ELECTRICAL ENGINEERING IN THE ROYAL NAVY

This is a much condensed version of the Address given by Sir Hamish D. MacLaren, K.B.E., C.B., D.F.C., B.Sc., LL.D., at his inauguration as President of the Institution of Electrical Engineers on 6th October, 1960. The complete text was published in January and February, 1961, in the Proceedings.

Sir Hamish was from 1945 until his retirement on 31st October, 1960, Director of Electrical Engineering at the Admiralty.

At the start, Sir Hamish referred to his 34 years' service with the Admiralty, being within a month of retirement. However, the prospect of his forthcoming Presidential year would help to soften the blow of saying goodbye to a Service which had provided a professional life of absorbing interest.

He recalled that the cost of warship electrical installations now accounts for about 30 per cent of the cost of the ship ; and, although the Director of Electrical Engineering is not directly responsible for some of the very specialized applications, he is responsible for the installation of all equipment and for its compatibility in operation in the ship as a whole. ' Security ' limited the subject-matter for the Address, but in any case he felt it would be more appropriate to select a topic of interest to the largest number, and so he reviewed the application of electricity in the Royal Navy from the earliest days to the present time.

First Electricity Afloat

The first application of electricity afloat was in the 1870s, when electric firing of guns was introduced. Pile type batteries were used, consisting of 160 sheets of alternate copper and zinc separated by ' fearnought '—a kind of flannel used for stokers' trousers dipped in a mixture of vinegar, salt and water.

The first dynamo was installed in 1875 to provide power for a searchlight for use against torpedo craft, while H.M.S. *Inflexible* (FIG. 1) in 1881 was the first ship to have electric lighting and searchlight installations. In this ship Swan incandescent lamps were connected in series to an 800-volt D.C. generator. This was not very satisfactory, and within a year the first fatal accident was recorded ; 80 volts was then adopted as standard, and by about 1885 some 100 vessels had searchlights and ten had electric lighting.

In those days, cables were rubber insulated, with a serving of cotton tape coated with preservatives—they were run in teak casings and embedded in putty. This was later replaced by a lead sheathing with layers of jute yarn instead of rubber. These all gave trouble, but a change to rubber insulation with a lead sheath in 1888 was much more successful, and this basic type of cable, with of course many improvements, continued to be used up to the end of the second World War.

A first class ship in the 1880s had three dynamos, each giving 200-amp at 80 volts, but by the turn of the century the power demand had grown so much that 600-amp dynamos were necessary. In 1899 an ' electrician ' was appointed to Portsmouth Dockyard, and he recommended increasing the voltage to 100. Soon after this, the Board of Admiralty set up a committee to have this new thing electricity, thoroughly looked into, and the outcome was the appointment in 1903 of Charles Wordingham (President of the Institution from 1917 to 1918) as the first electrical engineer at Admiralty Headquarters.

By 1905, proposals were made to raise the voltage to 220, tests having shown

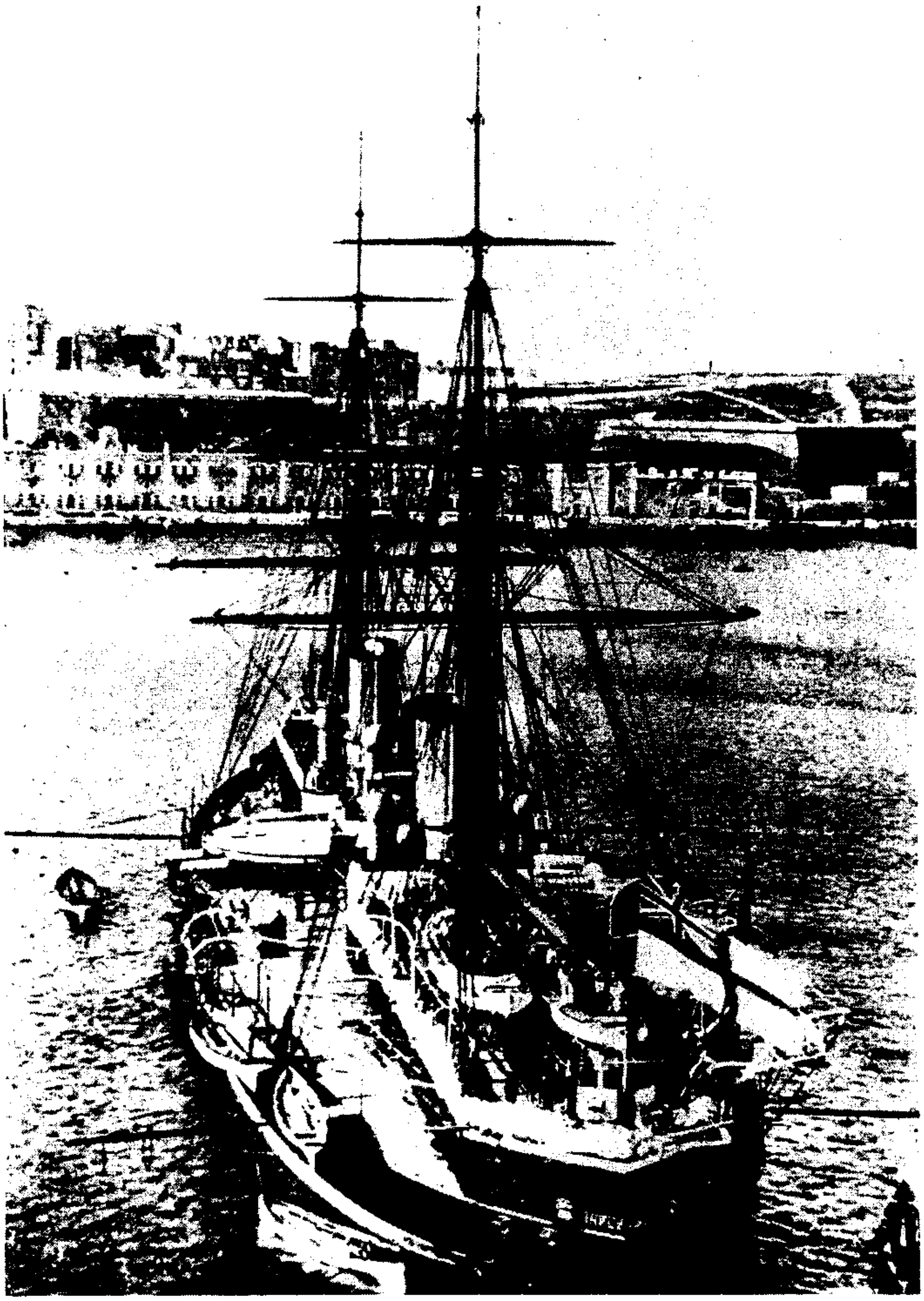

FIG. 1—H.M.S. INFLEXIBLE

that ' 220-volt shocks were unpleasant but not dangerous '. In 1908, H.M.S. *Defence* (FIG. 2) was completed, the first ship to have a 220-volt system. She also made history in that a watertight ring main system was installed, a fundamental departure from the simple central switchboard hitherto used. The ring main system, with many improvements resulting from experience in peace and war, is still at sea in many of our larger ships. In the early ring main, electrical equipment connected directly to it had to be in watertight enclosures, so that flooding in any part of the ship involving ring main equipment would not lead to short circuits and loss of power.

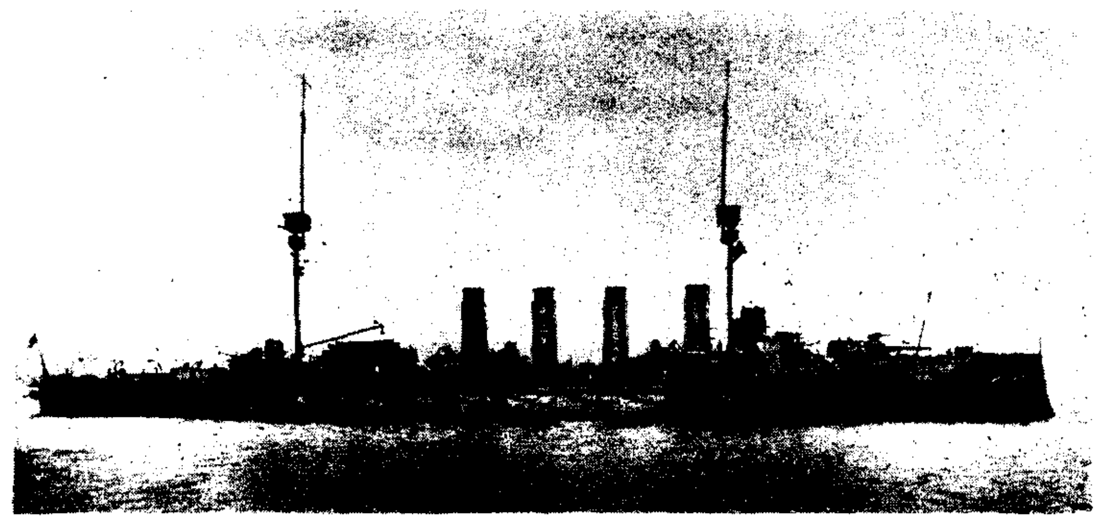

FIG. 2—H.M.S. DEFENCE

The First World War

Experience in the 1914-18 War showed that the watertight equipment rarely remained so in service, and it was not easy to isolate damaged and flooded sections under stress of action. This led to the development of an unusual piece of apparatus called the ' main guard ', which consisted of a miniature diving bell carrying an interrupter. The latter carried the load current from the generator ; and, in the event of flooding of the compartment, a flood switch circuit was completed, firing an explosive sharge in the interrupter and opening the circuit isolating the watertight from the flooded non-watertight equipment.

A later development to take the place of the main guard was the fuse release switch, in which a toggle-operated switch was held in the closed position against a spring by a stainless steel fuse which in turn was connected to the flood switch. Ring-main breakers were also introduced to automatically isolate damaged sections of the ring.

The 1930s saw a considerable expansion of warship construction, including the introduction of a new class of ship altogether, the aircraft carrier. The *Ark Royal* was the first ship to be designed and built as an aircraft carrier, and she had six 400 kW generators. The growing size of the electrical installations raised doubts as to the effectiveness of the fault protection system as used on the ring main and also as to the ability of the circuit breakers to deal with the fault currents which might well now be expected.

In late 1938, H.M.S. *London* was made available for extensive trials, consisting of imposing a comprehensive series of low impedance faults on the system with various combinations of generators running in parallel. The maximum short-circuit current measured during the trials was 33,000 amp with the four generators in parallel, and this was about the maximum which the type of ring main switchgear then in use could interrupt safely. Discrimination between circuit breakers was found to be unsatisfactory, and new overcurrent relays had to be designed which could be fitted in existing ships. Circuit breakers had to be fitted with back-up protection in the form of high breaking capacity fuses, and switchgear makers were given the task of developing breakers of higher breaking capacity for future installations.

This period also saw a steady growth in the use of power and in the functions of communication, data transmission, computation and so on. At the Admiralty Research Laboratories work of far reaching importance was also undertaken, for example, on the use of the magslip for data transmission and on the plotting table automatically recording a ship's position on a chart.

The Second World War

Sir Hamish then turned to the 1939-45 War, referring first to the problem of the magnetic mine. The first sweeps were energized coils wound on wooden rafts towed at a safe distance behind the wooden towing vessel. These were followed by the magnet ship—a remarkable vessel which had a 100-ft magnet weighing some 500 tons fitted to its forward end. The magnet was energized from a D.C. generator, later converted to a source of low-drequency A.C. supply to sweep mines of north and south polarity.

Use of these ships had to be discontinued when mines came to be armed with a device requiring an unknown number of actuations before exploding. Real success came when the towed buoyant cable sweep was developed. This method consists in producing a large magnetic field in the sea by pulsing currents of several thousand amperes through a loop of buoyant cable towed by the minesweeper.

In addition to sweeping magnetic mines, there was also the problem of making ships safe by fitting degaussing coils. Early installations consisted of coils sewn up in canvas and clipped outside the hulls. The next development was a single turn of rubber insulated heavy copper strip fitted to the external plating. After considerable research in 1940, it was found possible to obtain effective screening with the coils inside the ship's plating.

One of the first ships to suffer from a magnetic mine explosion was H.M.S. *Belfast*. The hull was severely damaged, and the extensive damage to the electrical equipment was sufficient to immobilize the ship. It was thus clear that the mechanical shock effects resulting from a non-contact underwater explosion were much more severe than had been anticipated. Resistance to mechanical shock was no new problem and a shock simulating machine had been in use for many years.

Fortunately, *Belfast* provided valuable data because it was possible to pick out certain identical items of equipment dispersed through the ship, some of which had suffered damage and others not. It is thus possible to decide how much to increase the intensity of simulated shock to produce corresponding damage, and to design a new shock testing machine to the new parameters. A new machine was designed and made at the Admiralty Engineering Laboratory and later similar machines were installed in the works of the principal manufacturers. Drawings were also passed to the United States Navy so that they might benefit from our experience.

It was a great blow when H.M.S. *Ark Royal* was lost in November, 1941. Although hit by one torpedo only, the result was disastrous, as it resulted in the immediate flooding of a boiler room and the main switchboard control room. It became impossible to control the system, and hand operation was impossible because of the state of the ship. It was evident that development of a new control system was of paramount importance. The outcome was a relay system in which all the control cables were normally dead. The new system made it practicable to introduce secondary control positions in the ship which could be brought into operation if the main control position became unserviceable.

The loss of *Ark Royal* emphasized another important factor, namely the necessity for having generators for maintaining essential supplies after loss of steam ; and immediate steps were put in hand to fit Diesel generators in those ships where none existed. At the same time, automatic changeover switches were introduced to provide alternative power quickly to close range anti-aircraft gun mountings and other essential services.

Electrical engineering played a much larger part in the war at sea than earlier experience had led to expect. One example is the development of remote power control systems for automatic control of armament in the early months of the war. War experience led to the development of the damage control organiza-

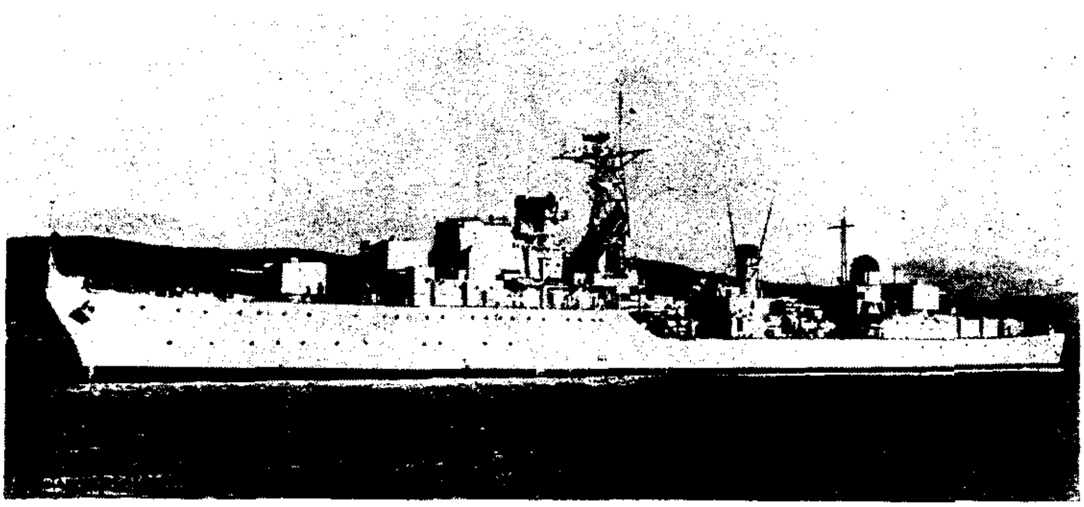

FIG. 3—H.M.S. DIAMOND

tion for all departments of the ship, which included a special communication system and secondary lighting by automatic emergency lanterns.

The pattern of the war at sea, the effect of non-contact underwater explosions and bomb damage, raised doubts as to the effectiveness of the ring-main system, very much in mind when the pros and cons of the changeover to alternating current were investigated after the war.

Changing to A.C.

The possibility of changing to alternating current had been investigated after the First World War and again in the early 'thirties, but the balance of opinion was then in favour of retaining direct current. However, the prospect of fitting generators of 1,000kW capacity or more for even smaller ships in the post-war era made a reappraisal of the position essential. It was clearly necessary to raise the voltage and to decide whether direct or alternating current should be used. Investigations showed that even for a small vessel with some 1,000kW of generating capacity, a 440-volt 3-phase system operating at 60 c/s could result in a saving of weight and space, with an increase in saving as the size of the installation increased.

The selection of frequency was not easy, but it was evident that a motor speed of 1,800 r.p.m. met a large number of requirements and that the lower speeds associated with a 50 c/s supply would introduce a quite unacceptable weight penalty. So, with the full support of industry when the facts were put before it, 60 c/s was selected. The first ship to complete with alternating current was H.M.S. *Diamond* (FIG. 3) and this was followed by several classes of frigate. The *Tiger* Class cruisers were the first large ships to have an A.C. system. These ships were laid down during the 1939-45 War but were not completed by the end of the war. Changing to alternating current on completion with modern weapons and radar made it possible to meet the very much greater electrical demand by substituting 1,000kW A.C. generators in place of the original 500kW D.C. generators.

The change brought many new problems, ranging from automatic voltage regulators for the A.C. generators to give very close control of system voltage to air break switchgear, control gear, distribution equipment, emergency cable system, etc., to meet the naval specifications, including the resistance to mechanical shock. The earliest opportunity was taken to study system and switchgear behaviour in fault conditions in an A.C. ship, and trials carried out in H.M.S. *Diamond* showed that changes were necessary to improve discrimination in fault protection.

Sir Hamish referred to developments in other aspects of naval electrical engineering, varying from conversion equipment and demagnetization to one of the outstanding achievements of his department, the development of electrical analogue computing systems for gunnery. Communication plays a vital part in the running of a warship, ranging in the modern vessel from straightforward 500-line automatic exchanges for administrative purposes to a series of operational communications systems. The most complex of all permits aural communication in an ambient noise level of 130dB—a condition which has to be met on the flight deck of a carrier when the aircraft jet engines are running.

He concluded this part of his survey by referring to the introduction of silicone-rubber insulation for cables, which permits higher ratings and, what is most important, remains effective after damage by fire, as the residual ash is non-conducting. Other changes have been the adoption of cable hangers instead of the old carrier plating, and the development of a multiple type gland box with considerable saving in bulkhead space.

On submarines, Sir Hamish mentioned the T-Class conversion, where the vessels were cut in two and lengthened to permit the installation of a fourth battery section and an additional propulsion motor on each shaft to give higher underwater speeds at 440 volts. The *Porpoise* Class which followed was a radical departure from previous design practice, as, for maximum speed, the batteries are connected to give 880 volts while for ordinary working the voltage is 440. Motor-driven cam-contactor switchgear is used, and special attention had to be paid to fault protection by means of high speed, high breaking capacity switchgear. To test the equipment, one of the largest D.C. short circuit testing installations in Europe was built at the Admiralty Engineering Laboratory.

The Future

Looking to the future, Sir Hamish thought that the pattern of increasing specialization in design must continue to an even greater degree. The serving naval electrical engineer and his civilian counterpart will need to be of the same high standard or even higher. In the material field, thanks to the close co-operation existing between the Admiralty and the electrical industry, knowledge of new discoveries and developments becomes available at a very early stage, so that possible naval applications can be kept in mind.

The biggest drive will be for increased reliability and reduction in size and weight. Generation of power may be at higher frequencies than 60 c/s and higher voltages than 440 may well be necessary. The fuel cell and thermo electro generators may become practicable, though much development remains to be done. Nuclear propulsion of submarines is already proved, but if it can be justified for surface warships it will present problems still to be tackled.

Sir Hamish concluded his Address by saying that these and similar problems would keep his successors in naval electrical engineering fully occupied, and would exercise their ingenuity and that of their colleagues in industry and elsewhere, whose enthusiastic co-operation would be just as essential in the future as it had been fruitful in the past.

OPPORTUNITY FOR CIVILIAN EMPLOYMENT

Engineer Officers, Chief E.R.A.s and E.R.A.s about to retire, or complete their Service engagements, may be interested to know that opportunities occur for employment as Technical Class Grade II and III officers in the Production Pool.

Admiralty Departments are provided with engineers and technicians from this Pool for duties relating to the production of a wide range of Admiralty equipment for ships. The technical officers of the Marine Specialization are employed mainly on inspection duties, either at the Contractors manufacturing the equipment, or in the private shipyards overseeing its installation. Staff are also employed as Authors to write the technical publications for maintenance of the various pieces of machinery or equipment.

The posts are un-established, but opportunities occur from time to time to compete in competitions arranged by the Civil Service Commissioners for established posts in these grades.

The present salary scales are :—

Technical Class Grade III (Assistant Production Inspector)— £795-£950
Technical Class Grade II (Production Inspector)—£950-£1,085.

Details of the higher grades of the Technical Classes are given in A.F.O.2261/60. Promotion is by merit.

Forms of Application can be obtained from :

The Superintendent of Production Pool,
Admiralty Offices,
Empire Hotel,
Bath,
Somerset.