SHORE TESTING OF A PROTOTYPE BOILER INSTALLATION

BY

LIEUTENANT-COMMANDER W. J. R. THOMAS, R.N., A.M.I.Mech.E., M.I.Mar.E.

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 700 lb/sq in. and 950 degrees F., 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 this 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, where fuel, feed and cooling water, and a condensing plant were already available. The plant was built by Messrs. 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

Almost every type of combustion equipment used at sea by the Royal Navy was designed and developed at this establishment, and the records there, describing the progress made through the century in the combustion equipment of boilers, make interesting reading. 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

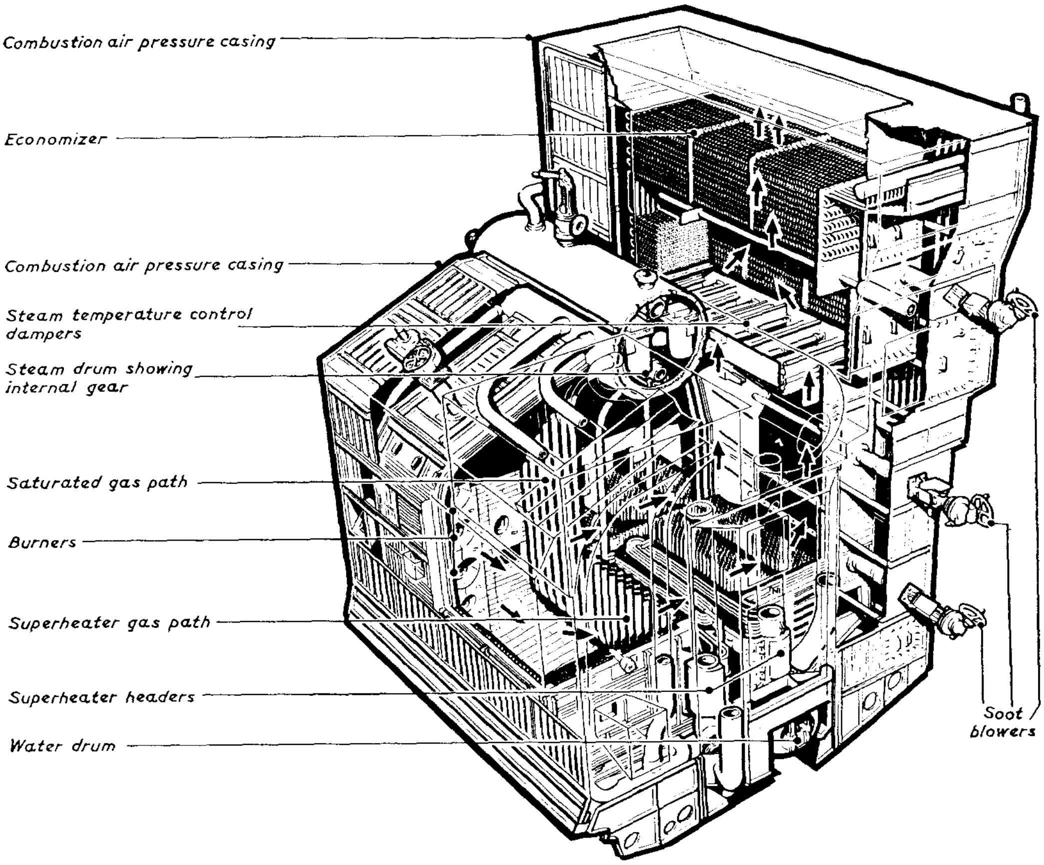

FIG. 1—REAR CUTAWAY VIEW OF GUIDED MISSILE DESTROYER BOILER

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 Messrs. 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 9 ins
Breadth	20 ft 1 in.
Height	23 ft 3 ins.

Weigh :

Approximately 35 tons

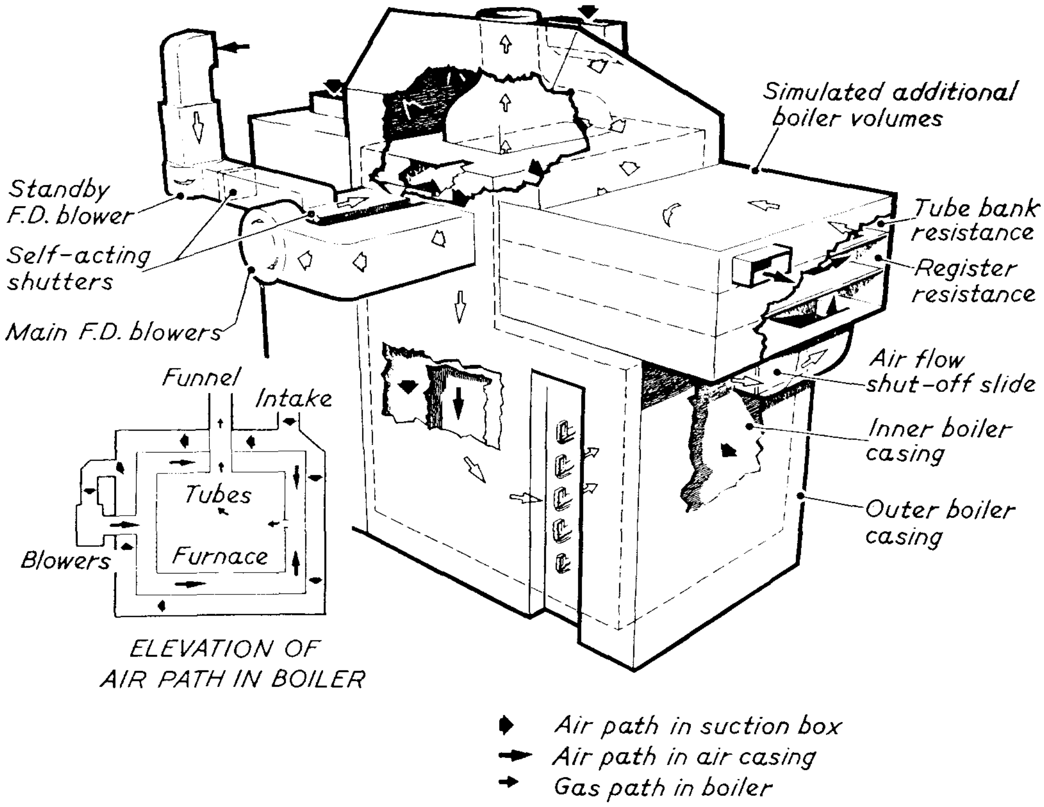

FIG. 2—ARRANGEMENT OF BOILER AIR BOXES IN THE SHORE INSTALLATION

Steam conditions:

700 lb/sq in. and 950 degrees F.

Steam and Water Pressure Drops at Full Power:

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

Heating Surfaces:

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

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 boiler casings 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 the same size as that

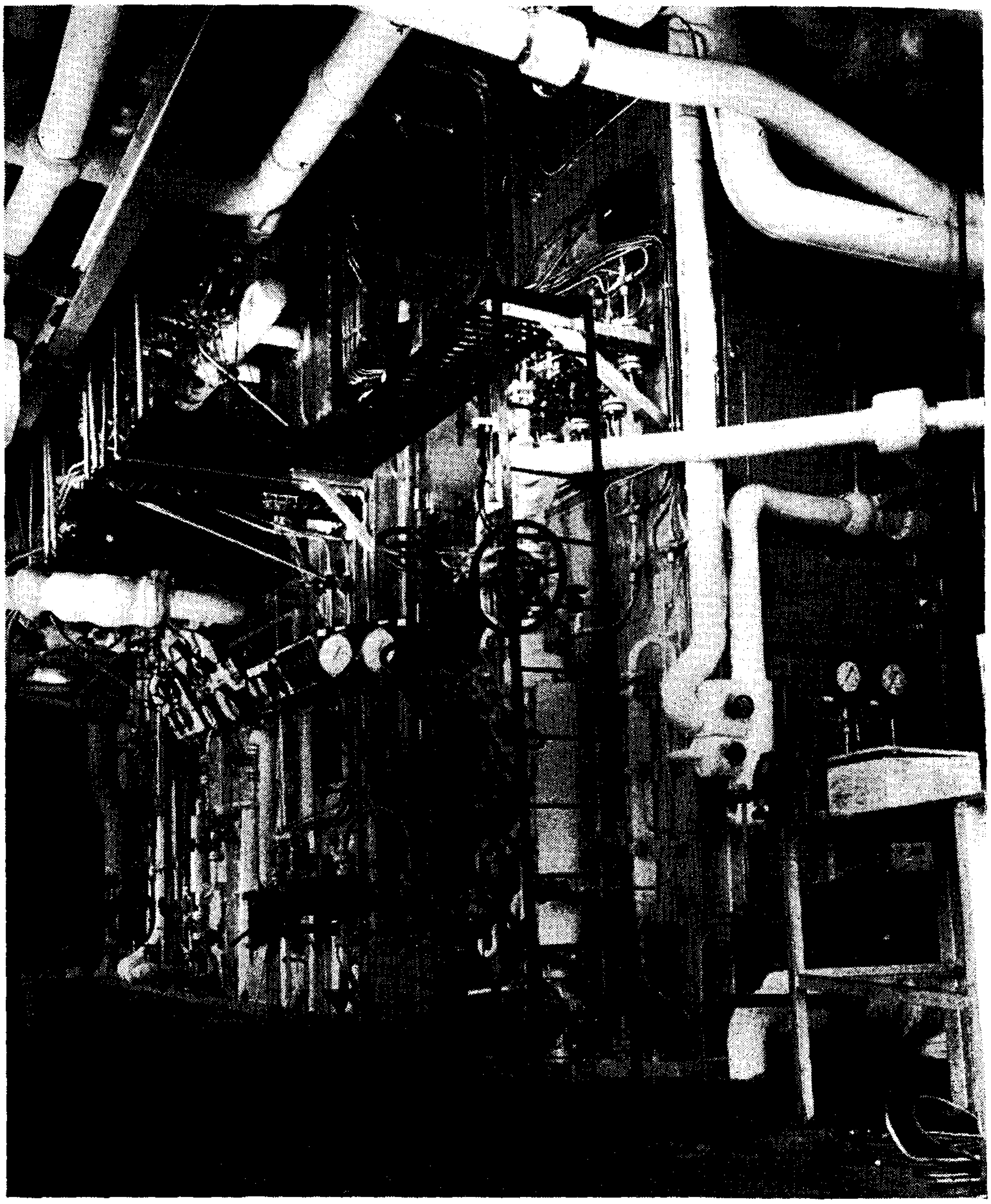

FIG. 3—GENERAL VIEW OF THE BOILER ROOM

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 Fuel Experimental Station are all identical to those fitted in the ships, but the main extraction pump and the stand-by auxiliaries are simply suitable ones which were available. The deaerator

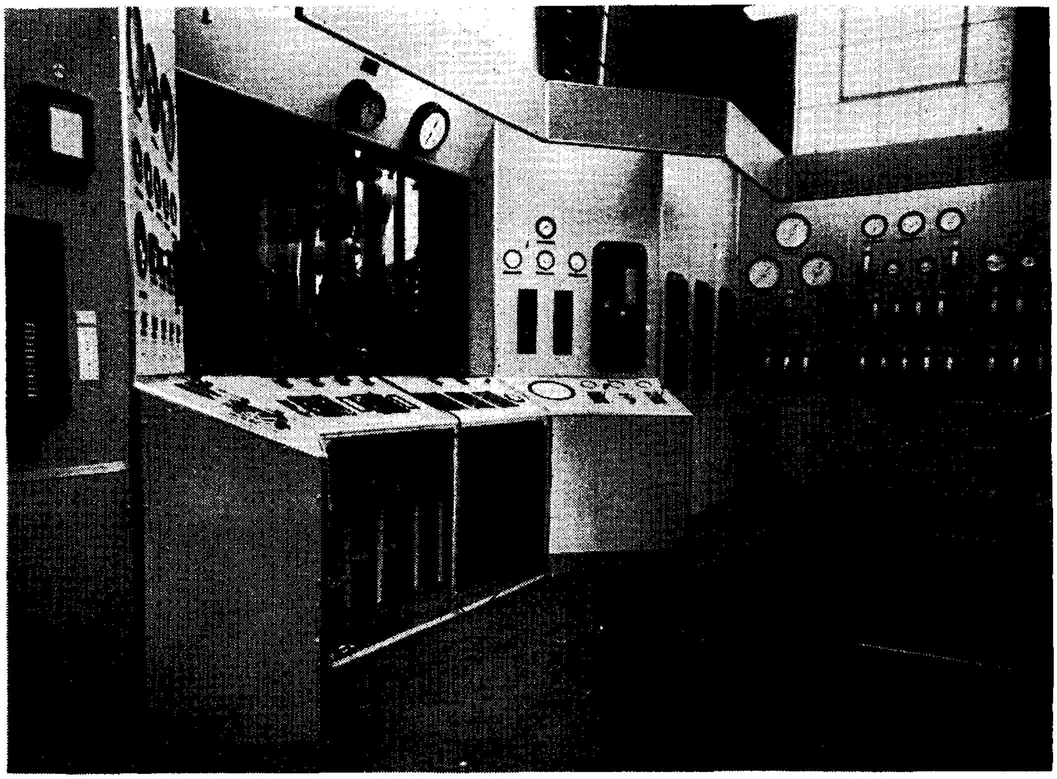

FIG. 4—THE CONTROL ROOM AT A.F.E.S.

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.

CONTROLS AND INSTRUMENTATION

The Control Room and General Instrumentation

The control room is shown in FIG. 4, and it was made large enough to conatin 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. Among 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 10 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 connections 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 27 lb/sq in. and were proportional to almost every quantity in the boiler system, were available to record at a very few minutes notice.

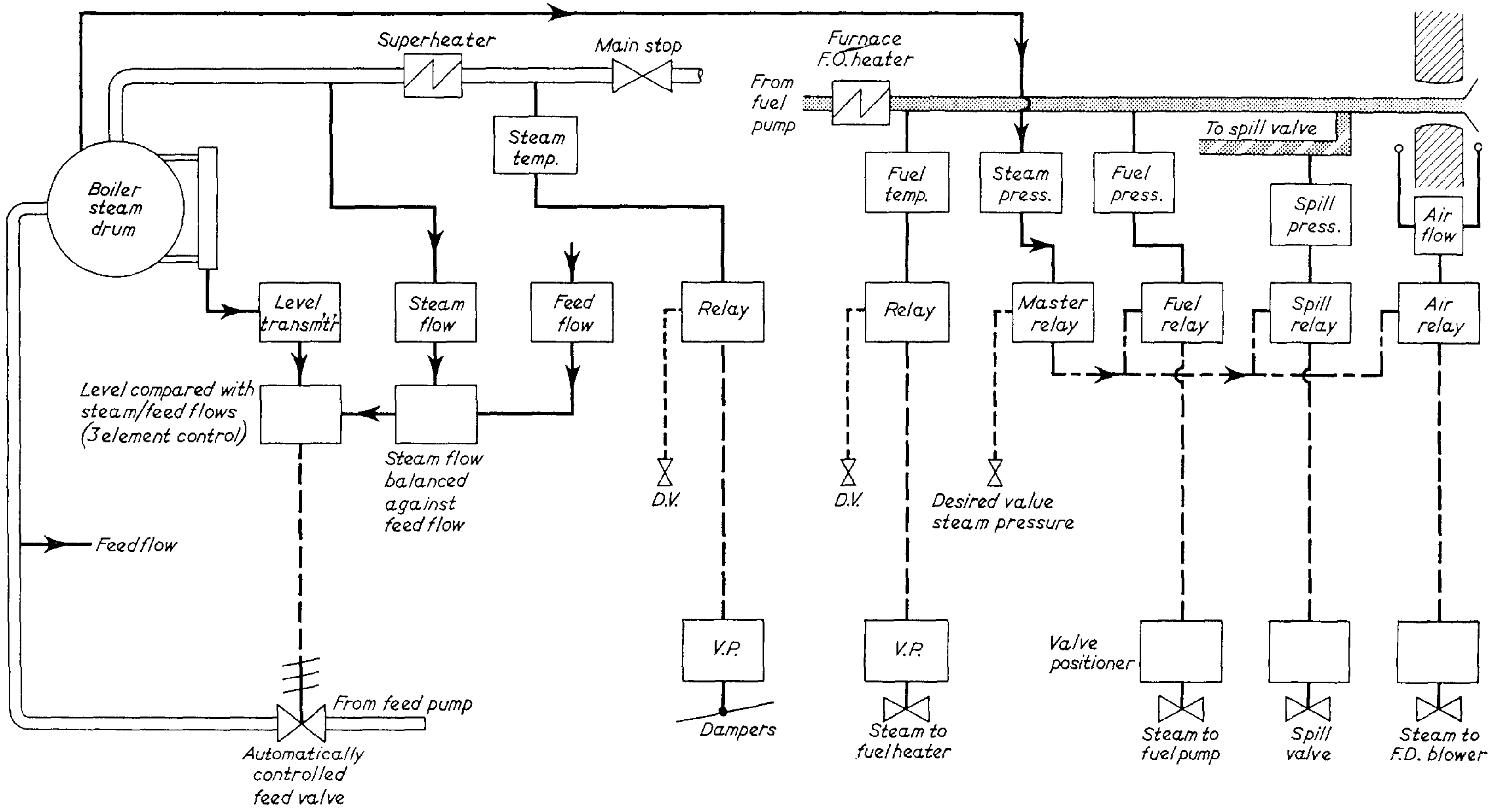

FIG. 5—SCHEMATIC LAYOUT OF THE CONTROL ROOM

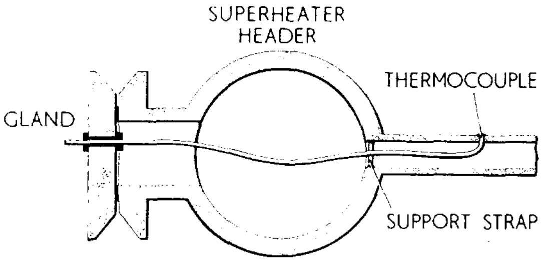

FIG. 6—METHOD OF MEASURING TUBE METAL TEMPERATURES

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

Instrumentation of the Superheater

The superheater tubes are of 2½ per cent chromium and one 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 degrees F.) 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 temperature 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 thermocouples were installed by Messrs. Babcock and Wilcox 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 new 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 steam temperature loop, while the others shed some light on the combustion, which is discussed in the next paragraph.

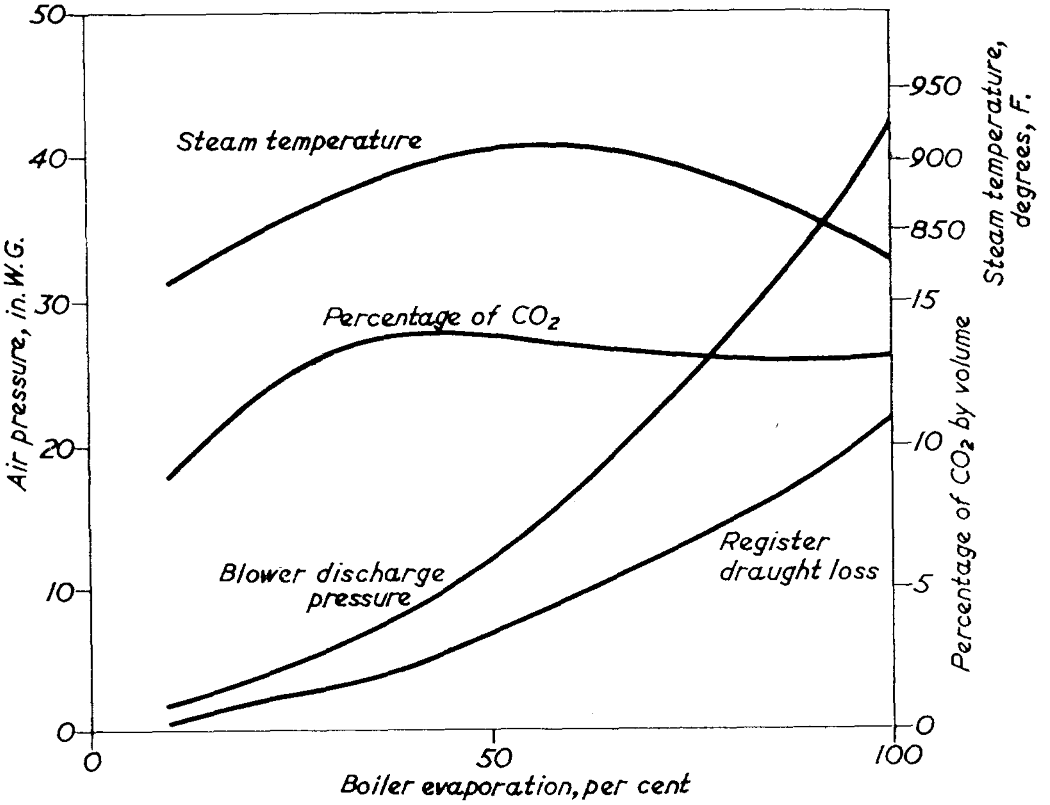

FIG. 7—TYPICAL CHARACTERISTICS OF THE BOILER

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 stand-by 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 requirements 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 200 lb/hr per atomizer, although the register draught loss range over which the funnel was clear was reduced to about $\frac{1}{2}$ in. water gauge at this output. The penalty paid for this wide range of burner operation is not only inefficiency at low outputs but also a very high register draught loss at high outputs, this being about 25 in. 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

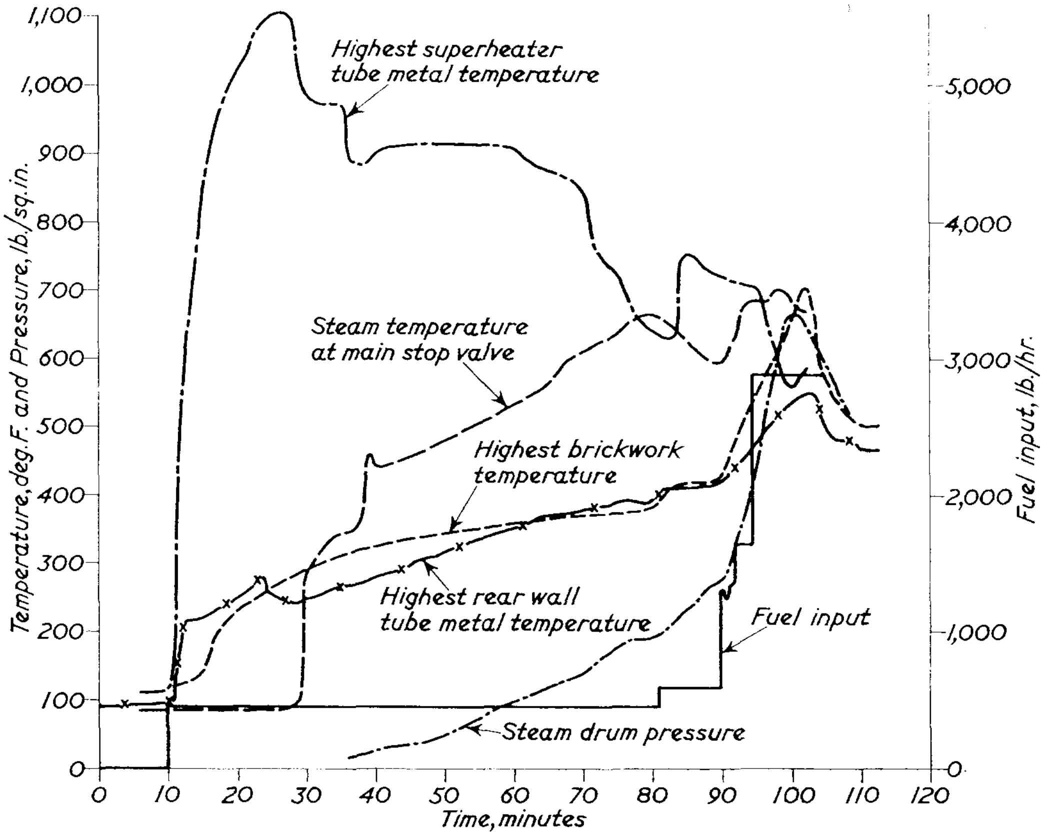

FIG. 8—NORMAL LIGHTING UP FROM COLD

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 shutdown.

RAPID LIGHTING UP FROM COLD

There is obviously a need for naval ships to be able to get under way quickly in 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 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, were selected those 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 clearly be seen.

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, with-

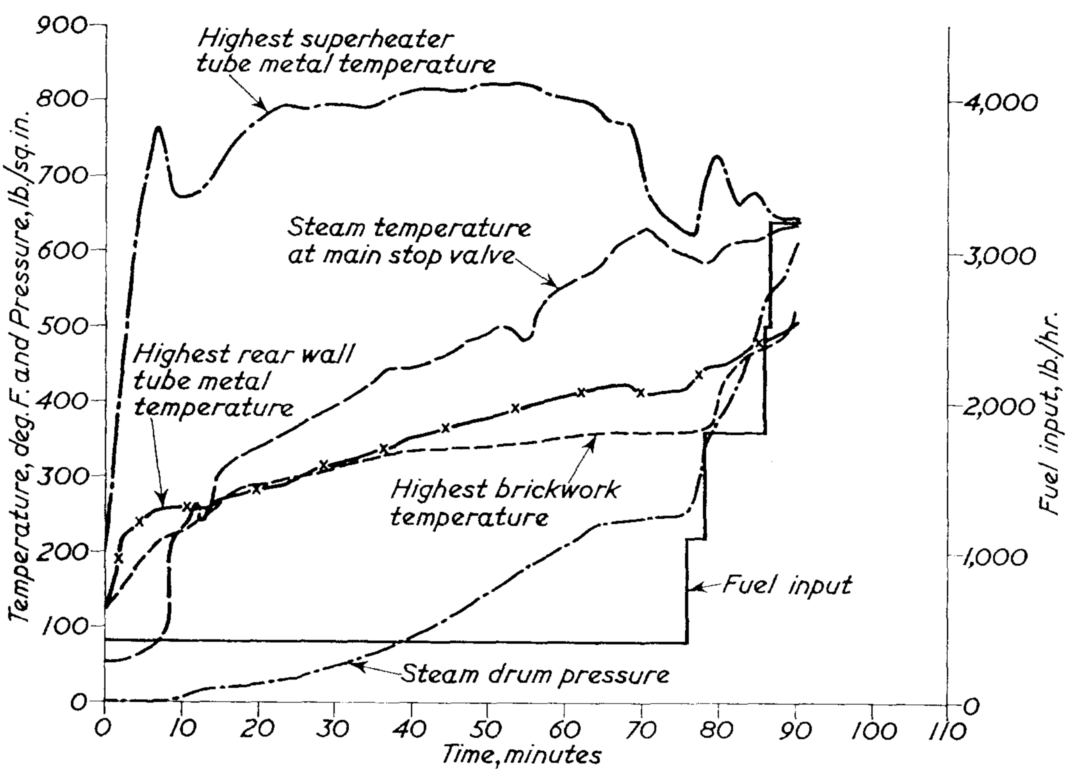

FIG. 9—LIGHTING UP FROM THE SIMMERING CONDITION

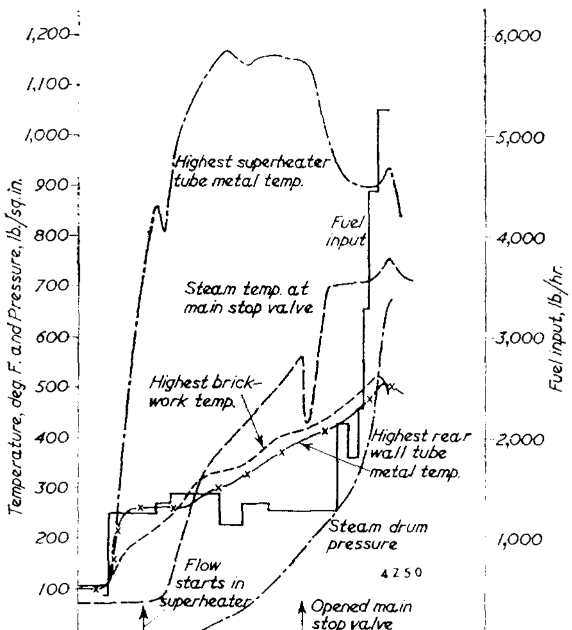

FIG. 10—RAPID LIGHTING UP

out 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 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 degrees F. The result is shown in FIG. 10, 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.

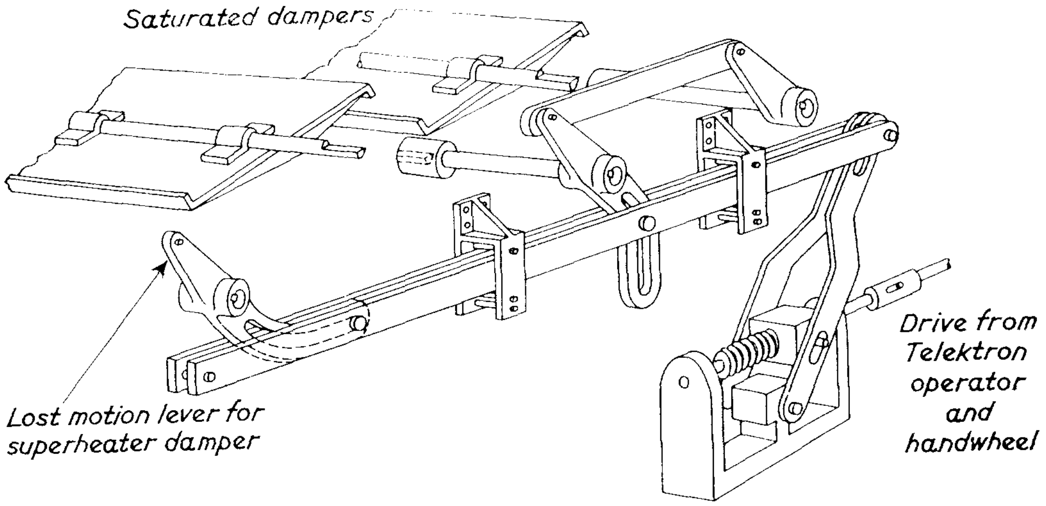

FIG. 11—ORIGINAL SUPERHEATER DAMPER OPERATING GEAR

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 handwheel control of both, the lost motion device shown in FIG. 11 was adopted, Telektron air motors being used to turn the screwblock drive when automatic or remote control was required.

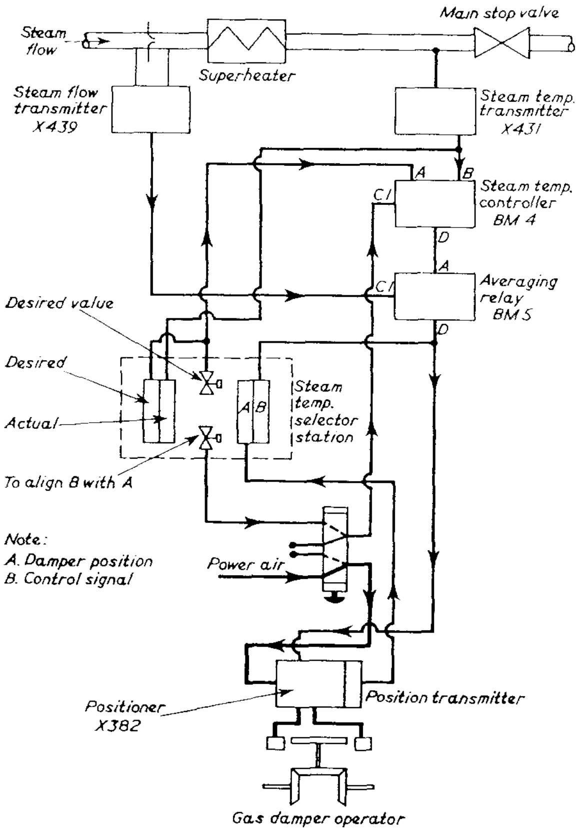

FIG. 12—ORIGINAL DAMPER CONTROL SYSTEM

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.

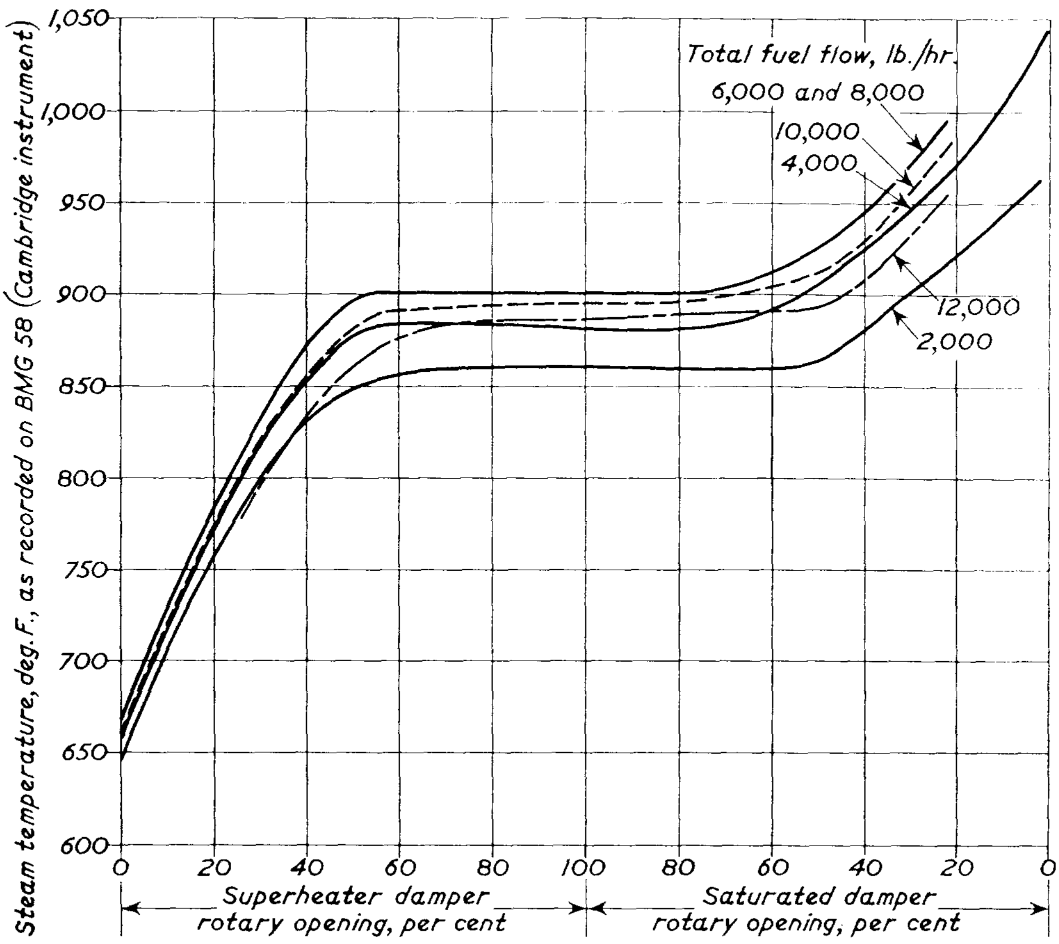

FIG. 13—ORIGINAL DAMPER STATIC CHARACTERISTICS

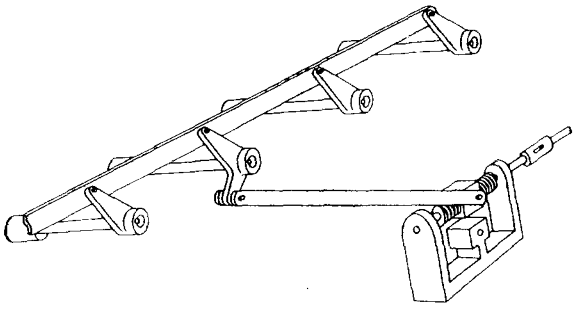

FIG. 14—SUPERHEATER DAMPER OPERATING GEAR AFTER MODIFICATION

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-

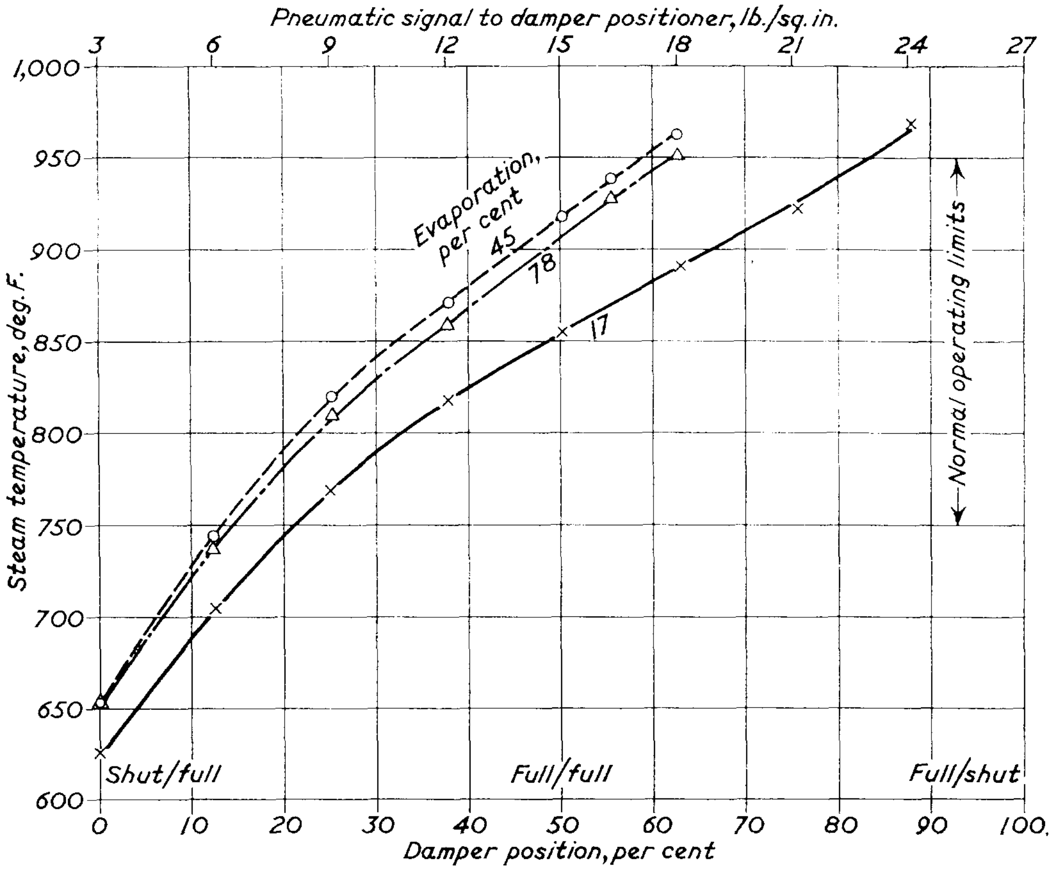

FIG. 15—DAMPER CHARACTERISTIC AFTER MODIFICATION

power. This at once rendered the original control scheme, of using a change of 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.

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 Engi-

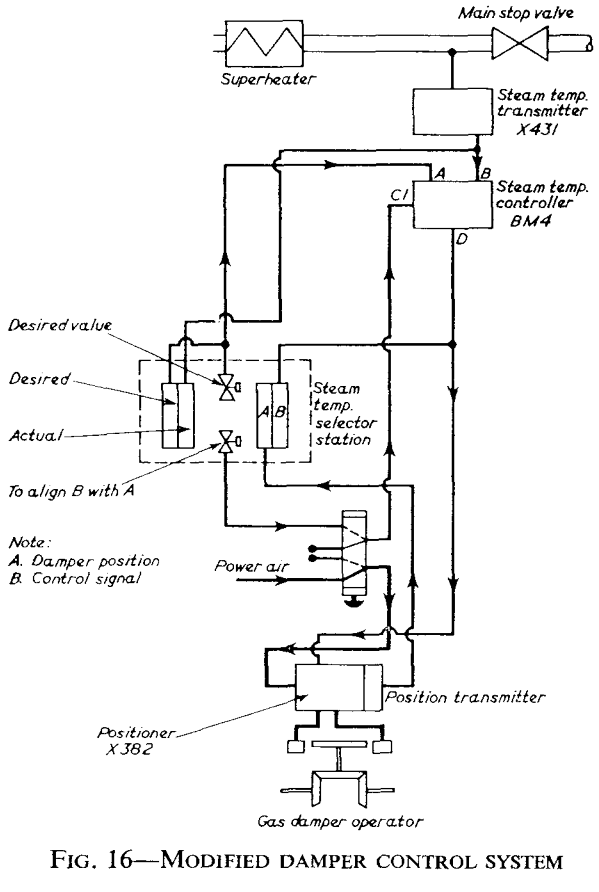

FIG. 16—MODIFIED DAMPER CONTROL SYSTEM

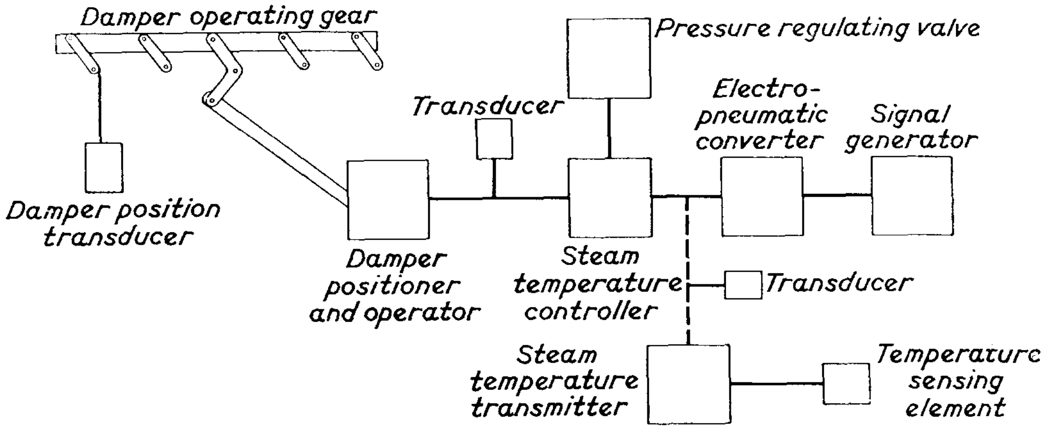

FIG. 17—LAYOUT OF RESPONSE ANALYSIS EQUIPMENT

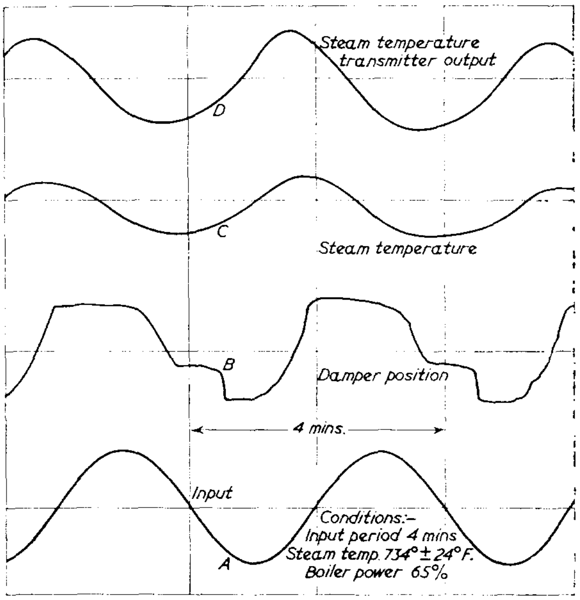

FIG. 18—TYPICAL RESPONSE ANALYSIS TRACE

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

Damper position input pneumatic pressure

Damper position

Superheated steam temperature (measured by an inconel sheathed thermocouple in the steam without a surrounding pocket.)

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 degrees F., these being the temperature limits between which it was required to operate the boiler in practice. FIG. 18 shows a typical trace obtained during the trials. As the frequency of the input sine wave 'A' is increased, the amplitude of 'B', 'C' and 'D'

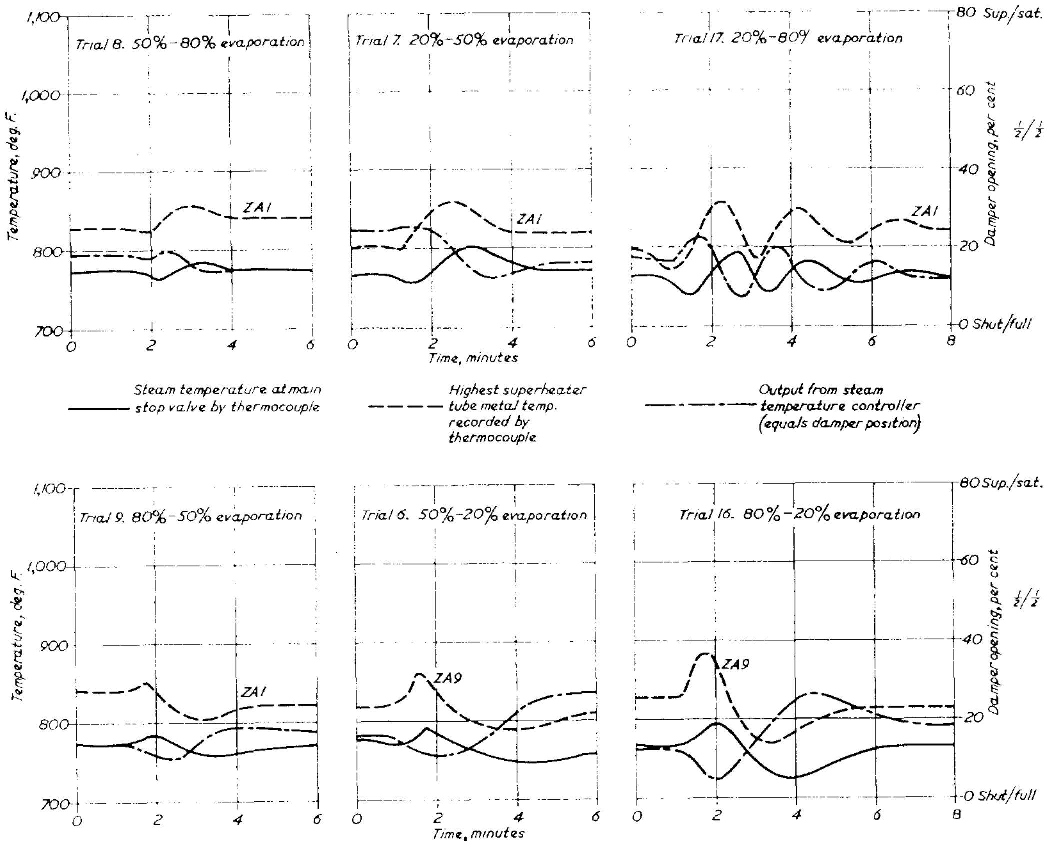

FIG. 19—EFFECT OF MANŒUVRING UPON STEAM TEMPERATURE

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 are derived for the loop components at the 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 the 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 degrees F., the higher value of 950 degrees F. only being used when steady steaming, a similar set of readings was taken with a desired steam temperature of 950 degrees F. 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 install this arrangement in the ships.

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 near-by 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 of 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

Measurement 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 the 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 degrees F. 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 for training, but almost every Officer, Chief and Engine Room Artificer 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 engineering ratings, used to putting on and off sprayers, altering blower speed, F.F.O. heater steam and so on during manoeuvring, 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 wholeheartedly 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 ancilliaries 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 emphasise that the trials described were the combined work of many. He is particularly indebted to the staffs at the Admiralty Fuel Experimental Station, and the Admiralty Engineering Laboratory, and to Messrs. Babcock and Wilcox, who were naturally intimately concerned with the trials. The views expressed are those held by the author and must not be construed as necessarily representing those of the Admiralty.

References:

1. Brown, J. P. H. and Thomas, W. J. R. 1961. 'The Automatic Control of Naval Boilers'. Trans. I. Mar. E. Vol. 73, page 101.
2. Dunlop J. M. and Good, E. B. 1962. 'Machinery Installations of Guided Missile Destroyers and General Purpose Frigates'. *Journal of Naval Engineering*, Vol. 14, No. 1, page 1.
3. Hayden, R. L. J., B.Sc.(Eng.) 1950. 'The Testing of Boilers'. Trans. I. Mar. E. Vol. 62, No. 2, page 85.