Trials

As soon as the boiler was ready to be used, it was lit up to prove the systems, the boiler and the auxiliaries. As it was feared that many of the superheater thermocouples would have a very short life, a series of trials was carried out at once, with several different combinations of damper positions at each of five powers. These trials were carried out with most of the boiler systems in hand control or, at best, servo-manual control, because the results of the trials were needed in many cases to determine the settings required on the controls to give satisfactory performance.

Several hundreds of readings were recorded during each of the many trials, and the result was a large fund of information which (although not all of it has been analysed and presented in a palatable form) is available, and has been used for the solution of particular problems which arise in ships and in future designs. It would be both pointless and impossible to present in this paper much of what was recorded, but Fig. 7 shows a few curves which are of particular interest. These were plotted from points obtained at five different powers with the dampers both wide open. The shape of the steam temperature characteristic, rising to a peak at mid-power, is interesting in that it proved embarrassing in the development of the

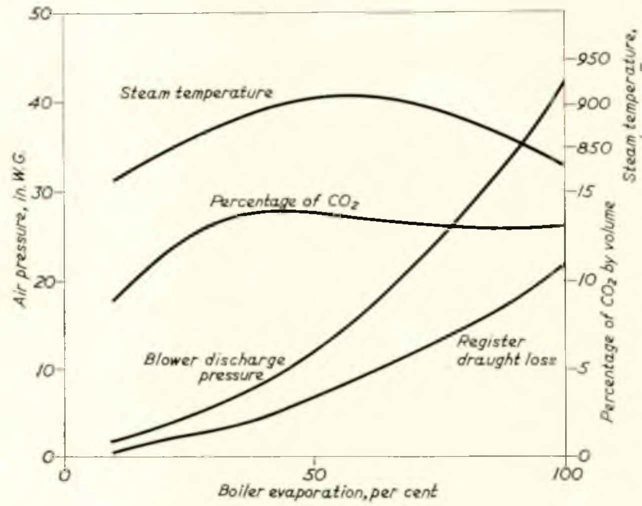

FIG. 7—*Typical characteristics of the boiler*

steam temperature loop, while the others shed some light on the combustion, which is discussed in the next paragraph.

Combustion

The design of the boiler was influenced by a width limitation which was imposed by hull design considerations. The result was a furnace shape and size such that the burners could only be accommodated vertically one above another. The inability of the flames to "see" each other might have been expected to have a bad effect upon combustion, but this was compensated for by an improvement in air supply, which in this arrangement was equally good for each. The combustion equipment was needed to allow the boiler to be steamed from the engines standby state to full power with all burners alight, for reasons discussed in reference 1. Fixed geometry registers were developed at the Admiralty Fuel Experimental Station to use Lucas spill atomizers, and it was hoped that they would give good combustion down to a fairly low power with stable, if not efficient, combustion right down to the boiler self-sustaining load. The results of the early boiler trials were therefore of great interest, and it was found with a certain amount of relief that the stringent requirement had been met. It will be seen in Fig. 7 that the funnel gas CO_2 content falls off sharply below about one-quarter power, but it was found that the flames were still stable at only 200lb./hr./atomizer, although the register draught loss range over which the funnel was clear was reduced to about ½in. water gauge at this output. The penalty paid for this wide range of burner operation is not only inefficiency at low outputs but also very high register draught loss at high outputs, this being about 25in. water gauge at maximum power.

Another requirement of the combustion equipment was, of course, that it should be capable of running for long periods without the need for attention such as cleaning, as the ships were designed to operate without the boiler room being manned. It was found that, as the burners were not only alight at all times but also had no small orifices because they were of the spill type, all the normal troubles were eliminated. Atomizer cleaning was found to be unnecessary, and even undesirable, after three months in use, provided the steam purging system had been used to clear the burners of oil, as they were shut off on boiler shut-down.

RAPID LIGHTING UP FROM COLD

There is obviously a need for naval ships to be able to get under way quickly in an emergency, and the COSAG design enables this to be done. There may, however, be an equally pressing need for full power, and it was therefore decided to carry out trials to determine just how quickly the boiler could

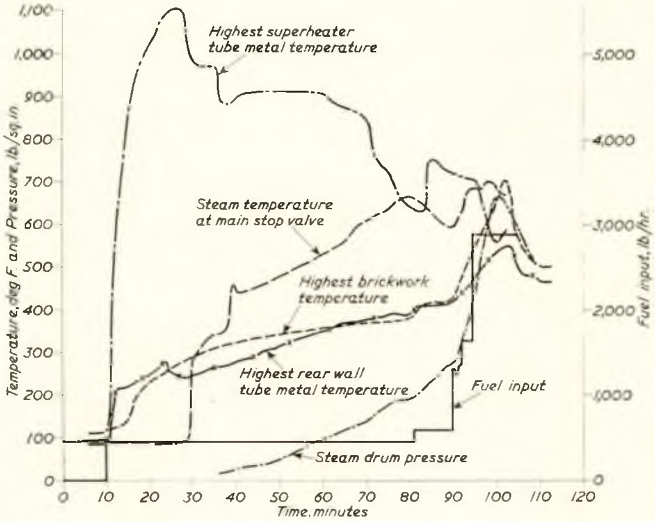

FIG. 8—*Normal lighting up from cold*

be lit up from cold without damage. These trials were carried out before the superheater thermocouples were removed, so that the risk to the boiler could be assessed accurately.

Firstly, a perfectly normal lighting-up routine was followed, and from the very large number of continuous readings obtained, those were selected which, it was believed, would throw light upon the limiting factors. Fig 8 shows some of the readings obtained. The start of steam generation is clearly seen as the point at which the steam temperature at the stop valve starts to rise, and, at the same time, there occurred a very large fall in the highest superheater tube metal temperature, as the tubes were cooled by the generated steam.

The next stage was to repeat the trial with an identical fuel input rate, but after the simmering coil had been in use for a considerable time. The latter is merely a loop of pipe within the water drum, through which steam from an external source can be passed. It is fitted specifically to reduce the time taken for lighting up from cold and, in the ships, the steam is supplied by the auxiliary boiler. The results are shown in Fig. 9 and the very much reduced maximum superheater tube metal temperature, due to the earlier steam generation, can be seen clearly.

The final trial in this series was suggested by the representative of the boiler designers. He proposed that if the boiler must be lit up from cold rapidly, without the simmering coil having been in use, it might be possible to reduce the time taken by violently increasing the firing rate in the early stages, so that the boiler started to generate the cooling steam needed

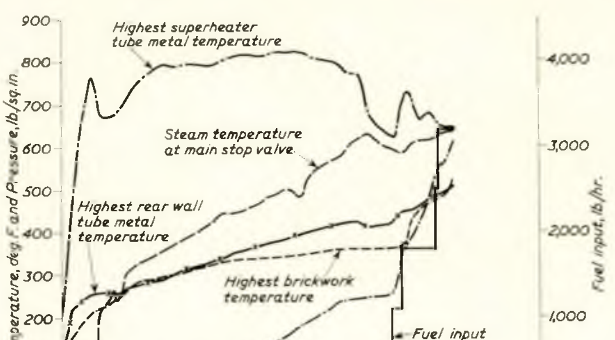

FIG. 9—*Lighting up from the simmering condition*

by the superheater tubes, before the latter had been brought up to a dangerous temperature. It was decided to test this theory, adjusting the firing rate from minute to minute so that the highest superheater tube metal temperature did not exceed 1,150 deg. F. (621 deg. C.). The result is shown in Fig. 10

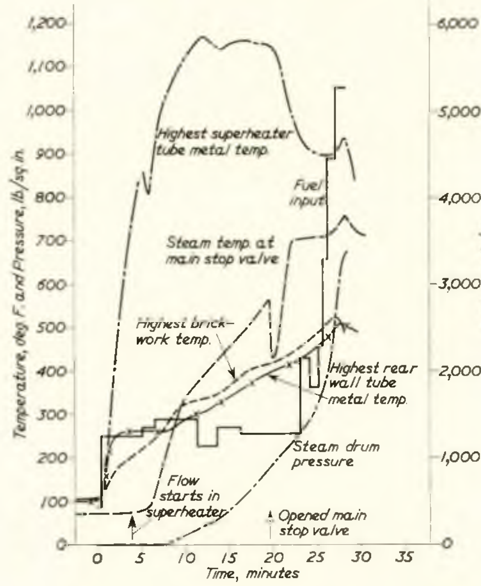

FIG. 10—*Rapid lighting up*

and it was found that the boiler could be brought up to its normal working pressure in under 30 minutes from dead cold, compared with the 90 minutes taken under normal circumstances as shown in Fig. 8.

Similar rapid lighting up trials have been carried out repeatedly on another boiler of similar design at the Admiralty Fuel Experimental Station and no ill effects have been seen on either the pressure parts or the brickwork. It is not suggested, of course, that lighting up at such a speed is good for the boilers, or that boilers should ever be lit up as quickly as a matter of course, but it does show what the two-drum boiler is capable of withstanding if this is really necessary.

THE STEAM TEMPERATURE CONTROL LOOP

The Original Mechanical Arrangements

The two dampers in the gas path were ganged together in such a way that the parasitic draught loss through them was always the minimum possible. To achieve single hand wheel control of both, the lost motion device shown in Fig. 11 was adopted, Telektron air-motors being used to turn the screw-block drive when automatic or remote control was required.

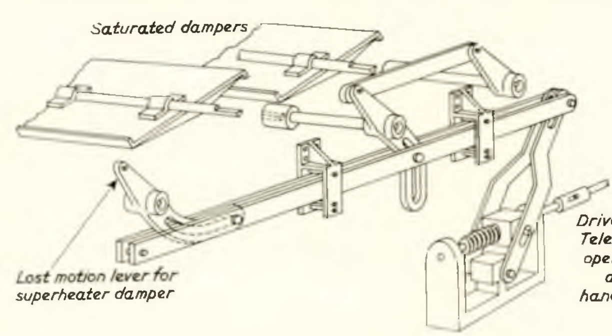

FIG. 11—*Original superheater damper operating gear*

The Original Control Arrangements

The control of many heat transfer loops is difficult, the thermal inertia of the materials of the heat exchanger and of the fluids often having a profound effect upon the response of the control loop. In the case of the superheater, fairly low velocity fluids are involved, and thus distance velocity lags are liable to occur. The sensing arrangements, too, are often high in thermal inertia and the time taken for the sensing bulb in a pocket to reach the temperature of the surrounding steam might be sufficient to ruin the response of the control system and endanger the superheater tubes. It was therefore decided to fit a two-element control system, in which the damper movement in the required direction was initiated by the change in steam flow. Final adjustment of the steam temperature was then achieved by comparing the desired and actual values of steam temperature and altering the damper position accordingly. This system is shown in Fig. 12.

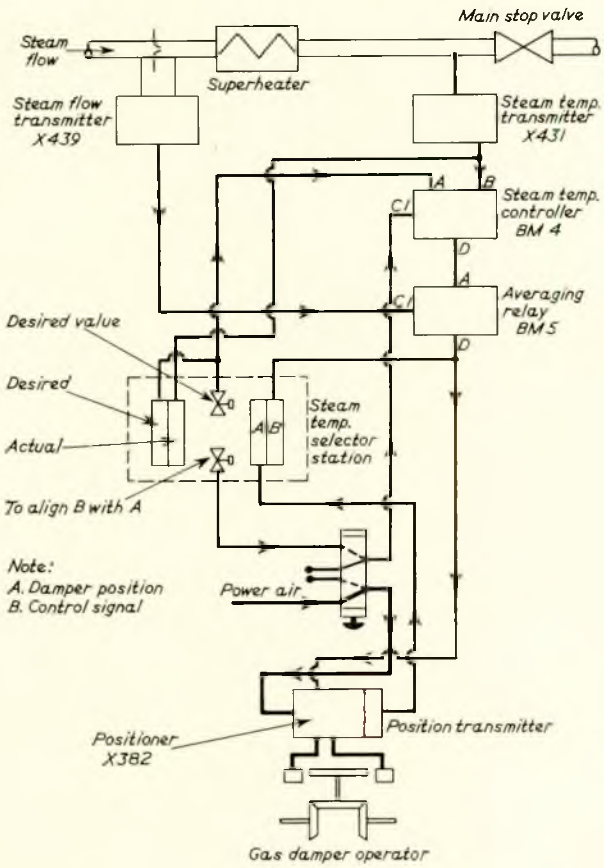

FIG. 12—*Original damper control system*

Static Characteristics of the Superheater

The static characteristics of the dampers were extracted from the readings obtained in the general performance trials already described and are seen in Fig. 13, which shows the variation of steam temperature with damper position for different powers. The effect of damper movement in mid-stroke was markedly less than was achieved by the same damper movement towards either end of the stroke. This serious non-linearity was bound to render doubtful the success of the steam temperature control arrangements, and it was therefore decided to alter the damper ganging to improve the static characteristic. Fig. 14 shows the modification which was made to the damper operating gear, while Fig. 15 shows the damper characteristic after the modification. It can be seen that this was sensibly linear, an added advantage being that many sources of undesirable backlash were removed.

Fig. 7 shows the superheater characteristic, plotted in terms of steam temperature against power for a given damper setting, and this rises to a peak at mid-power. This at once rendered the original control scheme, of using a change of

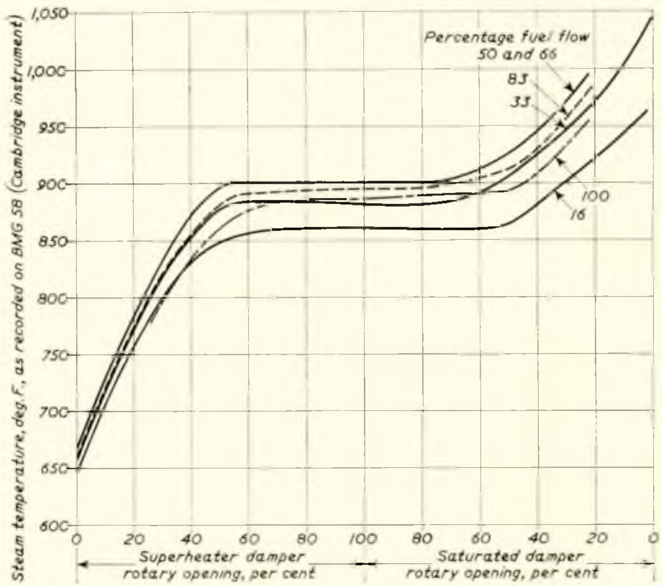

FIG. 13—*Original damper static characteristics*

steam flow to initiate damper movement in the desired direction, impracticable, as the desired direction would have been required to change at mid-power. The control system was therefore changed to a single element design as shown in Fig. 16, and trials were carried out to determine the optimum settings for the control system components.

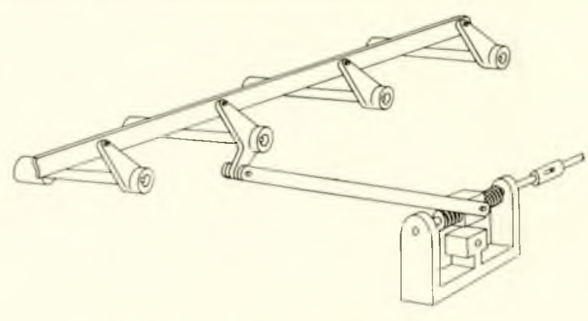

FIG. 14—*Superheater damper operating gear after modification*

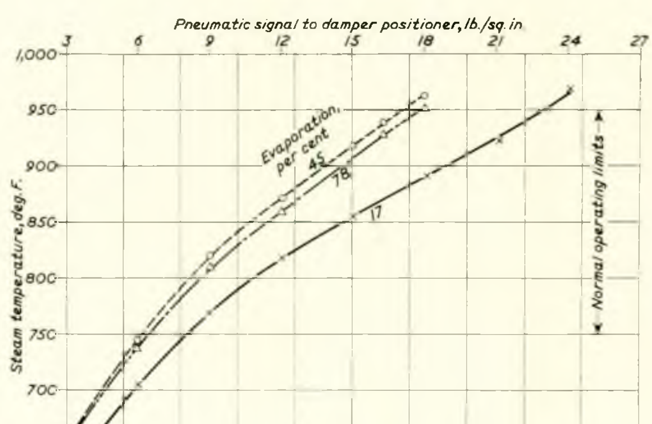

FIG. 15—*Damper characteristic after modification*

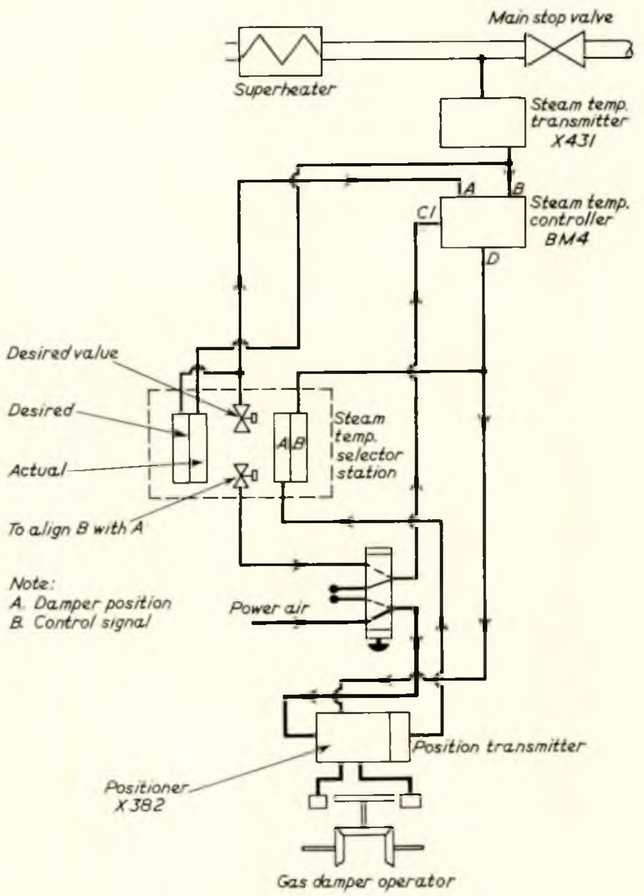

FIG. 16—*Modified damper control system*

Response Analysis of the Steam Temperature Loop

To assist in the determination of the settings and, more important, to provide basic information about superheat control which could possibly be used in future designs, a response analysis was carried out. This work was mainly undertaken by the staff of the Admiralty Engineering Laboratory, West Drayton, who already possessed the necessary instruments. A constant amplitude sine wave, at various frequencies, was injected into the steam temperature control loop, which had been opened, and the resultant phase lags and attenuations were measured across each component. Fig. 17 shows the layout of the test equipment. An electrical signal generator produced a sinusoidal output with adjustable frequency and amplitude. This was converted into an equivalent air pressure which was fed as the desired value to the steam temperature controller. The mean value of the sine wave was, of course, readily adjustable so that the tests could be performed at any desired steam temperature. Transducers measured the steam temperature transmitter and the controller pneumatic outputs, which

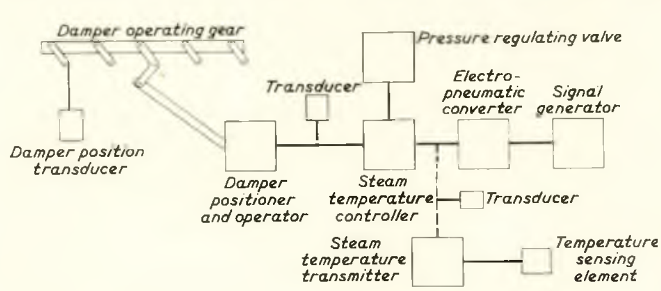

FIG. 17—*Layout of response analysis equipment*

were recorded electrically. A transducer also measured the damper position as close to the dampers as possible. The following variables were recorded on a multi-channel trace recorder at various boiler powers and steam temperatures:

i) damper position input pneumatic pressure;
ii) damper position;
iii) superheated steam temperature (measured by an inconel sheathed thermocouple in the steam without a surrounding pocket);
iv) pneumatic steam temperature transmitter output pressure.

Tests were carried out at boiler powers of 18, 45, 78 and 95 per cent full power, with mean steam temperatures of about 750 and 950 deg. F. (399 and 510 deg. C.), these being the temperature limits between which it was required to operate the boiler in practice. Fig. 18 shows a typical trace obtained

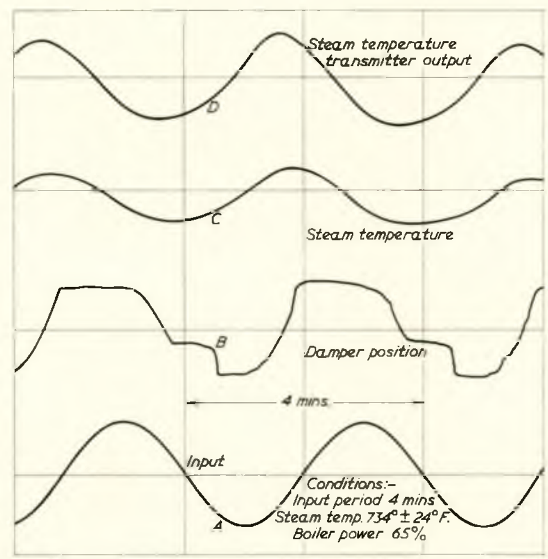

FIG. 18—*Typical response analysis trace*

during the trials. As the frequency of the input sine wave A is increased, the amplitude of B, C and D becomes less, and the degree to which this happens is indicative of the change in gain of the various loop components with frequency. A phase shift of B, C and D relative to A also occurs and the magnitude of this shift increases with frequency. This phase shift can be seen in Fig. 18. Transfer functions were derived for the loop components at various boiler powers and the use of these on a computer, to predict the performance of the superheater and its controls when subjected to given manœuvres, has given very close approximation to the results obtained in practice.

The Performance of the Superheat Control during Manœuvring

With the facts obtained from the response analysis, the controls were adjusted to best advantage and the superheater was then subjected to a series of manœuvres to ascertain whether its performance was satisfactory. Some of the results obtained are seen in Fig. 19, which shows what happened to steam temperature, the highest superheater tube metal temperature and the damper position when various step changes of evaporation were applied to the boiler. Although the boiler is only intended to carry out manœuvres with a steam temperature of 750 deg. F. (399 deg. C.) because of turbine limitations, the higher value of 950 deg. F. (510 deg. C.) only being used when steady steaming, a similar set of readings was taken with a desired steam temperature of 950 deg. F. (510 deg. C.) and it was found that even the most violent load changes could be carried out without the superheater tube metal temperatures reaching dangerous values. As the single element control system met the requirements and was as simple as possible, it was decided to instal this arrangement in the ships.

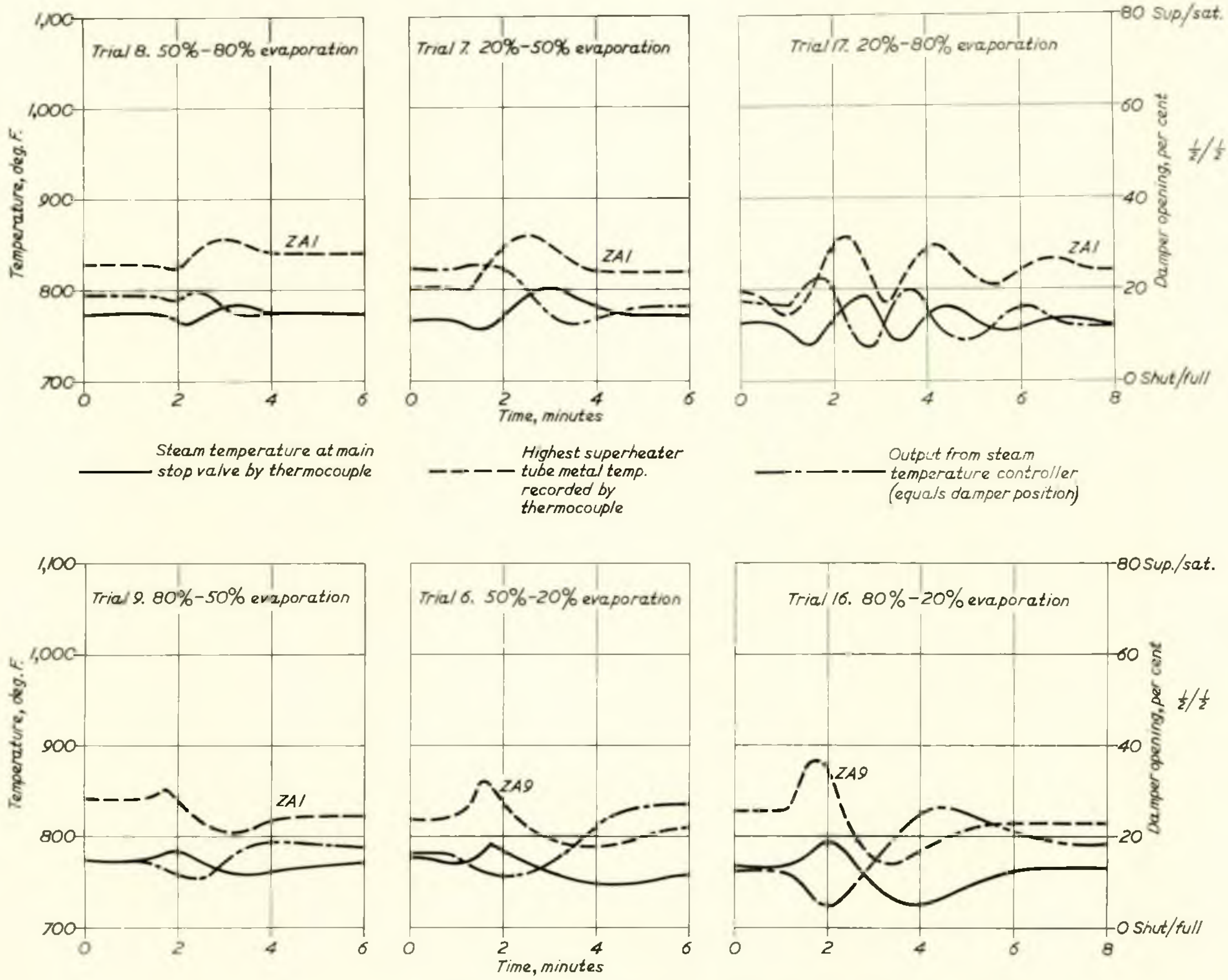

FIG. 19—*Effect of manœuvring upon steam temperature*

PLANNED MAINTENANCE SCHEDULES

As the boiler and the bulk of its auxiliaries were identical to those to be used in the ships, the opportunity was taken to carry out many of the planned maintenance schedules which had been prepared for them. As many members of the staff of the Admiralty Fuel Experimental Station who operate and maintain the boiler are extremely experienced, it was thought that more realistic results would be obtained if Chief and Engine Room Artificers who had never seen these particular machines were borrowed from a nearby Naval Establishment to undertake the work. After their efforts, amendments were produced for all the schedules tackled, and several minor design faults were highlighted and drawn to the attention of the manufacturers concerned.

FEED REGULATION

It has been common practice throughout the history of marine engineering to provide a boiler feed pump which is capable of producing far more pressure than is required to induce feed water to enter the boiler, and then to throttle the feed discharge as necessary to control the boiler water level. This has been acknowledged to be wasteful of power, the feed pump work being calculated as a loss as a matter of routine and, during the design of the Guided Missile Destroyer boiler, it was appreciated that there was a saving to be had if the feed pump control were tailored to meet the requirements of the boiler. Provision was made in the original design scheme for characterizing the throttling to reduce the loss. When the time came to try the system, however, it was thought that if the feed pump could always be run at the speed which was just fast enough to cause water to enter the boiler, with the feed regulating valve wide open, the maximum economy would be achieved. A diaphragm operated steam control valve was therefore fitted to the main feed pump, the output from a standard Bailey Meters three-element feed regulator being led to the positioner of this valve, while the feed regulating valve was left open. The results obtained were very encouraging, reasonable control of water level being obtained once the correct size of feed pump steam valve trim had been fitted. Unfortunately these trials were brought to an untimely end as a feed pump in one of the ships was damaged and that from the Admiralty Fuel Experimental Station was required to replace it. It is hoped to resume these trials shortly, and it may well prove possible to increase slightly the endurance of the ships, if the feed regulating valve can be opened wide and left open to reduce the useless pressure drop to the minimum. The initial trials indicate that it is only when the boiler is steaming at very low powers that the stability of the proposed system will be open to question, but it is hoped that, if the feed pump steam valve is correctly characterized, there will be no problem.

OTHER MISCELLANEOUS TRIALS

Boiler Response Analysis

While the equipment was available from the work on the steam temperature control loop, the opportunity was taken to carry out response analysis of the remainder of the boiler system. Feed regulation figured largely in the programme and it is hoped that the results will be of value in the continuing work on feed pump control. The description of the complete response trials and a discussion of the results is outside the scope of this paper and could alone form the subject for another.

Boiler Brickwork

Measurements of brick face, securing key and boiler casing temperatures were made and add to our knowledge of the service conditions of furnace linings. Trials of different materials for various purposes within the furnace were carried out and those now used in practice were specified as a result.

Pumping and Burning of Diesel Fuel

The ability of the fuel pumps to handle Diesel fuel, which is a notoriously bad lubricant, was tested over prolonged periods and the combustion was studied when burning the fuel.

Rear Wall Tube Metal Temperatures

As described in reference 2, trouble was experienced in the first of class of the General Purpose Frigates with overheating of a tube in the rear wall which was joggled around a sight hole and soot blower. A similar tube existed in the Guided Missile Destroyer's boiler, and so this tube was removed, and replaced with one in which thermocouples had been fitted, as previously described, to measure the tube metal temperature. The boiler was then subjected to all manner of manœuvres and combustion conditions in an attempt to induce a rise of tube metal temperature significantly above the boiler saturation temperature, but the maximum recorded was only 5 deg. F. (3 deg. C.) above. Thus the trial was, regrettably, inconclusive, as it threw no light on the *Ashanti* failures, but it did confirm that all was well in the Guided Missile Destroyer boiler.

TRAINING

Unfortunately no record exists of the exact number of officers and ratings who have visited the Admiralty Fuel Experimental Station, Haslar, for training, but almost every Officer, Chief and Engine Room Artifier and many of the Chief and Petty Officer Engineering Mechanics who have served in a General Purpose Frigate, a Guided Missile Destroyer or one of the *Tiger* Class cruisers have spent some time there. In many cases, several days have been spent in the boiler room, taking part in operating the boiler during its trials. It is believed that the demonstrations of this boiler, thought to be as fast-manœuvring as any other boiler of the same size in the world, has done much to make naval personnel realize the benefits of automatic control and accept them as commonplace rather than as black magic. It is asking a great deal of engine room ratings, used to putting on and off sprayers, altering blower speed, F.F.O. heater steam and so on during manœuvring, to expect them to sit in a control room isolated from the boiler and watch all these things happen without anyone touching them, even during entering harbour. That they can accept this is due partly to the reliability of the system, proved at the Admiralty Fuel Experimental Station, and partly to the fact that they have seen just what is possible.

CONCLUSION

In a paper such as this, it is obviously impossible to give details of all the trials which were carried out on the boiler, and it would be tactless and pointless to list the minor design faults in the boiler and its auxiliaries and systems which were discovered and rectified during the trials. There is, nevertheless, no doubt in the minds of all naval personnel concerned that not only are the Guided Missile Destroyers the better for having had some of the "bugs" taken out before they went to sea, but that our knowledge of this type of boiler and its associated auxiliary machinery and controls has been enhanced considerably by these trials. It is believed that this feeling is also shared by the many manufacturers who have benefited by having their products tested thoroughly, and who have co-operated whole-heartedly during the trials.

There is a further factor which is of considerable interest to the Admiralty: it is essential to have a modern boiler available in a research establishment on which to evaluate new ancillaries and ideas, and on the prototype Guided Missile Destroyer boiler at the Admiralty Fuel Experimental Station will be tried many of the features which, it is hoped, will figure in future designs.

ACKNOWLEDGEMENTS

The author wishes to emphasize that the trials described were the combined work of many. He is particularly indebted to the staffs at the Admiralty Fuel Experimental Station, Haslar, and the Admiralty Engineering Laboratory, West Drayton, and to Babcock and Wilcox Ltd., who were naturally intimately concerned with the trials. This paper is published by permission of the Admiralty, but the views expressed are those held by the author and must not be construed as necessarily representing those of the Admiralty.

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Discussion

Captain W. B. S. Milln, R.N., said that he was very grateful to Lieutenant-Commander Thomas for inviting him to open the discussion. He was no boiler expert and, looking at the list of those to take part in the discussion, he was horrified to see the number of experts; so he thought it best to confine his remarks to accentuating some of the points which the author had made.

Initially, there was a remark that he must make about being the senior engineer of *Ark Royal*. He had been the Chief Engineer of two aircraft carriers and could say from experience that, if Lieutenant-Commander Thomas had written the paper while keeping the *Ark Royal* going, he could assure those present that as much midnight oil as fuel was flowing in that ship.

In particular, he would like to stress again, even though the author had done so in his remarks, the value of those prototype trials. He could speak with some feeling on that, because he was the Engineer Officer—he thought that he was something like fifth in line—who actually took the *Victorious* to sea after seven years in the dockyard. The ship had a new design of boiler with a measure of remote and embryo automatic control. No one had told them how to work it. They had to find out the hard way. The first thing they had to do was to find out how long it took to raise steam and it took about a week the first time. The point there, was that in a ship it was not so easy as it might be ashore. One had to take it slowly. One did not have the instrumentation which it was possible to put into the sort of set-up that those present had seen in the illustration of the control room at Haslar.

Lieutenant-Commander Thomas had mentioned the problem of small design defects, and he thought that if he told those present a little story, it would highlight the point about the little defect. The machinery trials had been done, and the flying trials had just finished. It had just been piped over the flight deck "Flying trials completed". He was about to step into the after lift when the voice of the Commander Air came over the loud hailer saying "Commander E is wanted in the machinery control room. They have got water in the oil". He looked at the funnel and said "Rubbish", because it was as clear as a bell. But then a stoker-mechanic said "Will you come down to the control room? We have got oil in the feed water".

What had happened, presumably, was that the header drain of the steam purging system had been left shut, and the non-return valve between the steam and fuel oil had failed to close properly. The first indication of trouble that they had had was when a petty officer working in the laundry observed that the boiler suits which he was washing were getting dirtier and not cleaner. The non-return valve in failing to seat was allowing the higher pressure oil to bleed back into the ship's auxiliary steam system. The oil was even found in the washing up machine right up forrard in the fo'castle.

He shut the whole unit down at once. Luckily, they were on their way back to Portsmouth. It took them seven weeks to get the oil out of the steam and feed systems. Had they not been going back to Portsmouth to open up the boiler, it would have meant another non-operational ship and, as Lieutenant-Commander Thomas had said, headlines in all the newspapers. It was vitally important to be able to iron out troubles of that sort.

Because of the very special requirement of the Navy—they put a very high premium on space and weight—a very tight control had to be kept on the design of naval boilers, a great deal more so than in the case of normal land and marine practice. In the Guided Missile Destroyer, the boiler had had to be tailored round a weapons trough built overhead. That was not the sort of thing that one would think about until one came up against it.

The author had emphasized the gain to the Navy from prototype testing. Besides that, there was no doubt that there was enormous advantage in having the trials ashore where those in the Navy could bring together the designers, not only of the boilers, but of the auxiliary machinery and the combustion equipment and so on, and really get their heads together and iron out the problems. That was a very real advantage which one was apt to forget.

There was also the question of training, a point which the author had amplified in his introductory remarks. The previous week, the Institute had held a very interesting symposium on training, and he had been particularly struck by a paper by the French delegate which had dealt with the question of how engineers were to be trained to operate automatic machinery, which was obviously coming in and would be with them in the next ten years or so.

He believed that, had it not been for the shore prototype boiler being available at Haslar, the *Devonshire*, when it first went to sea, might have been in considerable trouble. They had been able to send not only the officers, but also the engine room artificers and the stoker petty officers to Haslar, where they could see the automatics working, they could also see the insides of the black boxes and what they did.

He was sure that it was important that, when a great deal of new equipment came into the Service, the men who had to operate it must learn not to be afraid of it and this could be done if one had the sort of set-up that there was at Haslar. That was a side effect which one could not cost—but its value was tremendous.

In the first year of the two years that he had been back in what he used to call the Admiralty and was now the Ministry of Defence, his job had been to get those ships to sea, and he had been very impressed by the performance of the ratings who had been able to see the boiler working ashore. He had seen them in the ship, which was in the hands of the contractor, who was putting it through its machinery trials, and they were standing there, just itching to get on with it. A confidence was bred in them by seeing what there was and really understanding it.

He supposed that he ought to ask a question. It might sound a little old-fashioned, but he wondered whether the author would like to say a word or two about what happened to a fully automatic boiler, of the type described, when there was, say, a fire in the switchboard, a complete blackout and if all the auxiliary air went.

He was very grateful to the author for inviting him to open the discussion, and he was sure that all present would wish to join with him in thanking Lieutenant-Commander Thomas for an excellent paper.

Commander A. J. H. Goodwin, O.B.E., R.N. (Member) said that they had learnt to expect from the author a carefully thought out and informative paper, and the present one was no exception. So often one heard opinions stated and had to ask "But where are the facts?" In the present case, so many facts were given that they found themselves asking whether they might have some opinions.

There were four areas where opinions from the author would be valuable, namely:

i) Whether controllable superheat was beneficial?
ii) Whether the provision of permanent instrumentation for superheater metal temperatures was feasible?
iii) Whether there were limitations on the rate of manœuvring that type of boiler once it had reached full pressure and temperature?
iv) Whether adaptation of the spill system to on-off operation of the burners would be advantageous?

With regard to the first point, it would be interesting to have the author's opinion as to whether superheater outlet automatic steam temperature control systems served any useful purpose. That was not a frivolous question, as there were examples of naval ships with selectable superheat boilers which had automatic steam temperature control and no automatic combustion control, which had automatic combustion control and no automatic steam temperature control, and which had both, and so there were obviously different opinions on the subject. For example, American ships now had no superheat control at all.

If selectable superheat was fitted, it would appear that three damper settings—full temperature, manœuvring and flashing-up—would suffice. Simulation work suggested that temperature transients during manœuvring would be no greater than with automatic superheat control. The only penalty would be the necessity of accepting a slightly reduced temperature at cruising power.

However, the paper pointed out that a further benefit of superheat control was that flashing-up could be carried out with the superheat dampers shut. It was assumed that that was the case during the flashing-up trials reported, although it was not stated.

With regard to the second point, the superheater metal temperatures with different lighting-up procedures shown in Figs. 8, 9 and 10 were particularly interesting. The reduced superheater metal temperature obtained by lighting up from the simmering condition demonstrated very clearly the advantage of that mode of operation. Could that not also be applied to the rapid lighting-up routine?

The peak superheater metal temperature of about 1,100 deg. F. (593 deg. C.) occurring in the normal cold lighting-up case was not far removed from an unacceptable level which could presumably be obtained from even a small increase in the firing rate during the initial lighting-up period. That might be a case where small design margins on the lighting-up equipment could be an embarrassment. The value of Figs. 8, 9 and 10 would be enhanced if the author could tell them whether the position of highest metal temperature changed with time during lighting-up procedure and whether it might also change with different conditions of boiler cleanliness.

In view of the high superheater metal temperatures which were possible under lighting-up conditions, would the author give them his views about the feasibility of fitting, as standard practice in highly rated naval boilers, a number of thermocouples in the superheater at selected positions which, from experience or test, were known to be critical with regard to temperature. Such permanent instrumentation would be a guide to ship's officers about what was happening. In nuclear installations they had to have that kind of instrumentation and, presumably, it could be made of sufficient long life for that purpose.

With regard to the third point, it had been customary in the past for those in charge of machinery at sea to take an appreciable time over a large change of power except in emergency. There was once a time when two minutes was recommended for each additional sprayer for boilers with a total of about ten sprayers, and a quarter of an hour to half an hour was allowed for slowing down to normal after a full power trial. With the references to stepped changes of 20-80 per cent and *vice versa*, was the author telling them that once a lighting-up period had been safely negotiated, there was virtually no limit to the speed at which modern boilers could thereafter safely change their power? Was there some more warming-through which had to be done before one could tackle those large steps?

There would clearly be advantages if one could combine the spill system with "on-off" operation of the burners. One would then get away from the very high draught loss of 25 inches, and be able to reduce the fuel pressure to below 500lb./sq. in. where fuel pumping problems would not arise. As regards register draught loss, this could be reduced to about five inches and yet overall turn-down of the installation would be as high as 20 : 1. Obviously, the author must have thought of that at some time or other, and Commander Goodwin wished to have his up to date views on it.

In conclusion, Commander Good had asked him to express his regret to the author that he was not able to be present that evening, and so he took it upon himself to thank the author and to assure him that his paper had been of considerable interest at Y.A.R.D. The author would no doubt have gathered that his friends, Messrs. Bowes, Herbert and Orr had contributed to the remarks which he had made.

Mr. P. L. Rogerson said that as the author had stated, the boiler was as fast manœuvring as any in the world, and to see the author playing tunes on it with very rapid changes in the evaporation rate from about 20 per cent to 90 per cent was an experience not to be missed.

His comments would be limited to the automatic control aspect of naval boilers since it was in that field that the Admiralty Engineering Laboratory became involved, in 1959, with the type of plant under discussion. At that time there was much controversy about the relative merits of various types of valve operators, and the Admiralty Engineering Laboratory was asked to optimize the dynamic performance of the reciprocating pecker-type air motors selected for naval use. That positioner-operator-valve minor loop had numerous variables, such as valve travel, feed-back spring rate, pilot valve sensitivity setting and the feed-back gear ratio, all of which affected the valve response. By a series of frequency response tests in the laboratory, it was found that the operating frequency could be raised from 0·35-0·9 c/s by choosing the correct value of the parameters, thus making its performance comparable with the conventional diaphragm operator while still retaining the advantage of fail-set and immediate hand control in an emergency. Subsequently, extended endurance tests under controlled conditions of ambient temperature and load torque were undertaken on numbers of those air motors and various modifications to components and materials were introduced which ensured a service life of at least five million cycles.

Pneumatic instrument evaluation had been a continuing commitment, and the static and dynamic characteristics of most components now in use had been obtained for future design use. The tests had included very severe shocks in three planes, and it was to the credit of the instrument manufacturers that failures under those conditions were relatively rare. One problem that on occasion had caused trouble was sensitivity of instruments to tilting. In one ship, fitted with a tilt-conscious squaring relay in the forced-draught blower control, the blowers could be heard changing speed in sympathy with the period of roll. Mounting of the instrument with its sensitive axis fore and aft reduced that effect, and steps were being taken to balance the offending component.

An important point in laboratory evaluation of components was to ensure as far as possible that test conditions were comparable with those met in service; for example, it was of little use to strive for the *n*th degree of perfection in a rotary valve operator under ideal laboratory conditions only to find that in the ship the component had connected to it many feet of hand control rod gearing and a massive hand wheel, which degraded its dynamic performance considerably.

On the question of electronic instrumentation, in the laboratory they had used electronic analysers for instrument frequency response testing, those being designed to reject all noise and harmonics contained in the signal under test and to present the attenuation and phase lag of the signal as functions of two meter readings. That was generally excellent in instrument work, since responses to sine wave disturbances were usually fairly sinusoidal. That was by no means the case in actual plant testing, as was well illustrated in curve B of Fig. 18 of the paper. Since one was very often interested in knowing the shape of a signal, as that might reveal the presence of mechanical back-lash or excessive friction, for plant testing they had recorded all signals directly using ultra-violet recorders and had analysed the hard way.

Lieutenant-Commander Thomas had mentioned the boiler frequency response trials carried out, and those were very extensive. The effects on boiler water level of feed flow, steam flow and fuel flow were investigated. Two of the flows were kept constant, while the third was oscillated at various boiler powers. A certain amount of analysis had been done, and it was hoped that eventually the results would prove useful in providing information both for design purposes and for analogue computer simulation of projected installations. That exercise had once again brought out the difference between the relatively small effort required to obtain vast quantities of records and that required to analyse and understand them!

Finally, another project to be undertaken in the near future was the instrumentation of a ship fitted with automatic boiler control to obtain the complete power plant/ship dynamic response. It was intended to move the throttles in a controlled manner and measure the effects throughout the system to the final result of ship speed through the water. That information was required for a design study now being undertaken for future ships which might have more fully integrated control systems than existed today.

MR. R. E. ZOLLER, B.Sc., A.C.G.I., D.I.C. (Member) said that it was difficult to discuss such a fair statement of fact, but he wished to comment on some of the conclusions put forward by Lieutenant-Commander Thomas. Fig. 7 showed boiler

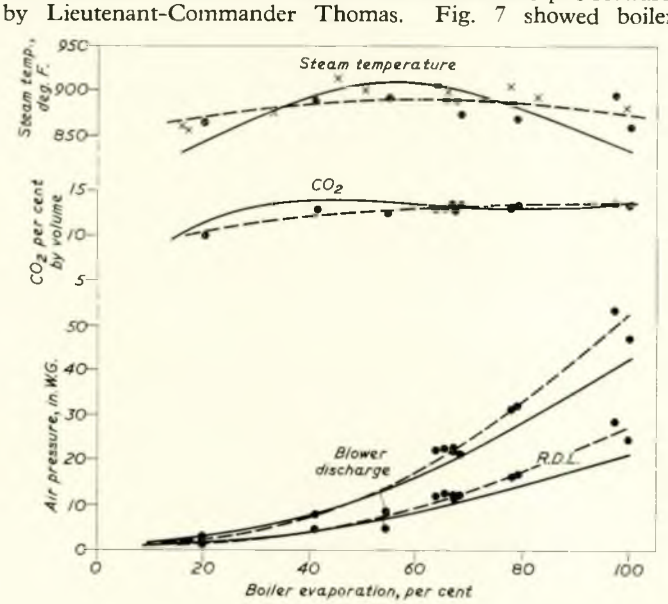

FIG. 20—*Curves showing characteristics of the boiler with test results*

characteristics by means of curves, but when the results of individual tests were processed by the statistical method of "least squares" one could not accept the smoothing. Fig. 20 was a repeat of Fig. 7 with test results shown as dots. The dotted curves were the best average polynomials. The computer correlation of steam temperature with load was a substantially flatter curve with a standard deviation of 11 deg. F. (6 deg. C.).

The crosses on Fig. 20 corresponded to the points where the smooth curves on Fig. 13 and 15 passed through the "both dampers open" position for each load. These also indicated a flatter characteristic than Fig. 7.

The boiler designer was required to produce the flattest possible superheat curve in case an incident should cause the dampers to jam at high or low power; this would cause a high superheat when passing through medium power if the curve rose as much as the paper suggested.

Even the superheat characteristics given by the author, with a pronounced inverted shape, would not have embarrassed a control manufacturer. Most land boilers designed today had the superheater in a zone where this law applied. It was no reason for preferring a single-element controller. Normal changes were readily handled with one element and the transients given in Fig. 19 were quite good for a single-element control with constant gain. The deviation was small, but the disturbance continued too long.

The six transients shown in Fig. 19 were many times more violent than would ever occur at sea. Turbines were not able to manœuvre as fast as the large astern valve, connected direct to a larger condenser, which produced 60 per cent load increased in about two seconds at Haslar. These curves had been simulated with an analogue computer and the results of the 20-80 per cent jump were given in Fig. 21. The top curve was the

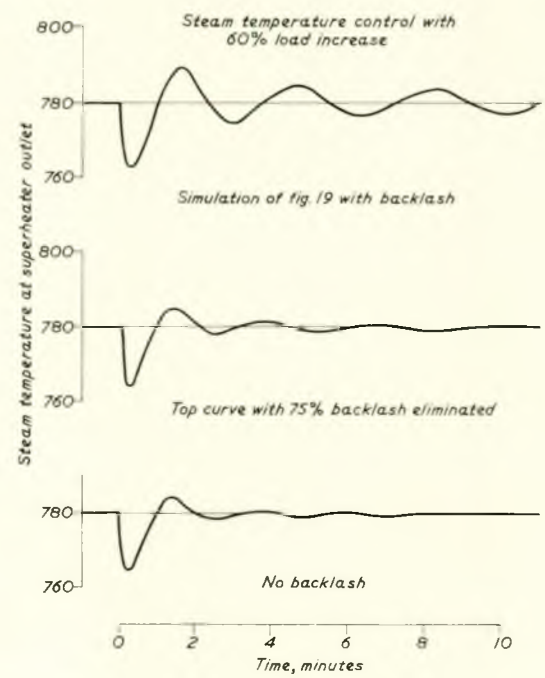

FIG. 21—*Curves showing effect of lost motion in control system*

closest on which the computer was able to repeat the boiler performance and this required the equivalence of considerable lost motion. The top curve of Fig. 21 was very like the top right hand curve of Fig. 19 although the lost motion equation on the computer was not comparable to the damper position curve in Fig. 18.

The centre curve in Fig. 21 was the effect of reducing the lost motion by 75 per cent while the bottom curve showed it entirely eliminated. It was not possible to differentiate between the effect of damper linkage and the control system itself which was a mixture of various makers' components not necessarily matched. The curves showed that the most important improvement would result from reducing lost motion as this would reduce the time of the disturbance.

The single-element system was unable to anticipate the initial sharp fall in steam temperature on each load increase and the corresponding rise when the load was thrown off. The readings were taken near the superheater outlet and would be smoother at the turbine stop valve as a result of the heat capacity of the steam piping. The first control logic shown in Fig. 12 used steam flow to anticipate these transients and one must agree on looking at Fig. 20 that this was incorrect no matter whether the characteristic was according to the full or dotted lines. The fuel loop kept the boiler drum pressure constant so that most of the initial superheat change resulted from the changed performance of the superheater. The differential of the steam flow, or better still, changes in steam drum pressure would, with suitable time constants, probably reduce the initial transient.

Selectable superheat boilers were first fitted in the H.M.C.S. *St. Laurent* with automatic single-element control of superheat by individual compressed air actuators in series to move each set of dampers. The next, H.M.S. *Whitby,* had identical boilers, but with mechanical linkage to independent damper handles; the drill was to keep one set of dampers always open as the fan power needed in service was near the design limit of the blowers. Later British ships had similar mechanical linkage, but with one operating handle and the lost motion introduced at the normal temperature was, if anything, an advantage with hand control. Circumstances were different in the *Devonshire* class because fan margins were adequate in service; one actuator was put on the hand gear whereas two directly connected would be better.

On page 277 Lieutenant-Commander Thomas regretted that he was unable to overheat the rear wall tube, although it was identical in shape to that which failed in H.M.S. *Ashanti.* Other ships of the *Tribal* Class had had no trouble, but they had all had the water side carefully searched before operating.

The paper did not mention the circulation trials which, at full power, proved that on the average the water flow was thirteen times the evaporation. The depression on the "long gauge glass" was 17in. compared with the designers' estimate of 20in. The fact that the depression was so small indicated there was less than eight per cent steam by volume in the mixture passing down the supplies to the water walls. The meters were checked carefully as this was the first boiler with large 8⅝in. diameter downcomers instead of 4½in. previously. The designer feared that the larger vortex in the steam drum might entrain more steam.

One final point was, that the paper failed to give the impression of complete abandon with which Lieutenant-Commander Thomas threw the boiler into the most violent transients and confidently watched the automatic control take over.

MR. L. J. CULVER, B.Sc. (Member) said that in view of the very wide interest represented by the engineers who would be reading the TRANSACTIONS, it was only fair to say that it had long been merchant navy practice to benefit from experience gained with the testing of naval boilers. Even where a civilian design had not been derived directly from a naval counterpart, the gain was still there, not least from improvements in oil burning originating from the work done at Haslar.

The brevity of the paper did not reveal the full scope of the trials, but the author might be consoled by a comparison with the prototype steam gunboat boiler tested ashore in 1941. The length of the complete report for that trial was less than the length of the paper and the discussion.

The change from a manual record party to comprehensive instrumentation and recorders brought its own problems. The author's comments on the general performance trials only confirmed a similar experience of sea trials with the Royal Australian Navy recently. Most exhaustive tests were carried out in the course of a week's steaming, and the original work accomplished would have merited the writing of a paper, but other requirements meant that only a summary of the essential facts was produced. Those concerned would have to find new ways of digesting the enormous weight of data obtainable with modern test equipment. As the years went by one found that there were one or two individuals with long memories, who were referred to first, and the large volume of tests data was always looked at last.

On page 270 of the paper there was a reference to the boiler gas casing, the pressure case and the suction box. He thought that piercing of the suction box, rather than the piercing of the boiler casings, was the condition when the blower suction would prevent contamination of the machinery space.

It must have been exceedingly difficult to know what to leave out of the paper. He had been trying to relate Figs. 7, 13 and 15, and perhaps the author ought to act as a referee between his own potential comment and that by Mr. Zoller. He thought that it would help if the design steam temperature characteristics were superimposed, say, on Fig. 7.

The author had referred to a high register draught loss as a penalty. Admittedly, it incurred a heavy blower power, but presumably compared with alternative methods of achieving wide range burner operation, "penalty" must be a comparative term. In common with previous speakers, he felt that it would be interesting to have the author's views on the subject of alternative methods of achieving turn-down.

Thinking of members unfamiliar with naval practice, the paper did not mention the use of steam circulation through the superheater prior to the opening of the main stop valve during the lighting-up sequences. That could be inferred from the arrowhead in Fig. 10 and from the shape of the steam temperature curves. He made that comment because from time to time merchant ships had to move rapidly, and a civilian version of the Weapons Class boiler had been used to move ship in 45 minutes from cold. He wished to correct the impression that there was something special about those naval boilers, whereas it was simply a question of keeping the superheater cool.

Finally, there was no reference in the paper to efficiency measurements, but it would be interesting to learn whether the efficiencies calculated from oil input and steam output matched the efficiencies calculated from the funnel gas losses, or what was the order of the discrepancies between the two methods.

MR. E. G. HUTCHINGS, B.Sc. (Member) said that there were several points in the paper which were worthy of comment, but, particularly as his name had already been mentioned, he proposed to confine his remarks mainly to the question of lighting up.

The curve in Fig. 10 on page 273 suggested that an increase in initial firing rate was unlikely to cause additional distress to the brickwork. If one looked at the curve closely, one would see that with the very rapid light-up, the increase in brickwork temperature was fairly uniform right up to the top rate, whereas in the case of the two other curves there was a sudden increase in brickwork temperature in the latter part of the process. Presumably one could infer from that and from other curves available to the author and himself that the brickwork would suffer no greater distress by lighting up rapidly.

In assessing the rate at which the boilers had been lit up, as indicated by the curve, it would be better to consider, not the time taken to get to full pressure, but the time taken to get to 200lb. pressure, because, in the ships, the steam auxiliaries came in at that pressure and from that point onwards one could increase the firing rate rapidly and get up to full load and maximum pressure in a few minutes.

With the normal light-up it took one hour twenty minutes to get up to 200lb. pressure. By the use of the simmering coil, the time was reduced to one hour. At the same time, the highest superheater metal temperature was considerably reduced. In other words, it was that much safer. With the rapid light-up, the period was reduced to 30 minutes from dead cold. If the simmering coil had been used, the period would have been reduced to 20 minutes and the metal temperatures would have been considerably lower.

It was worth mentioning that metal temperature in itself was not the only parameter which controlled the safety of the boiler. It must be considered in connexion with the pressure in the tube at the time.

The temperatures which were shown—1,100 deg. F. and 1,150 deg. F. (593 deg. C. and 621 deg. C.)—were not all that high for a superheater designed for a steam temperature of 950 deg. F. (510 deg. C.) corresponding to a metal temperature exceeding 1,000 deg. F. (538 deg. C.).

He was confident that one could light up the boiler even faster and possibly more safely. In fact, after the rapid light-up trial it was decided that they would carry out a further series of trials with different lighting-up periods with higher and lower fuel consumptions. He admitted that at the time they were not quite sure how they were going to get the higher fuel consumption because there were no pumps available, but in any case they were not able to do it, because of the excessive leakage from the glands on the thermocouples, and so the information never became available.

The object of lighting up with different rates of oil firing would have been to determine the manner in which the maximum superheater metal temperature varied with the speed of lighting up. Unfortunately, this could not be done from the three sets of curves, Figs. 8, 9 and 10, as the conditions were completely different in each case. In the first case, the boiler was dead cold and lit up slowly, in the second case the simmering coil had been in use for a considerable time and in the third case, the simmering coil had not been in use prior to the light-up but it was used in a different way during the light-up, therefore, the three tests were not comparable. Had it been possible to carry out the projected further tests, these might have shown that there was very little change in the maximum metal temperature with light-up periods between ten and 30 minutes, indicating that periods of this order should be acceptable and one did not have to be too fussy about the exact time, alternatively, it might have been found that the maximum metal temperature with a ten-minute and 30-minute light-up period was much higher and lower respectively than with a 20-minute period, which would indicate that it was safe to light up the boiler in any period greater than 20 minutes, but shorter periods would be dangerous. Alternatively, the situations might have been reversed and the maximum metal temperature recorded with a ten-minute light-up might have been lower than with the 20-minute time, indicating that it was safe to light up in periods shorter than 20 minutes, but longer times might be dangerous unless the light-up was prolonged to something like 90 minutes. He suspected, although he had no real facts, that this was in fact the case and that the curve of maximum metal temperature against time taken to light up the boiler had a peak corresponding to a light-up period in excess of 20 minutes and less than 90 minutes but, unfortunately, they had not been able to establish this curve.

He would go further than Lieutenant-Commander Thomas and suggest that it was better for the boiler to light it up quickly, partly due to the various expansions which went on in the casings, and also because if one lit up at a little slower rate than shown in Fig. 10, it was probable that one would get higher metal temperatures and not lower ones.

To return to the subject of the rapid light-up illustrated in Fig. 10, he had referred to a different use of the simmering coil. During that light-up circulating steam was passed through the superheater but, instead of being blown to atmosphere, it was passed through the simmering coil where it was condensed and then returned to the feed or drain tank. That had three significant advantages. It conserved water, which was very often valuable, particularly in a small fighting ship. It added heat to the boiler thus contributing to the lighting up, and it also assisted the circulation. All those things were worth while.

They had lit up a much bigger boiler than the one under discussion—one of 300,000lb./hr.—in 20 minutes, using the same technique of passing the circulating steam through a coil in the water pocket, but working with the fuel flow following a predetermined line, and although there was no steam temperature control, they raised full pressure without distress in 20 minutes. That was in the Swedish Navy some years ago.

He would like to know from the author whether any special arrangements were made to view the burners during the light-up when the burners came in and out, and also whether there were any difficulties in respect of flashing one burner from another. He understood that experiments had been carried out, even flashing the top burner from the bottom burner with cold oil. He would like to know whether they were conclusive in any way.

There was one other small point. It was only a matter of detail, but they had heard of the importance of details from a previous speaker. Fig. 6 was correct, but misleading. A support strap was shown. There was a support strap in the superheater as illustrated, but it was there to support another thermocouple measuring steam temperature, not to support the thermocouple measuring metal temperature. Similarly, just to put the record straight, the superheater tubes were of 2¼ per cent chromium and not 2½ per cent chromium as shown originally in the preprint.

Finally, he thanked Lieutenant-Commander Thomas and the Admiralty, as it was at that time, for the very skilful way in which the tests had been carried out, and he could confirm that the value of the trials to the boiler designer was difficult to measure in terms of money. His company had been associated with all sorts of trials in many places, and sometimes people had thought that they were a waste of time, but several years later a peculiar problem would arise and one would then look at the old records. It was then that one got the value for one's money; in fact, one got more than value for one's money.

COMMANDER D. O'HARA, R.N. said, in introduction, that he was one of the gentlemen who sat in the Admiralty and relied implicity on people, like Lieutenant-Commander Thomas at the Admiralty Fuel Experimental Station, to carry out research and development work, which they did extremely well. In the case of the Guided Missile Destroyer boiler, which was steamed for 3½ years as a prototype, they had done even better.

An immense amount of work had gone into the trials during those 3½ years and a great deal of his appreciation must go to Lieutenant-Commander Thomas, who was associated with those trials for about two years.

He wished first to comment on a point raised by Mr. Zoller. Mr. Zoller had said, during the discussion, that there were other navies and other sets of automatic controls, implying that naval boilers had been constructed earlier than that for the Guided Missile Destroyer, with automatic controls to the same standards. He would defend Lieutenant-Commander Thomas in this matter by saying that the boiler in question was certainly the first Royal Navy boiler to be so comprehensively controlled. He also was of the opinion that it was the first naval boiler anywhere in the world to be so accurately and comprehensively controlled.

In commenting on the paper, he thought that Lieutenant-Commander Thomas was indulging in wishful thinking when he put the boiler weight as 35 tons. On the other hand there might have been a misprint in the paper. The weight was more like 53 tons and perhaps as high as 58 tons.

The author had mentioned that the hull design had dictated the configuration of the boiler which had, as a result, a tall narrow furnace, with the burners one above the other. That arrangement was not a good one and there had been many doubts about the practicability of it. Some of these were centred around the difficulty of flashing one burner from another, but happily, this proved to be no more difficult than in the normal arrangement. As far as he knew, the only shortcoming that had been revealed had been in soot blowing at very low powers. There had been a tendency to blow the top burner out. The remedy, of course, was to refrain from soot blowing at low powers. Since that was a rare requirement anyway, no hardship was caused.

From the point of view of the development of the combustion equipment, it was a great advantage to have available the boiler on which the equipment was going to be used. All the registers for Her Majesty's Ships were and had been developed at the Admiralty Fuel Experimental Station. A great deal of testing was done on each design, with both single-register running and bank-burning on other boilers but it was realized that there was no substitute for burning all the registers together in a bank on the boiler on which they were to be used. The furnace shape made all the difference as to whether the burners would be suitable, would have the appropriate turn-down and would behave properly at all powers.

They were, therefore, able to check accurately, because of the extensive instrumentation, the design parameters and the criteria on which the registers for the Guided Missile Destroyer boiler were designed. They were, because of this, extremely fine registers.

The rapid lighting-up trials had been mentioned several times. They were very interesting and probably the most interesting carried out in the 3½ years. It was possible that they were the most risky, too.

The effect of the simmering coil on the rapid lighting up was very gratifying. It seemed a much neater solution to the problem than many more usual methods. He believed that in the merchant service, in some cases, they blanketed the boiler with steam from another source, or even filled the superheater with water to assist circulation during light-up.

He must, however, take the author to task on one point in this connexion. He believed that the prime purpose of fitting the simmering coil was to prevent corrosion of boilers during their idle time. He agreed that the ability to light up quickly from a half-warm boiler, due to the simmering coil, was an advantage and a great one. Nevertheless, he believed that the coil was originally fitted for the prevention of corrosion and that rapid lighting up was added profit.

There was brief mention in the paper of the burning of Diesel fuel. This was a big problem. The Royal Navy found it very easy to pump Diesel fuel to the boiler, but they had not found it very easy to use the same pump to pump hot residual fuel, and the reverse also applied. They were still working on that problem. They felt that the solution was in their grasp, but much remained to be done and they would be glad to hear from anyone who had the complete answer.

The prototype boiler had ceased to be a prototype, and it had—he would not say that it had gone into honourable retirement—graduated to the senior class and had joined the other station boilers to be used on other research and development tasks. He could only repeat what the author and others who had gone before him had said. They were very conscious of the tremendous advantage which they had had from their experience with the prototype boiler.

The paper gave an indication of some of the troubles—only some, he would add—which would have been embarrassing had they been built into the ship. There was no doubt in their minds, from the point of view of naval requirements, of the value of the shore testing of a prototype of each new design of boiler, expensive though it might be, and there was no doubt that it was very expensive. However, it was not only very desirable; it was, in fact, essential.

Mr. R. Barrington said that his particular sphere was the atomizer, which under the control outlined by Lieutenant-Commander Thomas allowed such wonderful manœuvring performances with an unattended boiler room. The type of atomizer in which he was interested was very small and he had brought one with him which he proposed to circulate amongst those present.

Frankly, he was an engineering "square" to whom atomizers and basic systems meant much and he was quite lost in admiration and wonderment at the work of people who produced even more superimposed systems which drove a ship on the principle of "Look at me—no hands!"

Lucas atomizers were casually mentioned in the paper, and would seem, therefore, to be continuing to do the jobs for which they were originally intended. In his contribution to the discussion which followed the author's earlier joint paper*, the five design desiderata which were considered necessary were outlined and also the ways in which they were met. Their intention was to try to design so well that no one should pass that way again and do better.

With regard to atomizer cleaning, it was agreed with the author that it was unnecessary under normal conditions, but it was considered a daily "must" when dealing with the built-in débris which emerged on sea trials. He himself was still trying to forgive the driller of a hole in a fuel pipe (to take a pressure gauge connexion) which resulted in long curls of swarf having to be extracted late at night from some of the atomizers.

Looking away from the stars (the atomizers), would he ever be forgiven for asking if the small pilot burner had had its due share of development to meet the severity of the new conditions? Was it sufficiently robust to go on burning day after day without attention, undistinguished in performance, unextinguishable in practice? So often the major task was brilliantly accomplished and the apparently easy task was treated too lightly.

Finally, he was delighted that the Admiralty Fuel Experimental Station, Haslar, was being, or had been, modernized as shown in the photograph. The "Road of Progress" might not start at Haslar, but it certainly went through there and the traffic had been fast and furious during the last 15 years. In his own field of heavy-oil burning, three atomizers the size of coffee cups, requiring continual attention, had been replaced by one the diameter of a two shilling piece, and now they argued as to whether it should be examined weekly or three-monthly. It was a very different picture. The old atomizers were very viscosity-conscious and very dirt-conscious, and they were large in size and had to be taken off and put on again. With the small atomizer one got a 20:1 turn-down and good performance with all types of fuel, which had enabled them to assist in all the wonderful things which Lieutenant-Commander Thomas had done with the boiler. Further, with the aid of the control systems already outlined by the author, those atomizers could meet the exigencies of the service without human help.

However, the real strength of Haslar lay in those sturdy characters, both permanent and transitory, who had manned it over the years, not forgetting the little expeditionary forces which went out so well equipped with instrumentation, on sea trials, and who were a tower of strength to those in trouble. He was glad it was being used as a training ground for the new era.

Mr. D. J. Strong said that Lieutenant-Commander Thomas had referred to some analytical work on superheater control which was carried on in parallel with his experimental work. The purpose was to obtain some quantitative insight into the system by trying to express the dynamic performance of each element in the system in the form of a simple equation, and then using an analogue computer to solve all these equations simultaneously. In this way a mathematical model should emerge on the computer which behaved very much like the real system. Apart from insight into the real problem, the model on the computer could be of value in speeding development; the viability of changes could often be checked quickly, experiments which would be dangerous, even lethal, on the real system might be performed in safety. When necessary the time scale of the system might be varied at will.

The mathematical model for the steam temperature control system to which Lieutenant-Commander Thomas referred

* Brown, J. P. H. and Thomas, W. J. R. 1961. "The Automatic Control of Naval Boilers". Trans.I.Mar.E., Vol. 73, p. 101.

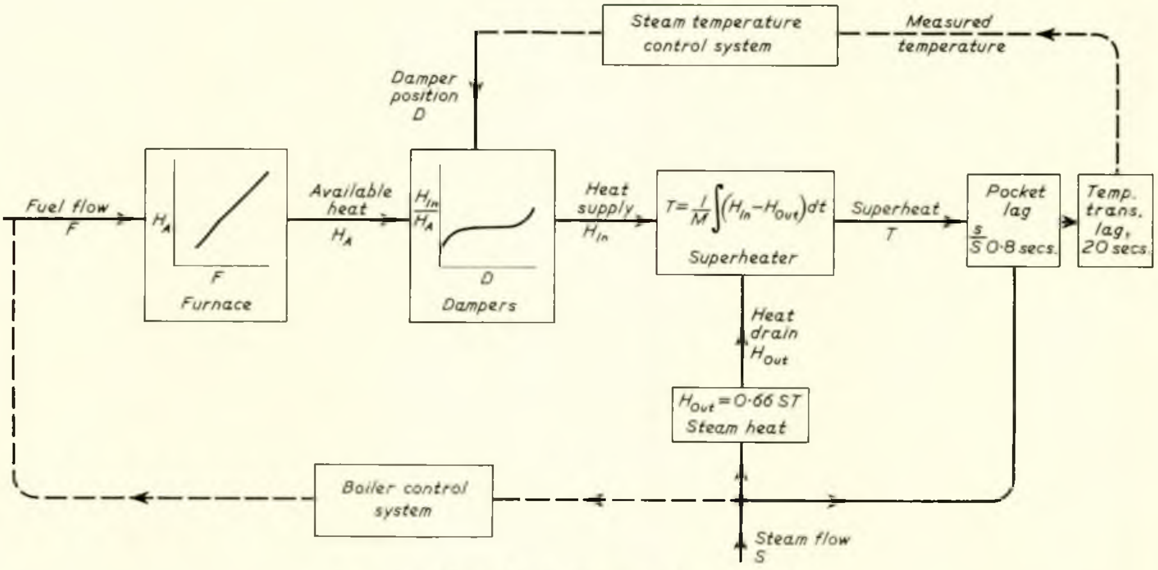

FIG. 22—*Dependence diagram of superheater*

was shown in Fig. 22. Some of the approximations used, for example, the representation of the superheater itself by a single block, might be abhorrent to the purist. To set against this a representation which was academically perfect would introduce so much complexity that really important features might be submerged. There was really little point in attempting to produce accuracies of higher order than that of the original measurements.

Referring to Fig. 22, the available heat to the superheater was very nearly proportional to fuel flow with some slight discrepancy at low power—presumably due to change in flame emissivity and shape. The damper characteristics had been explained in the paper. The superheater itself was the thermal inertia of the tubes of about 650 B.t.u./deg. F., with heat supplied from the furnace, and draining heat to the steam. This simple equation worked probably because the transient time of steam through the superheater was so short, less than one second at full load. Time lags in the thermometer and pocket were accounted for in the last two blocks.

The representations shown in Fig. 22 agreed with the static characteristics given in Figs. 13 and 14 in the paper, and with most of the dynamic tests. However, the presence of backlash in the damper drive often made it difficult to define the exact starting condition.

Fig. 23 showed a comparison between boiler and computer records of steam temperature following step movements of the dampers. As fuel and steam flows were constant, the active part of the mathematical model was restricted to damper and superheater characteristics.

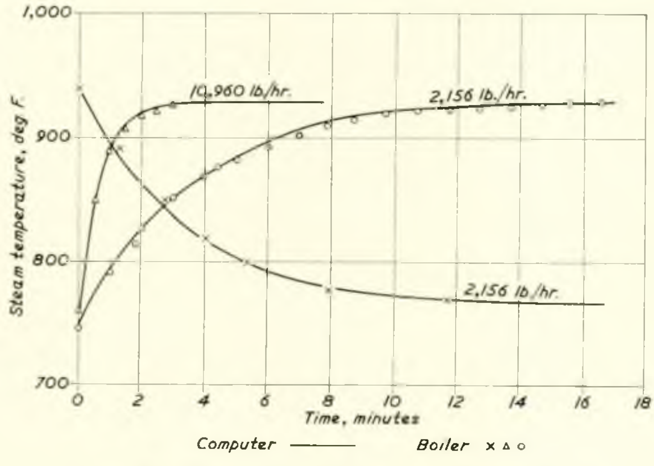

FIG. 23—*Computer and boiler performance for sudden damper movements*

Fig. 24 showed a comparison between boiler and computer records in which the whole mathematical model was used to simulate a typical manœuvre, where steam off-take from the boiler was suddenly increased. The initial drop in steam temperature occurred while fuel flow was catching up with the sudden increase in steam flow.

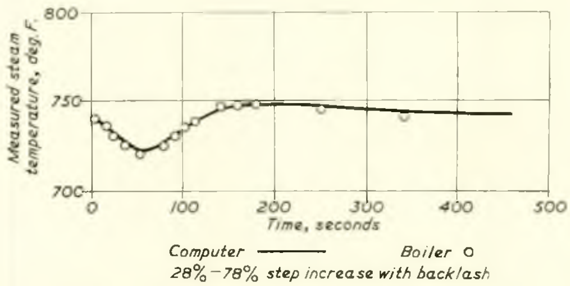

FIG. 24—*Computer and boiler performance for sudden increase in steam flow*

LIEUTENANT-COMMANDER M. F. GRIFFEY, R.N. (Associate Member) said that probably he ought to introduce himself. He had relieved the author at the Admiralty Fuel Experimental Station, Haslar, some sixteen months previously. At that time he was afraid that he might inherit a few skeletons as the boiler was turned over to him empty and open in the middle of winter, and with lots of little men busily drilling holes in the downcomers for thermocouples. There was also a major scheme afoot for fitting an enormous probe in the steam drum door to carry seven aspirated thermocouples. However, the skeletons did not materialize; the boiler turned out to be in good shape.

Speaking towards the end of the discussion, he found that some of his points had already been covered, but he thought that the following comments were still pertinent.

First of all, referring to steam conditions which were quoted in the paper, he could never understand why they were quoted as 700lb./sq. in. and 950 deg. F. (510 deg. C.), when at full power at the superheater outlet, only 650lb./sq. in. was available.

He appreciated that this was due to the pressure drop through the superheater at full power, but to him it seemed a very strange anomaly that just when the main engines and auxiliaries were required to produce their maximum output, they had steam at the minimum pressure condition. The comments of Lieutenant-Commander Thomas and of representatives of Babcock and Wilcox Ltd., would be appreciated.

Dealing with instrumentation, he thought that the most important thing to do was to build sufficient test points into the design of the prototype. After the boiler had been installed it was often very expensive and difficult to provide the odd one or two which had been forgotten. This particularly applied to test points on the pressure parts of the boiler and also to flow-measuring orifices in the various pipelines. On the whole, he found that this was well done on the Guided Missile Destroyer prototype, although it would have been useful to have had the downcomers calibrated before the boiler was built. The subsequent establishment of the velocity profile within the downcomer proved none too easy.

The furnace viewing arrangements were rather poor. It was appreciated, however, that, owing to the water walls and the suction box and casing layout, it was not a very easy matter to improve them.

Dealing with the general subject of prototype installations, to his mind three problems seemed to exist. The first was to get them commissioned sufficiently far in advance of the first production installation to enable any modifications resulting from their evaluation to be incorporated in the production models.

The second was the expense and the difficulty of clocking up significant running hours. In most cases the first ship soon outstripped the shore installation.

The third problem was how most usefully to employ the boiler after the prototype trials were complete. In the case of the Guided Missile Destroyer boiler, this latter point had not proved to be much of a worry. The training aspect had been mentioned by several people and this was as important as ever. Its steam conditions were the highest available at the Admiralty Fuel Experimental Station at the moment for the testing of both auxiliaries and valves. Also the pneumatic control systems lent themselves admirably to simple and rapid alterations for the evaluation of both single instruments and complete control systems.

Although he might be flying in the faces of his elders, he thought that it was debatable whether all prototype boilers would yield such dividends as had been yielded by the Guided Missile Destroyer prototype boiler. In fact, as mentioned by the author in his introduction, in order to enable computer studies to be made of projected new designs which might not have or indeed need prototypes, all the prime functions of the boiler were being subjected to harmonic response trials.

He wished to end with one more question which endorsed a remark made earlier by Commander Goodwin. It related to Fig. 19. He noticed that the highest tube metal temperatures were recorded by thermocouples on tubes A1 and A9. Those he knew, were, fitted in the upper tubes in the last pass of the superheater. Was it correct to assume that the highest tube metal temperatures in the boiler would occur in that area? He had doubts about this, and would be glad of the author's reassurance.

Mr. H. W. Leach said that, having read the paper with great interest, it occurred to him that their Lordships might be influenced to refit his present ship so that she could operate in the manner to which he had become accustomed.

He would like first of all to ask three questions to enable him better to understand the results which had been set out in the paper.

First, in Fig. 7, the CO_2 production showed a marked hump at about 45 per cent load, indicating the point of maximum burner efficiency. Thereafter the efficiency reduced. Did that indicate a flame impingement problem at higher flows because of the small furnace? Secondly, was that the only influence on the reversal of the steam temperature curve which, as it was stated, caused some anxiety in the production of a suitable control loop, or were other factors having a more marked influence than the fuel? Having looked at some of the later illustrations with a much flatter curve, that seemed to be rather more marked.

Thirdly, in all the curves of conditions shown for the light-up periods of the boiler, only the normal showed a steam temperature higher than the highest metal temperature in the superheater. Was that possibly because of some manœuvring valve control, or did instrumentation tolerance account for that, or was the highest metal temperature recorded not, in fact, the actual?

Naturally, as a member of a firm producing oil burning equipment, his main interest was in the production and performance of the burners, especially where they were to operate in conjunction with automatic controls in vessels with a wide range of operation, as outlined in the paper. He knew that there were some who would not agree, but they as a firm did agree that the form of approach to the problem was the right one. A system which could cover the required range of operation without the necessity for extinguishing burners, with all the attendant difficulties, must pay dividends in flexibility and the elimination of local control, and with less complication. As the author had pointed out, the penalties were high draught losses at maximum output and low CO_2 production at the minimum.

Now that the Admiralty Fuel Experimental Station, Haslar, had undertaken such a wide scope of investigation, the question of burner design and development must of necessity have taken a smaller place in the programme. Fortunately, they had a narrow furrow to plough.

Whilst the range of turn-down achieved on the boiler met the requirements, it was well known that other installations with lower self-sustaining loads would require a wider range of operation. A recent installation might be of interest. The furnace in that case was 560 cu. ft. and the fuel flow at machinery maximum gave a heat release of 400,000 B.t.u./cu. ft./hr. and at boiler maximum, 500,000 B.t.u./cu. ft. CO_2 production was increased up to the maximum burner flow to better than 15 per cent. In that installation the self-sustaining load was expected to be about one-twentieth of the maximum. In fact, one-thirtieth was nearer the mark to avoid blowing the safety valves when stopping the ship after a run at full power. That had been achieved with similar burners to those used on the *Devonshire* boiler, showing that there was still some development in the units to bridge the period of design and development of new units which must be made available to keep up with the more stringent requirements of naval vessels and automatic operation. He was sure that, without introducing on-off operations, which could be tricky in respect of cross-lighting, there was still sufficient performance in the burner to get over the period until they could make available new designs and new units.

Another benefit resulting from the achievement of the turn-down was a better CO_2 production at normal manœuvring turn-down and a wider band, some 1½in. w.g. at 200lb./hr. of fuel flow, between the smoke points, and on the test rig at least a weak extinction limit of some four times the normal operating draught. On the boiler, that would be expected to improve.

While the discussion was going on curves had been displayed showing rapid changes from 80 per cent to 20 per cent with clear stacks. The point which escaped him was how the fan inertia was overcome.

Mr. B. J. Moore said that, to his mind, the talking point on boilers generally was their maintenance, and that did not seem to have been mentioned in the paper, not in terms of internals. What he would like to know was whether any fuel treatment was carried out before the fuel was burned, and also whether there had been any slagging at the superheaters. That question would tie in with what grades of oil were at present being burnt, what one had already tried to burn, and also what one thought would be burnt in the future.

MR. P. W. R. WINDRIDGE said that the paper was of particular interest to him because he, some years ago now, had been concerned with the work on the Y.E.A.D. type of prototype boiler, which was carried out by Pametrada, which might be said in some ways to have laid the foundations for the work reported here.

On that account, he thought that one could not too strongly support what Lieutenant-Commander Thomas and others had said about the development of auxiliary machinery. Without adequate auxiliaries, the boiler was lost.

With regard to the response analysis tests shown in Fig. 18, he wanted to know whether attempts were made to measure the response of drum water level to changes in steam off-take, and if so, for how many cycles it was necessary to continue the tests before a stable mean level in the drum was obtained.

Correspondence

CAPTAIN J. SIDGWICK, R.N. wrote that as one who had often kept the "lighting up" watch in H.M. Ships, he was intrigued by the section on rapid lighting up.

The author compared a "perfectly normal" routine with more rapid methods. Had the former any solid technical basis, or was it only traditional and arbitrary routine?

The author warned that rapid lighting up was not good for boilers and should not be adopted as a matter of course. Could he be more specific on the dangers he foresaw?

Captain Sidgwick also noted in Fig. 8, that the steam temperature at the main stop valve sometimes exceeded the highest superheater tube temperature, suggesting that some uninstrumented tubes were hotter than the highest tube temperature.

MR. I. G. BOWEN commented that the present paper followed the previous one* by Brown and Thomas in 1961 and he wished to reiterate some of the comments made in his contribution to that paper. These comments referred to combustion and the type of burner and control system selected.

On page 272 of Lieutenant-Commander Thomas's paper, the section on combustion indicated that all burners were ganged together and the range was obtained by setting the initial air pressure at a very high value and using plenty of excess air to achieve smoke-free combustion at the bottom end of the range. As a technique for perfection of combustion, this, of course, was not the optimum, but the Admiralty had felt that it simplified the control system and that it was worth the penalties which were attached to this choice. He thought that a better arrangement would be to divide the burners into banks and to use a self-cooling spill burner which did not need retraction when in the non-firing position. The usual objection to doing this was that control whilst manœuvring was made more difficult. This was not necessarily so, provided an impulse was given to the bank selection by the steam flow. In other words, whilst the steam pressure was being maintained constant by alterations in spill pressure, the correct choice of numbers of burners was made by instantaneous measurement of steam flow.

He believed that such a system could be made to work with obvious advantages over that presently employed by the Admiralty. These might be summarized as follows.

Air pressure loss across registers at full load could be reduced to reasonable values say in the 6-in. w.g. to 12-in. w.g. bracket. Secondly, the quality of combustion, being dependent on air pressure, could be maintained at a high level over the whole operating range. Thirdly, the use of lower excess air could positively ensure a smoke-free stack over a wider range of boiler operation. Lastly, boiler efficiency was increased, both as a result of lower auxiliary power and lower excess air.

COMMANDER J. M. C. DUNLOP, R.N. (Associate Member) wrote that he was pleased to see that a paper had been produced about the prototype trials of the Guided Missile Destroyer boiler. At the same time he felt that those who did not know, might not get a true impression of just how much work had been put into these trials by the author and his associates and the tremendous value they had been and were still being, both in providing information for the boiler designers and for ships in service. Since he was now serving in a Guided Missile Destroyer he could testify to the effectiveness of these trials in producing a sound reliable boiler and control system, and proven methods of operating them. This was not to say that there had been no problems on board ship, but these had been insignificant by comparison with what would have arisen had there been no prototype trials. The importance of shore testing of any new marine engineering equipment, designed to meet the stringent requirements of naval vessels could not be overestimated, even when no major departure from established practice was involved.

The training aspect mentioned by the author was absolutely invaluable and the only complaint was that the Admiralty Fuel Experimental Station could not provide enough of it. This was hardly surprising since to combine the objectives of training in plant operation and prototype trials in the running of a single machinery installation was obviously an extremely difficult task.

On only one point would he disagree with the author and that was the question of "Feed Regulation". In every other respect it seemed that the design of the control system had been trimmed to provide the best answer with the minimum complexity. What was the real saving in terms of specific fuel consumption to be achieved by fitting this undoubtedly complex arrangement? It seemed that this arrangement could only prejudice that reliability which must be the main aim in machinery design for warships.

COMMANDER J. P. H. BROWN, R.N. (Member) was particularly pleased to note that one of the objects of the trial was to establish the static and dynamic characteristics of the plant. During the early stages of the development of automatic boiler controls for the Royal Navy, when he had had the pleasure of working with Lieutenant-Commander Thomas, the necessity to establish the static and dynamic characteristics of each component of the installation had not been sufficiently appreciated. They had very quickly found that not only was it necessary to know the characteristics of the installation before attempting to design a set of automatic controls, but frequently that it was necessary to alter some of the characteristics if the automatic controls were to be successful. The modification to the superheater damper operating gear was of course a typical example of this.

The fitting of automatic controls had started to bring about a better understanding of boiler performance in general. This knowledge could be further improved by the use of harmonic analysis. He was very interested to hear that it had been successfully used in the investigation of the steam temperature loop. Many of the boiler control loops were, however, interacting and he wondered whether the more general use of response analysis was likely to be so successful. Feed regulation, for example, seemed to be a very ambitious subject for a response analysis.

The rate of manœuvring which had been achieved by this boiler was far higher than would be required in practice, even in one of H.M. Ships. The fact that it could accept such

* Brown, J. P. H. and Thomas, W. J. R. 1961. "The Automatic Control of Naval Boilers". Trans.I.Mar.E., Vol. 73, p. 101.

violent changes in power proved that the design of the boiler, its auxiliaries and controls were carefully matched, and would ensure an exceptionally close control under normal manœuvring conditions. He wondered whether the more consistent control of combustion which must be obtained in the Guided Missile Destroyer boilers had resulted in a noticeable saving in wear and tear.

He thought that one of the great advantages of having a prototype boiler installation for test ashore was that it enabled a complete set of performance figures to be established for the plant steaming at various outputs and conditions. Could Lieutenant-Commander Thomas confirm that such information had been prepared for the Guided Missile Destroyers. Usually the only full set of trials figures available to an Engineer Officer were those recorded on the contractors' full power trials. Frequently, however, one needed to check whether the boiler plant was performing correctly, but was not in a position to carry out a full power trial. What was required was a basis for comparison over the whole range of power outputs. He thought that there was also a case for the main condensers of modern ships to be fitted with dump steam connexions adequate for full power steam flow, so that the boiler plant, its auxiliaries and controls could be tested up to full power under harbour conditions. This would not be an expensive addition and need not involve any increase in the heat exchange area of the condenser. It would also be of great assistance in setting up the controls and he felt sure that the author would agree that setting up a control system was something that was much more easily done at A.F.E.S. than in a seagoing ship.

He would like to know whether the superheater instrumentation had shown a particularly wide variation in metal temperatures between various parts of the superheater under lighting-up conditions. Appreciable build-up of condensation in the superheater headers could possibly result in steam flow, through tubes sited immediately above interpass diaphragms, being cut off, with consequent overheating of those tubes. Was not superheater header drainage liable to be a problem under rapid lighting-up conditions? Could the author confirm that this rapid lighting up was done with the superheater damper closed?

COMMANDER R. M. INCHES, R.N. (Member) wrote that the author's introduction could be interpreted in the sense that there was something unusual about the decision to carry out prototype shore tests of the Guided Missile Destroyer boiler. In fact, the shore testing of new designs of boiler for service in H.M. Ships was a firm and long established policy. The only significant break with this policy occurred in the case of the "I" class destroyers built in the early 1930's. For these, extensive sea evaluation had been planned before they entered normal service, but this plan had to be abandoned under the pressure of international crises. Just how big a price the Navy paid for this change of plan was impossible to assess, but the lesson had certainly not been forgotten.

From Fig. 7 it seemed that the variation in register draught loss over the operating range of the furnaces was substantially greater than 10:1. The measurement of this register draught loss, sufficiently accurately to allow it to be used for control purposes, must have presented a major problem. Could the author perhaps enlarge a little on this point?

While what the author had said about the benefits of simmering coils for rapid lighting up was very interesting, the principal purpose of fitting them was to reduce corrosion under non-steaming conditions; internally by keeping the temperature of the water up and thus reducing the tendency for oxygen to dissolve in it, and externally by reducing condensation. Could the author say whether there was any evidence of the effectiveness of the coil in the A.F.E.S. boiler in that connexion?

From the author's remarks on rapid lighting up, one got the impression that he considered this slightly less safe than slow lighting up. While obviously a thorough investigation, such as was carried out in this case, was necessary to establish how quickly a given design of boiler could be brought up to working pressure, without overstepping any limits, once this had been established, the writer could see no objection to accepting this as routine procedure, if there was something to be gained by doing so.

In fact the establishing of optimum operating, as well as maintenance, procedures was one of the benefits of a shore trials unit, which he thought needed more emphasis. Past practice was not a reliable guide, where substantial design changes had taken place; at the same time experiments with equipment in normal service to establish new working rules were not acceptable. Furthermore the ordinary operator had not got the equipment, and probably not the background either, for this sort of work. He was sure that the boiler being discussed in the paper must have been useful in this respect, apart from allowing maintenance schedules to be checked.

The author mentioned that "combustion was studied" when burning Dieso in the boiler. That he said no more suggested either that there was no significant difference between conditions when burning Dieso and when burning F.F.O., or that the information gained was so extensive and important as to merit a separate paper. Could the author say which?

Finally he wished to endorse, from direct experience, the author's estimate of the usefulness of the whole plant rather than just the boiler, for demonstrating automatic boiler control and training people in its use. The Guided Missile Destroyer unit at Haslar had undoubtedly contributed substantially to complete acceptance of, and reliance on, automatic controls in an even wider range of H.M. Ships than was quoted by the author.

MR. P. J. WHEELER was of the opinion that descriptions of actual experience in the running of plant were always valuable and that this paper was particularly so, because of the ruthless manner in which the author and his colleagues had pushed the boiler plant to its limiting conditions, both in manœuvring and in starting from cold; the paper gave valuable facts in a field where so much was done (and must necessarily be done) by intelligent guesswork.

The history of the experimental work on the steam temperature control system emphasized the importance of certain fundamental principles in control system design.

Firstly, it was interesting to see that a satisfactory standard of control could be obtained even under conditions of extremely rapid and large load changes by the use of a simple control system correctly set up. Techniques such as the frequency response analysis described in the paper were of considerable interest and would be of value in designing future systems, but such results would be completely meaningless when applied to a system with a static damper characteristic shown in Fig. 13. It seemed to the writer that the most vital part of the work was the simple plotting of the static damper position versus temperature characteristic shown in Fig. 13 and the modification of a damper system to give the characteristic of Fig. 15.

The experience with the attempt to use steam flow as an "anticipation signal" emphasized that the correct starting point in system design was the simplest possible control loop; additional features should only be added if experience showed them to be necessary. This approach was particularly applicable when a plant was available over a reasonable period for experimental work, as in this case.

The steam temperature and load curve of Fig. 7 was typical of a good approximation to the ideal characteristic of constant temperature at all loads; it indicated however, that there was no progressive change of damper position with load which could be "programmed" by the open loop signal.

The best "anticipation" signal to minimize temperature changes after sudden load changes could only be determined after detailed study of the performance of the boiler during the transient conditions; it was possible that either the derivative of steam flow or deviation of steam pressure from the set point would be useful signals.

The experimental work on control of drum level by means of speed control of the pump alone, without the use of a feed water regulating valve, was extremely interesting and it was to be hoped that it would be possible for this to be pursued further at Haslar.

It would be useful to hear the author's views regarding the choice of control signal to be applied to the feed regulating valve when the basic control was by means of the three-element signal applied to the pump; should this be simply remote manual control or, for example, automatic control, in sequence with pump speed, to give throttling after pump speed reached its minimum value?

Author's Reply

The author was grateful to all who had given up their time on a warm sunny evening to take part in the discussion, and to those who had sent written contributions. He had feared that, as Mr. Zoller had mentioned, the paper was too factual to provoke discussion, so he was doubly gratified by the response.

As he had written in the paper, much of the work on the boiler was concerned with the rectification of small defects. Although he did not report this unspectacular work in detail, it was nevertheless important, and he was glad that Captain Milln had emphasized this. A minor fault in the boiler or its auxiliaries was probably easily overcome at the prototype stage, but its rectification in a ship might be a long and expensive undertaking, involving the removal of piping, wiring and auxiliaries to give access to the offending part. Long delays might attend the manufacture of modified parts, and the Press would be justified in their critical headlines because the ship would be unoperational and unnecessarily expensive, even if the defect causing this was in itself trivial.

Captain Milln had mentioned the advantage to the Royal Navy of having shore trials involving close contact with the various designers, while Mr. Culver had spoken of the benefit to the Merchant Navy. The author agreed wholeheartedly, and acknowledged a debt to all the service and design staffs who had helped in the work at Haslar, and from whom he was privileged to learn much. He had made many friends during the trials, and could see nothing but good coming from this close liaison. He also believed that discussion of the methods and results, within the limits of commercial security, with other interested authorities was valuable to all concerned.

Captain Milln had asked what would happen if electric power and servo air supplies failed in a ship. Failure of the air supply to either pecker-operated valves or diaphragm-operated valves fitted with "lock in" relays resulted in their failure "set". Thus a total servo air failure should merely cause the boiler to continue steaming happily at constant power. The author was sure that the Officer-in-Charge at A.F.E.S. would be pleased to arrange a convincing demonstration when Captain Milln was next there. It was relevant that when a disaster occurred in a boiler room, the "average man" felt a strong desire to leave the scene quickly. The author had never seen a black box run up a ladder, and believed that the average black box was at least as reliable as the "average man".

Commander Goodwin and his Y.A.R.D. team had asked four important and controversial questions and, in giving his opinions, the author wished to emphasize that they were indeed his own and were unconnected with the Ministry of Defence. Firstly, he believed that all unnecessary complication in warships should be avoided, and that the case for superheat control was not proven. He thought that to ask a Petty Officer Engineering Mechanic to control simultaneously the number of sprayers in use on each of two boilers, the fuel temperature and pressure and the combustion air supply was more than enough. To expect him also to operate four damper control hand wheels, controlling the steam temperature of the two boilers, looking after the other machinery in the boiler room, and keeping an eagle eye on the water levels of the boilers at the same time, was too much. It was the author's opinion, supported by observation in several ships fitted with selectable superheat, that the Petty Officer often moved the dampers to what he imagined was a safe position and left them alone, and that only rarely was the superheat intended by the designers used. Automatic control could, of course, be used instead, but this meant adding another system. The author felt that in a warship, where frequent manœuvring and bursts of high power were normal, and long periods of steady steaming unusual, efficiency should be subordinated to reliability unless the loss was significant, and that reliability was best achieved by simplicity. He did, however, believe that some form of control should be fitted to permit adjustment of the superheat characteristic. Prototype trials were always exciting for the boiler designer, and if he concealed a sigh of relief on finding that the superheat characteristic was reasonably close to his design, it was none the less real. The type of combustion equipment used had a profound effect upon the characteristic, and the author believed that the designer should have a means readily available for adjusting the final result. He thought, therefore, that the best proposition for a warship was a boiler with as flat a natural superheat characteristic as possible, but with dampers fitted to be used, as Commander Goodwin had suggested, in any of three positions. Incidentally, it would be an easy matter to fit a device to move the dampers to the manœuvring position automatically if the boiler power changed significantly, and this could prevent damage to the turbines should the "average man" in the control room have an "off moment".

Secondly, the author thought that it should be possible to fit permanent superheater tube metal measuring thermocouples to boilers, given a little development. The main difficulty would be knowing where best to fit them although, in fairness to the designers of the boiler under discussion, it must be admitted that the temperature pattern was as predicted. During the early trials on the boiler, the designers and the author became aware of which thermocouples were giving the highest readings, although the exact position of the highest reading changed with power, excess air and damper position. These few thermocouples were separated from the remainder and displayed on their own continuous recorder, which was then used for rapid checks on the worst tube during any trial. In Figs. 8, 9 and 10, the thermocouple reading was shown which yielded the peak temperature for each particular lighting up process. This accounted for the fact, pointed out by Captain Sidgwick and Mr. Leach, that the steam temperature appeared to exceed the highest tube metal temperature at times. It was unfortunate, too, that thermocouple failures made it impossible for the same thermocouple to be recorded for each of the lighting up trials. The author would like, here, to pay tribute to the painstaking thoroughness of the staff at A.F.E.S., led by Mr. Ansell, in checking the instrumentation. The accuracy of the instruments in trials of this nature was most important, and Mr. Ansell's team was meticulous in checking each recorder every night, and in calibrating pressure gauges and funnel gas analysis instruments very frequently.

On Commander Goodwin's third question, the author believed himself on firmer ground when he suggested that blower inertia imposed the only limit required on manœuvring rate. To the best of his knowledge, the Boiler Design Section of the Ministry of Defence did not initiate the "one sprayer every two minutes" creed, and during his three years in that section it was held that it was physically impossible for a stoker to light sprayers quickly enough to cause trouble. No doubt Commander Goodwin would agree that the limitation was often disregarded, as any Engineer Officer who had served in a dashingly handled destroyer would testify. In the author's experience, naval boilers only suffered tube failure through shortage of water, and he had yet to hear of a failure which was attributable, beyond all doubt, to manœuvring unassociated with feeding trouble. The Guided Missile Destroyer prototype boiler at A.F.E.S. had been manœuvred violently immediately after lighting up on countless occasions, and no ill effects had been observed. It was the author's opinion that any boiler of similar power and size with good circulation (an obvious need) should also be able to stand this treatment.

Commander Goodwin's last question, Mr. Bowen's contribution and one of Mr. Culver's points dealt with other methods of achieving turn-down. Anyone who had seen the Guided Missile Destroyer boiler manœuvring could not but agree that the combustion control system met its requirements and the author felt that, having suffered the birth pains of this system, the Royal Navy would be foolish to adopt at once another system to replace it. This was not to say that other systems should not be investigated ashore in the meantime, and it must be admitted that the advantages claimed by Mr. Bowen were attractive, although one must face the fact that the burner and register were more complex. If one considered an aircraft carrier in low wind conditions, one might feel that working up to full power 30 or 40 times during the flying day would give the on-off registers a trial which they would not get in many other places. Reduction of the register draught loss, too, brought a problem in the form of increased flame size, and this might be critical in a naval boiler aiming at small volume for high power.

If a new ship design required a greater turn-down than was now obtainable with straight spill, one of two things must happen; either an entirely new system must be invented, and this would probably involve some form of variable area if air/fuel ratios were to be reasonable at all powers, or we must use on-off burners. The author believed that the main difficulty with wide range registers lay in the provision of good air/fuel mixing, and that the atomizers designed by Mr. Barrington should be exploitable over a greater range than at present if mixing could be improved. It was, however, true that a fair amount of effort had gone into trying to develop a satisfactory variable area register with little success, and thus on-off burners had a strong case for their use in a very wide range application. A full scale trial ashore was essential, however, in the author's view, to prove that they would permit manœuvring at naval rates with a clear funnel. Let it not be thought that these rates were unnecessarily high, by the way. In an aircraft carrier with steam catapults the boiler power changes were large and frequent of necessity, and the need for a clear funnel much stronger than in other ships.

Mr. Rogerson's contribution revealed some interesting details of the controls work of the Admiralty Engineering Laboratory at West Drayton. The thorough testing of the components used in boiler control systems was an essential prelude to the design, let alone the full scale testing, of a new system. There were two important results: firstly, the number of defects arising during the main boiler trials could be materially reduced; secondly, those engaged on the component testing acquired a fund of basic knowledge which frequently assisted in the solution of problems which arose in the complete systems. The author had often had cause to be grateful for the sound understanding of fundamentals which Mr. Rogerson and his team brought to bear when needed. Mr. Rogerson would, however, no doubt agree that a close liaison was required between his team and the engineer responsible for running the trials, and the author felt strongly that they should ideally be housed under a common roof. That Mr. Rogerson had "got his feet wet" in many boiler rooms was obvious from his reference, so true, to the importance of matching test and service requirements. The pure scientist working in splendid isolation was unlikely to produce any results of direct use to the marine engineer.

Mr. Windridge had asked about the response analysis trials related to water level, and Mr. Rogerson partially answered him. The author had, regrettably, had little time for thinking about response analysis during the past sixteen months, but was not surprised to learn that the A.E.L. staff was still submerged in the sea of paper so easily produced in a few days of boiler trials.

Mr. Rogerson's last point hinted at the day, not far distant, when one might expect to see the Captain able to dial the speed he needed, and have the ship work up at a predetermined rate to achieve this. In the present systems it was possible for a man to operate the manœuvring valve fast enough to beat the controls and cause "saturation". The easiest way to prevent this was to make the work-up automatic and remove the man from the system. Incidentally the proposed trials mentioned by Mr. Rogerson should lead to some interesting facts about the ship and its power requirements, and it was to be hoped that the results would be published in due course. It would be interesting to know whether work of this kind had been undertaken elsewhere, or whether new ground was being broken.

The author agreed with Mr. Zoller that perhaps the steam temperature characteristic shown in Fig. 7 painted too black a picture. He could only say that this was possibly due to the fact that so many points were available from the trials that one could almost prove anything by making a judicious selection. However, the amount of the peaking was not a point that the author wished to labour. The fact that it peaked at all, and peaked more at some other damper settings, meant that the first movement of the dampers could not be initiated by the change of boiler load. Mr. Zoller correctly pointed out that there were other ways of initiating the damper movement, but in this particular case there was no point in using them because the single element control, in the event, proved perfectly adequate, as Fig. 19 showed.

The author wished to make it clear that no adverse criticism of the damper operating gear or the control system proposed had been intended in the paper. There had, as Mr. Zoller had said, been good reasons for the original scheme, and these had in any case been approved by the Admiralty. The author's object had merely been to show the sort of work which had occupied him during the two years of trials.

He also wished to confirm that a continuing instability, such as was shown in the topmost of Mr. Zoller's three curves (Fig. 21) showing the effect of lost motion on the controls, did occur when the boiler was steamed with the lost motion included in the system. It would be interesting to try Mr. Zoller's proposal to use either steam drum pressure or the differential of steam flow as a second element on the actual boiler, to see whether a significant improvement could be achieved which would justify the extra black boxes.

The author agreed wholeheartedly that the circulation of the boiler was excellent, and regretted that he was himself unable to complete the analysis which was about to be made as he left A.F.E.S.

Mr. Culver had mentioned the need for new ways of digesting the data from trials. The author agreed and suggested that there was also a need for new ways of storing the data until they were required, and for indexing what was available. He had often had cause to be grateful to the present staff at A.F.E.S., who could produce any of the hundreds of pen recordings made during the trials, but he feared that a change of staff might cause a problem.

Mr. Culver's point regarding the piercing of the boiler suction box was, of course, valid, as one could obviously not accept any significant leakage of the boiler gas casings. The opportunity had been taken to amend the paper to avoid misleading any future readers.

The author was also sorry that an error had appeared in the original Fig. 15. With the lost motion removed from the dampers, they never reached the full/full position, and again the paper had been amended, now showing half/half in the mid position. This might explain the slight discrepancies between Figs. 13 and 15 in the preprint, and the author hoped that this alteration, together with Mr. Zoller's contribution and the author's reply, would settle any doubts in Mr. Culver's mind. The author could not help feeling, however, that he would have received a few sceptical remarks if all his figures had matched exactly.

The author agreed that the rate of lighting up hinged on cooling the superheater, and Mr. Hutchings' contribution answered Mr. Culver's question regarding circulation through the superheater during rapid lighting up. The boiler was normally lit up with the main stop valve wide open, with the drains open on all auxiliaries and systems. During the very rapid lighting up trial, steam had to be provided from another boiler for running the fuel pumps and blowers to reach the required fuel inputs, because the motor-driven lighting-up pump and blower were small. The main stop valve therefore had to remain closed until the boiler pressure equalled that in the range.

The joggled tube which had interested Mr. Culver was joggled around two furnace sight holes, each joggle being towards the furnace in the original design. It was this tube in which the metal temperatures never rose to more than 5 degrees F. above saturation, although the design was subsequently altered to joggle the tubes away from the furnace.

At full power, the designed efficiency and the actual efficiencies calculated by the methods of losses and heat balance were within about 3 per cent of each other.

The author agreed with Mr. Hutchings that if the boiler installation were designed so that it could be brought up to 200 lb./sq. in. drum pressure on motor-driven auxiliaries, full power could be reached literally a few seconds later without damage. The use of the simmering coil could also speed the process, and the true limit on rate of lighting up might well be imposed by the time taken for men to start the steam-driven pumps and blowers.

It was unfortunate that the further rapid lighting up trials proposed by Mr. Hutchings were prevented by thermocouple gland failures, and it was hoped that the Ministry of Defence would consider including these trials in the programme for the next boiler to be shore tested. The author also hoped that the next boiler would have arrangements to permit tightening or blanking of the individual superheater thermocouple glands, so that the maximum value might be extracted from all which remained serviceable.

It was relevant here to mention the importance of a flexible trials programme. Very often the author had found that he had to consider one day's results before he could decide what was best done on the following day. It was impossible to plan far ahead except in broad terms, and an allied point was that the total hours steamed by the boilers each week were not necessarily a true reflection of the useful work done.

Commander O'Hara was, of course, quite right when he said that the boiler weight was greater than the 35 tons quoted in the preprint. A boiler weight had unfortunately been quoted which excluded the weights of the superheater, the economizer and other sundries. The author had amended the figure to 56 tons in the present printing.

Both Commander O'Hara and Commander Inches had pointed out that the original object of the simmering coil was to prevent corrosion. Its obvious importance in rapid lighting up had rather overshadowed its early history, and the author regretted that he could not offer any opinion as to its value in reducing corrosion. It was not normally used at the Admiralty Fuel Experimental Station because of difficulty in providing the steam needed, and it was in the ships that its value would be proved.

Mr. Barrington's *cri de coeur* regarding debris during trials echoed Mr. Zoller's dark hint about the joggled tube. The author believed that, in the case of fuel systems, trouble could be avoided by fitting special gauze and magnetic filters, easily drained and removed for cleaning, at critical points in new systems. They could then have their elements removed after serving their purposes, to be stored and replaced when major repair work on the system made their use desirable.

The author was unsure of current official thought on pilot registers, but inclined to the view that they should only be used for lighting up (if one should happen to wish to do this slowly). The effect upon the boiler of instantaneous re-ignition of all registers at full power after restoration of fuel following a failure was too unpleasant to contemplate. One unfortunate officer from A.F.E.S. was present in a boiler room at full power when the rating in charge shut, and then reopened, the emergency fuel shut-off on an old Admiralty three drum boiler, and the consequent near explosion in the furnace made it necessary for almost every casing to be replaced. Modern boilers, with their higher register, tube bank and funnel draught losses, had become more like the traditional spy's bomb, complete with ominously smoking small hole, and the author would prefer not to be too closely associated with pilot register trials on a modern boiler.

The author was grateful to Mr. Strong for showing something of his follow-up work on the response analysis trials. Although with any new design "the final proof of the pudding must be in the eating", the need for intelligent prediction of the dynamic performance of the proposed control system was just as great as the need for accurate estimation of the boiler static characteristics. While life was exciting in the days when the author was involved with others in the "design" (he hesitated to use the word) of the control systems for new ships, he was firmly convinced that the fair certainty of success, based on reasonable estimates of the dynamic performance of the various system components, would be infinitely preferable. The author was aware that the Central Electricity Generating Board and some boiler manufacturers were interested in the relatively new art of boiler system analysis and was glad to say that the Royal Navy was enjoying a friendly liaison in this field. He used the word "art" advisedly, and could assure anyone who questioned it that one needed to be artful when trying to adjust the fuel, combustion air, feed and steam flows, and the damper positions to such set values in "open loop" control that the boiler would not only steam for several minutes without the steam pressure or temperature altering, but accept sinusoidal variations being applied to one of the quantities without lifting safety valves or shutting itself down. He believed that Mr. Rogerson would agree, although he conceded that the derivation of transfer functions from the trial results was distinctly scientific!

The author was glad that Lieutenant-Commander Griffey did not find too many bones rattling in the A.F.E.S. cupboards. His first point, whether to sense boiler pressure at the drum or superheater outlet was interesting. Fig. 25 showed the static pressures which must obtain for the two possible cases, and point X was that which must in each case be reached if main engine full power were to be achieved.

Thus on purely static considerations, the constant superheater

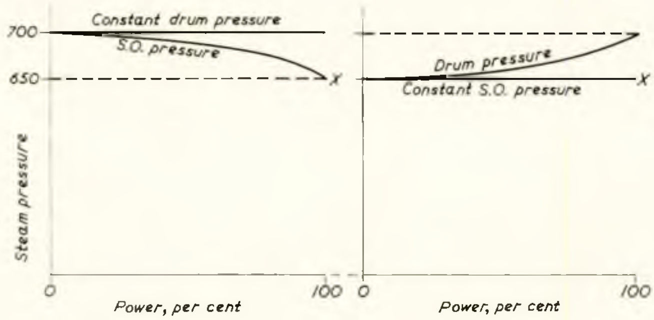

FIG. 25—*Drum or superheater outlet sensing*

outlet pressure offered the advantage of a lower drum pressure at all powers except full, but there were disadvantages. Firstly, to increase power one must add not only the heat necessary to reduce the water weight in the boiler, due to the change in specific volume of the steam/water mixture in the generating section of the boiler, while increasing to the new equilibrium firing rate, but also the heat necessary to raise the drum pressure to its new value. This might have a dramatic effect, as it did in the case of H.M.S. *Tiger* where superheater outlet sensing was used initially. Fig. 10 of Reference 1 showed the violent effect upon fuel input, which resulted in blower inertia preventing matching of combustion air to fuel during the power increase. In that ship the sensing point was changed to the drum, and the problem was solved. Secondly, the feed pump and feed regulator must cope with a downstream drum pressure which varied with power, and this might bring problems depending upon the magnitude of the pressure drop through the superheater. The latter was, however, most unlikely to be less than 50 lb./sq. in. in any new naval design, so its effect must be considered. Thirdly, the safety valves might not protect the superheater from burning out during the very heavy firing necessary to add the latent heat for raising the boiler pressure. Plainly, the choice of the sensing point for any new installation must be made considering the manœuvring rates required, the stability of the fuel, air and feed control loops, and checking that the thermal inertia of the superheater would protect it adequately during manœuvring.

The author agreed that the calibration of the downcomers during building would have been helpful, and hoped that this would be done in any future prototype boiler.

Regarding furnace viewing, he thought that one must beware lest the prototype boiler became too much unlike the production models.

On the question of whether or not to test boilers ashore, the author believed that if the boiler and/or its ancillary equipment was novel or advanced, if at least six production models were needed, and if a use could be found for the boiler afterwards, then shore testing was worth while. If the boiler was to be automatically controlled, it was considered essential for the correct auxiliary machinery and controls to be fitted with it if the test were to prove of value. It was highly relevant that the majority of the work on the Guided Missile Destroyer prototype boiler centred on the auxiliaries, the controls and their matching to the boiler, and that little development was carried out on the boiler itself.

Lieutenant-Commander Griffey's doubts regarding the exact location of the hottest superheater tubes were justified. Depending upon the steam flow and firing rate at any moment, the location changed, and tubes in the second pass were often hotter than those in the last pass.

To Mr. Leach the author would say very firmly (as he and Commander Brown had tried to emphasize in the last section of Reference 1) that he did not believe in putting new wine into old bottles. He thought that if boiler automatic control were to be entirely successful, the design of the boiler, auxiliaries and the controls must be integrated. To start with many limitations already built in must inevitably jeopardize the success of the controls.

Mr. Leach had asked about flame impingement, but the author thought that the inability of the fixed area register to achieve good air/fuel mixing over a very large air flow range

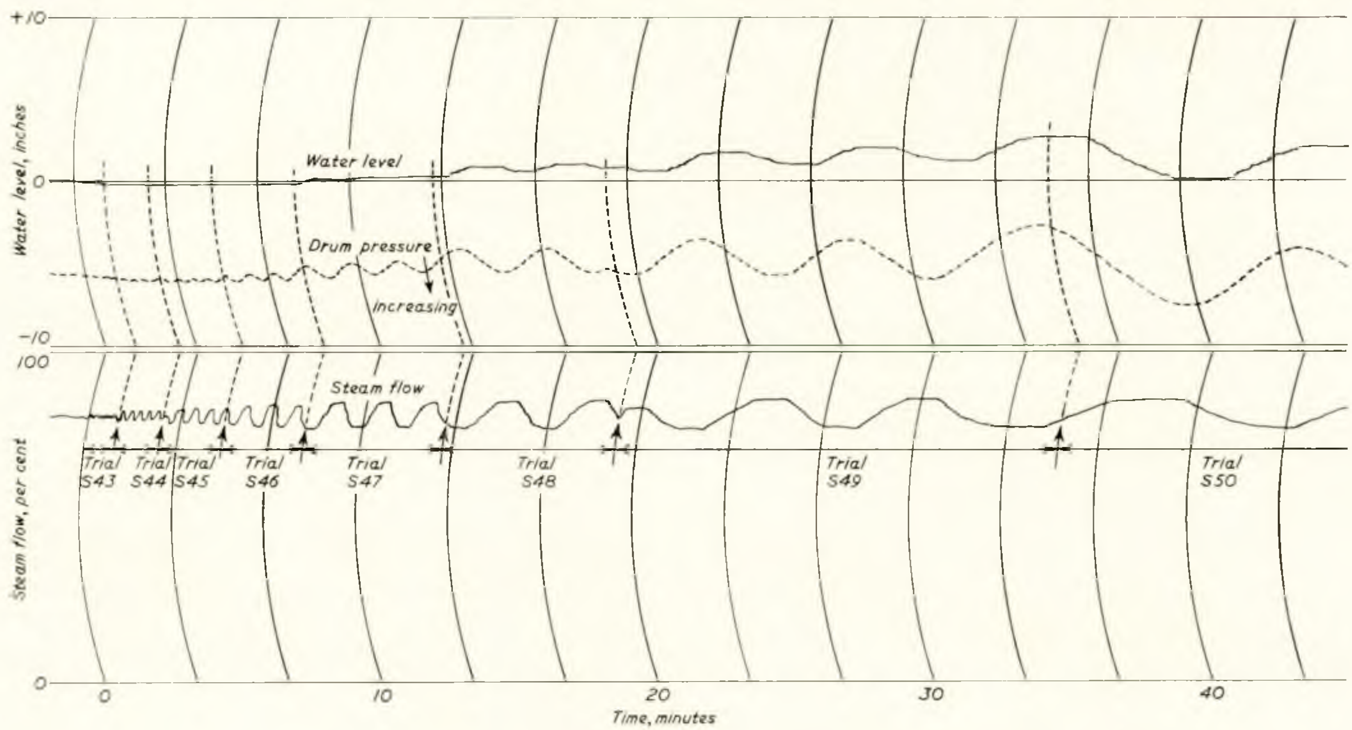

FIG. 26—*Feed system response pen recording*

was more responsible for the CO_2 content of the funnel gases falling with reducing power. There was no evidence of significant fuel impingement on the furnace walls, despite the small furnace width. The shape of the steam temperature characteristic was inevitably affected by the air/fuel ratio, but this complex topic could scarcely be discussed here, as Mr. Leach would understand.

The author was interested to hear of the success of a recent installation from Mr. Leach. He felt that one must, however, draw a distinction between the maximum possible turn-down, achieved under ideal conditions with all the experts present, and that which could be expected in practice with the combustion equipment and the controls deteriorating in performance with service. The author had seen a flame in the G.M.D. boiler at A.F.E.S. at 40:1 turn-down, but would hesitate to recommend it for more than 15:1 in service.

Fan inertia was kept low by using two small units instead of one large, and by ensuring that their specifications were not much above the true requirements.

Mr. Moore had asked about fuel quality and treatment. The fuel used was to normal naval specifications, and was rather better than that often used in merchant vessels. The boiler stayed remarkably clean, considering that it was lit up once and sometimes twice each day. When the author left A.F.E.S. it had steamed for about 1,500 hours over a period of two years, but had not been cleaned externally because the fouling was not thought heavy enough to warrant this. The oil to be burnt in future was a matter for speculation, but if one could believe the major oil companies, the quality of their fuel had remained unchanged since pre-war days.

Fig. 26 showed pen recordings taken during the response analysis of the feed system which had interested Mr. Windridge. The drifting of the mean water level was due to the need to establish the mean value of feed water flow in "open loop" control, and unless this was made exactly equal to the steam flow, the latter remaining constant, some drifting was inevitable. One of the main difficulties with this work on a boiler, as Mr. Windridge knew, was interaction of the fuel, air damper control and feed flow loops, and we were so far only scratching the surface of this subject. Commander Brown had also commented on this problem, and to both of them, the author could only say that time would show whether worthwhile results were possible.

The author had already discussed rapid lighting up, but assured Captain Sidgwick that he was not an advocate of a very long lighting up process. However, when the tube metal temperatures were running as close to the limit as those shown in Fig. 10, obviously care must be taken. The danger the author foresaw was burning out superheater tubes, and he thought that until it had been proved conclusively that the very rapid method was perfectly safe, it would be better to stick to existing times which, Captain Sidgwick would admit, did not seem to be causing many boiler troubles. (He was certainly not accelerating the process in his present ship!). Commander Inches had also supported the author's view that thorough testing must precede the introduction of very rapid lighting up as a standard routine.

Commander Dunlop's views on feed regulation evidently coincided with those of the author. The reduction in fuel consumption by characterizing the feed discharge pressure was small, being of the order of twenty horsepower for each feed pump. If, however, the feed pump could be run as slowly as possible there should be a very marked reduction in wear and tear on the pump. If Commander Dunlop could only hear the noise in the boiler room at A.F.E.S. under the time established method of constant feed discharge pressure, and then hear the noise level fall away to almost nothing as the feed regulator valve was opened wide and the feed pump slowed down to compensate, the author was sure that he would ask for the system to be fitted in his own vessel, particularly as no extra black boxes were involved. The only snag envisaged was that one must get the characteristic of the feed pump steam control valve exactly right to give the feed loop stability at all powers. The author believed that this scheme would enhance, rather than detract from, the reliability which both he and Commander Dunlop valued so highly.

In answering Commander Brown, the author regretted that he had no information available regarding whether combustion control had reduced boiler wear and tear in the Guided Missile Destroyers, and thought that it was possibly a little too early to judge. Nor did he know whether part load performance details had been issued to all ships by the Ministry of Defence, although he had himself given much information unofficially to some of their Engineer Officers.

The author agreed that the ability to run a full power trial in harbour would be invaluable. Both he and Commander Brown remembered trials in that unfortunate repair ship in which they would have needed several destroyers alongside taking steam and electrical power to reach anything like full power, and which could only use about one quarter of her boiler power at sea with the main engine at full power.

Commander Brown's questions regarding lighting up were interesting. There was, indeed, a fairly wide variation in superheater tube metal temperature during lighting up, but although the results were all available, they had not been fully analysed. The steam flows in the superheater varied from tube to tube, depending upon the pressure drops and conditions along the superheater headers, and the boiler designer's figures were confirmed by a check of the full power conditions. It was unfortunate that once any flow was established in the superheater, the pressure drops in the various sections of the headers militated against good drainage. Fig. 27 showed a diagrammatic view of a superheater and it would be seen that as P_1 exceeded P_2, steam must blow upwards through the drainage hole in the diaphragm between the first and second passes, opposing the drainage of water downwards. This did not appear to present a problem in this particular boiler, but it could be significant in others.

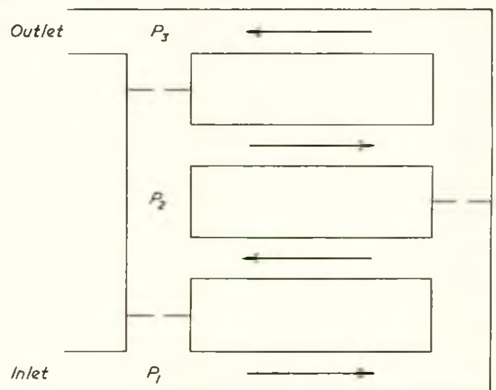

FIG. 27—*Superheater pressure drops*

Commander Inches had asked about measurement of register draught loss. The standard instruments supplied by most control firms measured air pressures over a range of about 40:1 with reasonable accuracy, and certainly no difficulty was experienced at A.F.E.S. What did cause trouble, however, was the furnace combustion "noise" which was superimposed on the register draught loss and, when amplified in the combustion air loop, could lead to instability. This rendered necessary either damping of the register draught loss signal or reduction in the loop gain, and either method did not improve the blower response. The square law connecting the air flow and the register draught loss was also an embarrassment in that it made the response of the loop different at high and low powers. The square law was a cross which control engineers had to bear, not only in this loop.

The author agreed with Commander Inches that past practice was not necessarily a reliable guide. With each advance in marine engineering, we must look anew at our methods, discarding those which were outdated and adopting some which, were previously, unacceptable. Prejudices must be broken down, and thorough investigation ashore provided the most convincing evidence with which to do this.

The combustion equipment accepted Diesel and boiler fuels with equal equanimity, as was intended, and there was little detectable difference in the boiler when burning either fuel.

Mr. Wheeler was right, of course, when he pointed to the importance of the static characteristic of the dampers. Plotting this characteristic was an integral part, and the starting point, of any response analysis, and it was merely for the sake of clarity in the paper that the steam temperature loop work was separated from the response analysis section.

As he had already said, the author agreed wholeheartedly with the "simplest possible approach" advocated by Mr. Wheeler.

He also believed that if the water level of a boiler were given a rising characteristic with load (ideal in any case and easily achieved by suitable ranging of the feed and steam flow transmitter units of the three-element regulator) it was likely that it would prove possible merely to send a maximum servo manual signal to the feed regulating valve. In other words, the requirements for feed flow should never fall to zero while the boiler was generating steam and the regulator was in use. This work was about to continue at A.F.E.S., and the author hoped to hear shortly that the scheme proposed had been proved successful.

In conclusion, the author wished to thank again all the contributors, and he hoped that he had answered adequately all their questions. He had, at any rate, answered them to the best of his ability and hoped that any errors would be forgiven on the grounds that he was now about two years out of touch with the work which he had described in the paper.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at the Memorial Building on Tuesday, 12th May 1964

An Ordinary Meeting was held by the Institute on Tuesday, 12th May 1964, when a paper entitled "Prototype Trials of a Naval Boiler at the Admiralty Experimental Fuel Station, Haslar" by Lieutenant-Commander W. J. R. Thomas, R.N. (Member), was presented by the author and discussed.

Mr. W. Young, C.B.E. (Chairman of Council) was in the Chair and seventy-five members and visitors attended the meeting.

Thirteen speakers took part in the discussion which followed.

The Chairman proposed a vote of thanks to the author which was accorded prolonged and enthusiastic acclamation.

The meeting closed at 8.00 p.m.

Section Meeting

Auckland

A general meeting of the Section was held in Auckland, on Friday, 26th June 1964, at 8.15 p.m.

The Chairman of the Section, Mr. H. Whittaker (Local Vice-President) was in the Chair and twenty-eight members and twelve guests were present.

A lecture entitled "Personal Reflections on Future Trends in Marine Engineering" was presented by Captain W. S. C. Jenks, O.B.E., a past Chairman of Merseyside and North Western Section. At the conclusion of the lecture the meeting was opened to discussion and Captain Jenks answered the many questions most ably.

Captain F. H. Bland, R.N.Z.N. (Member of Committee), proposed a vote of thanks to the speaker which received enthusiastic acclaim.

A thirty-minute film showing the construction of the first Japanese 132,000 ton supertanker was then shown.

The meeting concluded at 10.45 p.m. after which light refreshments were served.

OBITUARY

Sir Frederick E. Rebbeck, K.B.E., D.Sc., D.L., J.P.

An appreciation by the President

Sir Frederick Rebbeck, Chairman and Managing Director of Harland and Wolff, Ltd., from 1930 until he retired in March 1962, died at his home in Belfast on 26th June at the age of 86 years.

Sir Frederick, one of the outstanding British industrialists of the age, spent the greater part of his life in Northern Ireland and there is no doubt that the massive success of his work for shipbuilding and marine engineering in Belfast brought great benefits to the Province and its people. After serving an engineering apprenticeship in England he went to Queen's Island, Belfast, where he began his long association with Harland and Wolff, Ltd. When that firm was at the start of its development of the Diesel engine, in association with Burmeister and Wain, Copenhagen, he was managing their engineering works in Glasgow, and it can be said that Sir Frederick was a pioneer of the Diesel and throughout his career advanced its development. Subsequently he returned to Belfast to continue his steady rise to top executive positions.

Sir Frederick was at the helm of Harland and Wolff, Ltd., during both boom and lean years and throughout, his confidence in the future of the industry was unshaken. The volume of production at Queen's Island during the Second World War was in itself a great triumph of organization and, needless to say, an example of hard work and devotion to duty. He was responsible, among many other big projects, for the rebuilding programme at the great Belfast shipyard after the severe damage suffered during the war and before his retirement he saw the start of work on modernizing the Musgrave yard.

Many of us who became acquainted with Sir Frederick quickly realized his ability to handle men and get the best out of them. In his relations with the workers he was firm but sympathetic and one only had to join him on a tour of his shipyard and shops to appreciate the high esteem in which he was held by his men.

For many years Sir Frederick was Joint Chairman of Lloyd's Technical Committee and in 1931 was President of the Institute. He held these and many other offices with distinction and always gave of his best.

For his services to industry he was knighted in 1941, and appointed a Knight Commander of the Most Excellent Order of the British Empire during the Coronation Year. His elder son, Dr. Denis Rebbeck, C.B.E., is now Managing Director of Harland and Wolff, Ltd.

Obituary

The Right Honourable The Earl Howe, P.C., C.B.E.

Earl Howe, who was President of the Institute in 1923, died on 26th July, 1964, at the age of eighty. He was a former member of Parliament for South Battersea and a Conservative Whip, and was well known for his motor racing activities.

Francis Richard Henry Penn Curzon, P.C., C.B.E., fifth Earl Howe, was born on 1st May 1884, an only son. He was educated at Eton and Christ Church, Oxford. He joined the Sussex Division of the Royal Naval Volunteer Reserve, which he was later to command, in 1904 and, in 1914, as Commander Viscount Howe, was given the Howe Battalion of the Royal Naval Division, with which he fought at Antwerp. After leaving this force, he served in H.M.S. *Queen Elizabeth* throughout the Dardanelles campaign and to the end of the war.

In 1918, he won South Battersea as a Conservative and, until his succession to the earldom in 1929, was a vigorous, hard-hitting member of Parliament. He succeeded Lord Jessel as London Whip in 1927. He was A.D.C. to His Majesty The King from 1925 to 1928. In 1924 he was created C.B.E. and, in 1929, became a Privy Councillor.

Earl Howe crowded many activities into his life; he had been Premier and Perpetual Governor and Trustee of the King William IV Naval Asylum, Chairman of the Royal National Life-Boat Institution from 1956, and will be remembered for his valuable contributions to the sport of motor racing as chairman of the Royal Automobile Club Competitions Committee. He had taken up motor racing in 1928, at the age of fourty-four, becoming a keen competitor, and was one of the few holders of the 130 m.p.h. Brooklands badge. Much of his time was given to the tuition of novices in the sport and he was the Editor of the *Lonsdale Library* volume on motor racing. He was also interested in the training of police drivers and testing for driving licences. He often spoke in the House of Lords debates on road safety, defending the skilled motorist against those who wished to impose extreme restrictions.

With acknowledgement to *The Times*

John Paterson Cauley (Member 11450) died on 29th March, 1964, aged 63 years.

He served his apprenticeship with Wm. Walker, of Maryport, from 1916 to 1918, and with the Oughterside Colliery Co. Ltd., from 1919 to 1921. He also studied engineering for three years at Workington Technical College.

Mr. Cauley spent many years at sea, serving as fourth to chief engineer in various ships of several companies, and held a First Class Steam Certificate. Two short periods of shore employment were spent as a maintenance engineer in power stations in London. He finally came ashore in 1946, to become Station Superintendent at the Shoreditch Generating Station, transferring to the Hammersmith Generating Station in 1963.

Mr. Cauley was elected a Member of the Institute on 9th September 1947. He leaves a widow.

Alexander Davidson (Member 5306) died in Umtali, Southern Rhodesia, on 16th April 1964, after a short illness. He had been a Member of the Institute since 12th January 1925.

Born in Bathgate, Scotland, on 6th March 1888, he was educated at Bathgate Academy and served his engineering apprenticeship with McKie and Baxter, engineers and shipbuilders of Govan, Glasgow. He afterwards remained with the company as a journeyman fitter until October 1910, serving the last five months as acting foreman fitter. In that year he joined the African Lakes Corporation and went to Portuguese East Africa, on a three-year contract, and served as caterer, chief engineer and Captain in the stern-wheel vessels which plied between Chinde and Port Herald, the only means of transport to and from Nyasaland at that time.

For the next three years he was an engineer with the Illovo Sugar Estates, Nova Luzitania, on the Buzi River, 140 miles from Beira. In 1917, he joined the Beira Boating Company Ltd., as superintendent engineer of the workshops and craft. He left the company in 1925 to found, in partnership with the late J. R. Broadfoot, an engineering business, under the name of Davidson and Broadfoot; the partnership was dissolved in 1938 when Mr. Broadfoot returned to the United Kingdom. Mr. Davidson continued in the business on his own until September 1949, when he disposed of it to a Portuguese company which now operates under the name of David and Broadfoot (Succrs.) Ltd.

Over the years, Mr. Davidson carried out marine engineering surveys on behalf of Lloyd's agents in Beira and, on retiring from business, continued with these and general cargo surveys until 1954. In that year he became engaged in the sampling of mineral ores —manganese, chrome ores and chrome concentrates from Northern and Southern Rhodesia—on behalf of the shippers. He continued with this work until the end of 1962, when poor health compelled him to relinquish it.

In March 1949, he was honoured by the Portuguese Government with the award of the Ordem de Benemerencia, in appreciation of his good work in the country, in which he resided for fifty-four years.

Mr. Davidson is survived by his wife and a daughter.

Captain Henry Bramhall Ellison, C.B.E., D.S.O., A.D.C., R.N. (Associate 16209) died suddenly on 31st May 1964.

Born on 9th November 1900 he was educated at Stubbington House School and the Royal Naval Colleges at Osborne and Dartmouth. He joined the Fleet in 1917 as a Midshipman in H.M.S. *Barham.*

During his long, varied and distinguished career in the Royal Navy, he served aboard a large number of H.M. warships, specializing at first in gunnery and gunnery instruction. He displayed high academic qualities when, in undertaking five courses for the rank of Lieutenant, he gained a First Class Certificate in each.

At the outbreak of the Second World War, he was in command of H.M.S. *Fowey,* with the rank of Commander, and, in that vessel, joined the Western Approach Escort Force. He was awarded the D.S.O. in May 1940, after sinking *U.55* in January of that year. An appointment followed, as Staff Officer Operations to the Commander-in-Chief, South Atlantic. His duties included the complete organization of South Atlantic convoys and he was the author of the South Atlantic Convoy Instructions. In August 1942, he was appointed Captain Minesweeping, Tyne Area, and was promoted to the rank of Captain in December of that year. From May 1943 to June 1946, he held appointments as Officer Commanding H.M. Gunnery School, Chatham, Director of Landing Craft, Mediterranean, Admiralty representative on the delegation for the destruction of enemy installations in liberated areas and Head of the British Naval Gunnery Mission in Germany.

After the war, Captain Ellison commanded H.M.S. *Belfast,* the Flagship of the Far Eastern Station, and, for two years, his services were on loan to the Government of India, as Commodore Superintendent, Royal Indian Naval Training Establishments. In 1951, he was Senior Officer, Reserve Fleet, Portsmouth, and in command of H.M.S. *Howe.* His duties included the administration of seventy ships in reserve and the material state of these ships, mostly at short notice for service.

He was created C.B.E. in the New Year Honours List for 1951, and in June of that year was appointed A.D.C. to His Majesty The King.

In 1952, having retired from the Navy, he joined the Yorkshire Copper Works Limited as Area Manager for the North of England, working from the branch sales office in Newcastle. In 1962, he was transferred to London to take charge of the newly-built area office and large warehouse which served the Greater London area. He continued in this capacity until the time of his death.

During his commercial career, the interests of the Yorkshire Copper Works Limited were merged on an equal basis with part of the interests of the Metals Division of Imperial Chemical Industries Limited, and Yorkshire Imperial Metals Limited was formed. Captain Ellison brought, to his commercial life, much of the flavour and character of his previous career and he was loved and respected by all who knew him, both in the company and outside it. This was particularly so on the North East coast, where he formed inumerable friendships.

Captain Ellison was elected an Associate of this Institute on 2nd March 1955; he was also an Associate of the Royal Institution of Naval Architects and of the North East Coast Institution of Engineers and Shipbuilders.

James Alan Goddard (Member 2767), the founder and a director of J. Alan Goddard Limited, died on 5th May 1964. He had been a Member of this Institute for over fifty years, having been elected in November 1913. He was also a Member of the Institution of Mechanical Engineers.

Born in 1887, Mr. Goddard served his engineering apprenticeship with Clarke, Chapman and Co. Ltd., afterwards remaining in their employ, eventually to take charge of the testing department. He also saw several years' sea service and held a First Class Board of Trade Certificate. He founded the firm of mechanical engineers, which bears his name, immediately after the First World War.

In the early years of the Second World War, he became an assistant director with the Ministry of Supply, in a department concerned with the production of special mobile equipment. A few years later, when this work was completed, the staff were absorbed into another department concerned with fighting vehicle development, when he became a deputy director.

Immediately after the war, Mr. Goddard was transferred to Reading as Regional Controller for the Ministry and finally returned to his own business, in which he remained active until his last short illness.

Throughout his professional career, as well as in his social life, he was very much respected for his high principles and greatly liked for his kindly generosity, by all who had dealings with him.

Cecil George Hutton (Member 13210), superintendent engineer to the Ben Line, died in Edinburgh on 23rd May 1964. He had been with the company for forty-one years and a Member of this Institute since March 1951.

Born on 12th September 1895, Mr. Hutton served an apprenticeship with Ramage and Ferguson Ltd., of Leith, and returned to them after the First World War, during which he served with the Royal Engineers and won the D.C.M. After completing his apprenticeship he joined the Ben Line in October 1923. He gained a First Class Steam Certificate in 1926 and a Motor Endorsement in 1928.

During the Second World War, he served at sea and was in *Benarty* when she was sunk by a German raider in the Indian Ocean in 1940. He was a prisoner for six months in Italian Somaliland. Subsequently he served in the first Merchant Navy aircraft carrier and, just prior to the end of the war, was appointed chief engineer of *Benlawers,* the first turbine ship in the Ben Line fleet. At the conclusion of the war he was awarded the O.B.E.

Mr. Hutton was appointed senior assistant superintendent engineer in 1946 and Superintendent Engineer in 1962.

He leaves a widow and a daughter.

Thomas William Thatcher (Member 4418), a Member of the Institute since 5th December 1921, died on 19th April 1964, in his ninetieth year.

He was apprenticed to Hornsby and Sons of Grantham and, in 1890, joined the Royal Navy. He served with the R.N., from apprentice to Chief Petty Officer Artificer seeing twenty-two years' sea service, until 1932.

After leaving the Navy, he took up an appointment as handicrafts instructor at the Willenhall Central School, from which he retired in 1942, through ill health.

Reproduced above is the document authorizing the Grant of Arms to the Institute. This Grant of Arms was made possible by the generosity of Mr. Robert Beldam (Member) in memory of the long association of his family with the Institute and, in particular of Mr. Asplan Beldam, his great uncle, who was its first President, and Mr. Ernest Beldam, his father, a Member for fifty-five years.

The background of the shield is the conventional way of showing water in heraldry and stands for the ocean which is cut by the prows of ships symbolized here by the pile. The calipers signify exact measurement essential in designing and making ships. In the crest the mercantile crown stands for the peaceful use of ships while the sea-lion, joining the Royal lion with the sea, is collared and lined for control and the cog wheel stands for the transmission of power for the purposes of propulsion. The sea-lion supporters are brought under control for teaching. The torch is for learning, and the rod of Mercury for commerce. In the badge the wreath of excellence encircles an emblem of engineering and propulsion upon waves of the sea.