PAPERS ON ENGINEERING SUBJECTS.

HYDRAULIC AND PNEUMATIC POWER IN H.M. SHIPS.

Though up to the present time steam and electricity have between them provided convenient means for the distribution of most of the power required for auxiliary purposes in warships, yet compressed air and compressed water (or other suitable liquid) have been found increasingly useful, especially in connection with armament machinery. Hydraulic and pneumatic machinery passed satisfactorily through a long and searching test in the late war, and as there are indications that in the future an extended use will be made of them, a short survey of the more recent development of these two systems in the Navy may be of some suggestive value.

The peculiar suitability of hydraulic power for certain kinds of operations in warships is generally appreciated. For the moving of heavy masses through small distances, intermittently and with extreme nicety of control, water under high pressure provides a convenient medium, which has been used for the working of heavy guns, their turrets, projectiles and machinery almost from the time of their first adoption in fighting ships. The form of the power plant has remained standardized for years. Two or more steam-driven hydraulic pumping engines, each of about 500 i.h.p. supply lubricated water under a pressure of 1,100 lbs. per square inch to a " ring main " which distributes to the various turrets, and which embodies valves so placed that, if one section of the ring be damaged, a supply of water can be made to all turrets by an alternative route. The pumping engines, which in pre-Dreadnought ships were seldom called upon to deliver anything approaching to their specified output, later became subjected to a severer strain; multiple turrets and the system of Director firing rendered necessary the momentary production of large volumes of water for running out and depressing the guns, and means had to be adopted (which will be described later) to relieve the pumping engines. But apart from this partial deficiency, a supply of water-power to the gun turrets has always been assured; and on this postulate all recent designs of turret machinery and equipment have been based. Secondary hand-operated gears have gradually been eliminated; where necessary, power units have been duplicated. The late war, confirming our knowledge of what happened in the Russo-Japanese war, gave ample evidence of this reliability of the hydraulic systems of H.M. Ships. So far as is known, no single failure was reported to the Admiralty.

A proposal was made in the early days of the century to substitute electricity for hydraulic power in gun turrets. Large strides had been made in the development of electric power in the Navy, and the opinion was held that, by its application to gun machinery, advantages would be secured of weight, cost, life, and efficiency of control, in addition to the elimination of the hydraulic pumps and the pressure and exhaust piping throughout the ship. At first it was proposed to equip one turret of H.M.S. "Lord Nelson" with electric machinery, but eventually a decision was made to give the idea a more extensive trial; it was approved for all four turrets of H.M.S. "Invincible" to be electrically operated, two to Messrs. Vickers' and two to Elswick design, but the predictions on which this trial was based were not confirmed by experience; the electrical machinery, as embodied in the "Invincible" was the reverse of satisfactory, and on the recommendation of a Committee of Investigation, which was appointed in 1912, it was removed and the turrets were converted into hydraulic-operated turrets of the usual type. Since this experience hydraulic power has been specified for the turret systems of all H.M. Ships.

From the time of the "Invincible" experiments the question has frequently been debated, whether in the particular circumstances electric power was not tried at a great disadvantage, and whether the result was a true criterion of the relative values of hydraulic and electric power. Certain it is that electricity is far more in favour with foreign Navies than with our own, and that with electric machinery foreign Navies achieve, at any rate, fairly good results. Into the causes underlying these preferences we need not here inquire; it will be as well to treat the whole question with an open mind. At the same time it appears to be beyond doubt that, in the present state of technical development, for certain operations hydraulic machinery possesses special advantages over the rival form. Two cases may be cited—operations in which a nice control and a perfectly continuous increment of speed (and not a "step-by-step" increment) are required; and operations in which the momentum or the static pressure of the liquid is utilised—for instance, for seating a projectile securely in its rifling after having thrust it home in the gun chamber.

It appears that in the course of time the Germans have been forced, in spite of their predilections, to conclusions similar to the above. In previous designs they had endeavoured to use electric power almost exclusively for their gun machinery, but in the "Baden" Class they adopted hydraulic power for some of the most important operations in the turrets. In the "Baden" electric power was led into each turret by cables near its base, and was converted into hydraulic power inside the turret by means of a self-contained electrically driven pump.

A hydraulic machine "acts as its own brake"; as the velocity of the liquid through pipes and valves increases, the frictional losses increase, the efficiency drops off, and a limit is set to the speed at which the machine will run. Hence hydraulic power is most efficient when dealing with slow motions. It is of historical interest to note, however, that in a certain case hydraulic machinery was introduced into H.M. Service on account of its ability to give, by means of the well-known multiplying press, a rapid motion; viz., in the hydraulic boat-hoist. First fitted experimentally in H.M.S. "Vulcan," and then in the "Sans Pareil" and later ships, the hydraulic boat-hoist realised an important advantage over steam drive or electric power, as then developed, in that it provided a means by which a boat could be hoisted from a rough sea with comparative safety. The hydraulic presses were so arranged that a pressure could be admitted to one of them just sufficient to keep taut the boat-slings, but insufficient to lift the boat, and not too great to prevent the ram from "overhauling" and surging in phase with the boat as it rose and fell on the waves; until at a suitable moment, by the application of pressure to the main press, the boat could be lifted out of the water rapidly enough to prevent it from being overtaken and hit by a wave. Such a boat-hoist proved very useful in the "Vulcan." Its special advantages were of less importance however, when applied to larger displacements. As warships increased in size and steadiness, and as ships' boats increased in weight, lower speeds of lift became sufficient and desirable; electric eventually superseded hydraulic power, a low speed of lift being specified in order to reduce to a minimum the weight of the boat-hoisting machinery.

Generally, the use of hydraulic power in H.M. Ships is still confined mainly to armament machinery, to shell and torpedo loading and transporting gear, to the working of heavy guns and the rotating of armoured hoods and turrets. Conveyers, bollard winches, dredger hoists, and other fast-running or isolated machines are in general electrically operated. In H.M. Submarines hydraulic power is more extensively used. In the mercantile marine the development of internal combustion engines, in particular, has had an effect of drawing attention to hydraulic machinery as a means, in lieu of steam, of distributing power for auxiliary purposes, for cargo lifts, anchor gear and the operating of water-tight doors.

High-pressure compressed air has been developed in the Navy since the year 1880 almost entirely in connection with the Whitehead torpedo, its propulsion and discharge.

Clearly defined progress has periodically been made in the compression and storage of air; working pressures have increased, the reliability of compressors and storage reservoirs has improved. The mechanical as well as the thermal advantages to be obtained from certain features in the design of air-compressors are now generally appreciated. Multiple-stage compression with its consequent small ranges of pressure and temperature in each cylinder; distilled water injection; suitable metals for valves and seatings; accurately-moulded packings; large intercoolers—all these features have now received study and have contributed to the general improvement of the air-compression supplied for the torpedo service of modern ships. The substitution of large-diameter solid-drawn bottles for the multi-tubular reservoirs previously specified has greatly improved the reliability of air storage. But most marked has been the improvement in the air-compressors themselves. It will be recollected by senior officers that, with the old types of air-compressor which compressed air in two stages to a pressure of 1,700 lbs. per sq. inch, a temperature of compression of nearly 400° F. was obtained, even when injection water was in use. And as ordinary undistilled water was generally used, this meant that a film of chalk was deposited on valves and barrels, with the result that the leather packings were soon spoiled and the valves rendered inefficient through leakage. To obviate the use of undistilled water a small distilling condenser was then embodied, and this is still supplied with all steam-driven compressors ordered by the Admiralty.

The development of internal-combustion engines and their adoption for warships use led, in the first decade of this century, to a more general and widely diffused study of the problems of air-compression than had previously obtained. Internal-combustion engines working on the Diesel or semi-Diesel principle generally required dry compressed air for their fuel injection, and this had to be provided by air-compressors which formed part of the equipment of the internal-combustion engines themselves. The duty imposed on these compressors was far more severe and searching than that required of the torpedo air-compressor; they must run continuously, and without injection water. This necessity involved the elimination of all non-metallic packings and the generation of high temperatures of compression. Until sufficient experience had been accumulated to show the direction in which alteration of design was required, many of the early difficulties which had been met with in the development of torpedo air-compressors presented themselves again in connection with these engine compressors, in particular, the generation of high temperatures of compression not only caused distortion of the valves and seatings, but produced a danger of explosion from the presence of lubricating oil, two effects which seriously depreciated the reliability of the oil engine. The air-compressor was the weak part of the equipment. In recent years these difficulties have been largely surmounted, and the faults in the early designs have been eliminated. And in connection with this process the development of the torpedo air-compressor has been of significant value as indicating the direction in which improvements were necessary.

The presence of a large store of high-pressure compressed air in capital ships has led, in recent years, to frequent consideration of its use for various purposes in connection with armament.

Compressed air was in use in the "nineties" for operating, through the direct agency of water, the shield-bars of submerged torpedo tubes. Soon afterwards it was utilised for ejecting gas and débris from the bores of turret guns, in both cases the air being drawn as required from the torpedo storage reservoirs. In 1907 air was adopted, in the absence of an hydraulic system and in preference to springs, for "running out" the twelve-inch guns of the electrically operated turrets experimentally designed for H.M.S. "Invincible" by Sir W. G. Armstrong, Whitworth & Co. Air, stored in a recuperator at 1,000 lbs per sq. inch pressure, was compressed on recoil of the gun to 1,700 lbs. per sq. inch, and by its expansion to its original volume it then returned the gun to the firing position.

This experiment was completely successful. The result showed that, by a suitable arrangement of sealing glands, high-pressure air could be maintained in a recuperator for long periods without appreciable gland-leaking, and that an actual gain in rate of loading was obtained—other things being equal—by the substitution of pneumatic for hydraulic running-out gear. Nevertheless it was decided, in the case of the "St. Vincent" and later classes of capital ships, to adhere to the well-tried hydraulic run-out. Eventually it was found necessary to reverse this decision. With the general adoption of Director firing, and with a continuous increase in the mass and maximum elevation of turret guns, the disadvantages of hydraulic run-out became serious. As already stated, it was found necessary to relieve the pumping engines of the strain which resulted from the simultaneous running-out of the heavy guns. In some ships extra pumping engines were fitted; and during the war several ships in active commission had their gun-mountings converted to pneumatic run-out, on the lines of the "Invincible" design.

(It is of interest to note that for a different reason, pneumatic run-out (or recuperation) had to be adopted during the war for many types of Army gun. The failure of springs, which suffered from fatigue after being subjected to an unexpectedly large number of compressions, necessitated the substitution of compressed air. The 15-inch howitzers, which were contributed by the Navy, and which were manned by the R.M.A. in Flanders, were actually converted in the field. Recuperators, designed on the lines of the "Invincible" were made by the Coventry Ordnance Co., and fitted by them. Small petrol-driven air-compressors were provided for initially charging and for making good leakage.)

Several of our smaller types of naval gun mounting are now fitted with pneumatic recuperators, and these are charged from the ships' main reservoirs. For preventing leakage of air from their rod-glands, two different systems are in use; one of these relies on maintaining a liquid (water and glycerine) in the lower part of the recuperator, adjacent to the rod-gland, the compressed air being imprisoned above it; the other embodies a differential arrangement of pistons which hold liquid between them, so designed that the liquid, which surrounds the glands, is always at a slightly higher pressure than the air which is imprisoned behind it.

Compressed air, obtained from the main reservoirs or from other source, is also used in H.M. Ships for air-blast for casemate guns, for cleaning boiler and condenser tubes, for testing condensers and water-tight compartments, and for transmitting messages; flagships are supplied with sets of pneumatic tools for the use of divers and for other emergency. In Submarines compressed air is used for an even greater variety of operations. The hundred or more air-bottles which a submarine carries constitutes a static reservoir of great capacity and usefulness; and this stored air can be used, at any desired pressure, for such operations as the blowing of tanks, the discharge of torpedoes, the starting of motors, and the lifting of gun-hatches as well as of the guns themselves upon their pivotted mountings.

In recent years considerable use has been made for local operations of variable-stroke hydraulic pumps, such as the Williams-Janney and the Hele-Shaw, and these, driven by constant-speed electric motors, may be used as convenient sources of hydraulic power, though generally they are used in combination with fixed-stroke pumps of similar form, purely as transmission gears. In cases where the loss of power in transmission is of small consequence these local electro-hydraulic power or transmission units may be found to constitute the best arrangement; in the former case the advantages of electric transmission from the central source of power are combined with those of an hydraulic control. Where, however, the number of operations is large, a corresponding multiplication of machines is entailed, and the disadvantages of this decentralization may tend to outweigh the advantages. In H.M. Ships these variable-stroke power units are used for certain gun machinery; as transmission gears they are to be found in use for gun and torpedo machinery, capstans, winches and derrick hoists; in Submarines, for operating rudders, hydroplanes, etc., etc.

Mention has been made of the use of hydro-pneumatic gear-compressed air acting through the agency of water for operating the shield-bars of the early submerged torpedo tubes. A significant instance of this use of air and water in combination is provided by the "M" Class of H.M. Submarines. Each of these vessels carries a 12-inch gun as its main gun armament, and the power required for operating this gun, and for transporting its projectiles, is derived from a hydro-pneumatic accumulator. A small electrically-driven hydraulic pump delivers water at 1,100 lbs. per sq. inch pressure to the lower part of an accumulator cylinder which contains a moveable piston, the upper side of which is in connection with a number of air-bottles charged to 1,000 lbs. per sq. inch. The piston, which is 13 inches in diameter and which has a long indicating rod attached to its lower side, can travel through a stroke of 60 inches; and near each end of its stroke a projection on its rod is made to operate tappets which electrically control the motion of the pump. The pump forces the piston upwards against the pressure of the compressed air, and stops when the piston is at the top of its stroke. Suppose that water is drawn off from below the piston, for some operation in the gun-house, the air at once forces the piston down and maintains an almost constant pressure in the hydraulic system. When the piston approaches its bottom position the tappet, moved over by the projection on the rod, starts the pump, which continues to deliver water until the piston is near its top position again.

By this arrangement, since hydraulic power is only required intermittently throughout the cycle of gun-house operations, it is possible to provide a sufficiency of water for any probable combination of operations by means of a relatively small pump. A static reservoir of water-power is provided, moreover, by which a number of operations can be performed without the starting of any machine. Upon drawing off water for any operation the compressed air expands to the requisite extent behind the descending piston; the loss of pressure in the air depending of course on the number of air-bottles with which the accumulator is connected. In " M " Submarines fifteen bottles are provided for this duty, and are separate from those provided for blowing tanks and for torpedo work, in which the pressure varies according to circumstances.

This application of the accumulator principle to hydraulic machinery in the Navy is also used in the later classes of submarines for divers purposes and offers considerable advantages where the duties are intermittent. In these submarines it is used for raising and lowering the periscopes and wireless masts, duties in connection with the Q.F. armament, and in the case of the steam submarines to the boiler-room air vents. It affords a reliable source of power from a central system and so results in a simplification of plant, which, in view of the diversity and duplication of power systems otherwise necessary, tends to improve the efficiency of the machinery as a whole. There may be cases in the future in which a considerable extension of this system would offer advantages.