ing's,@@1 in which a gimbal-ring and four curved pistons take the place of the disk. Two curved pistons are fixed on each side of the gimbal-ring, and as the shafts revolve these work in a correspond­ing pair of cavities, which may be called curved cylinders, fixed to each shaft.

212. Attempts have been made from time to time to devise steam-engines of the turbine class, where rotation of a wheel is pro­duced either by reaction from a jet of escaping steam or by impact of a jet upon revolving blades. A revolving piece which is to extract even a respectable fraction of the kinetic energy of a steam jet must move with excessive velocity. In Mr C. A. Parsons’s steam-turbine this difficulty is overcome and a moderate degree of efficiency is secured by using a series of central-flow turbine wheels, in the form of perforated disks, all on one shaft, with fixed disks between which are perforated to serve as guide-blades. Steam passes from end to end of the series, giving up a small portion of its energy to each, but retaining little at the end.

XII. Marine Engines.

213. The early steamers were fitted with paddle-wheels, and the engines used to drive them were for the most part modified beam-engines. Bell’s “ Comet ” (§ 21) was driven by a species of inverted beam-engine, and another form of inverted beam, known as the side-lever engine, was for long a favourite with marine engineers. In the side-lever engine the cylinder was vertical, and the piston-rod pro­jected through the top. From a crosshead on the rod a pair of links, one on each side of the cylinder, led down to the ends of a pair of horizontal beams or levers below, which oscillated about a fixed gudgeon at or near the middle of their length. The two levers were joined at their other ends by a crosstail, from which a connecting- rod was taken to the crank above. The side-lever engine is now obsolete.

In American practice, engines of the beam type, with a braced-beam supported on A frames above the deck, are still common in river-steamers and coasters.

214. An old form of direct-acting paddle-engine was the steeple-engine, in which the cylinder was set vertically below the crank. Two piston-rods projected through the top of the cylinder, one on each side of the shaft and of the crank. They were united by a crosshead sliding in vertical guides, and from this a return-connecting-rod led to the crank.

215. Modern paddle-wheel engines are usually of one of the following types. (1) In *oscillating cylinder engines* the cylinders are set under the crank-shaft, and the piston- rods are directly connected to the cranks. The cylinders are supported on trunnions which give them the necessary freedom of oscillation to follow the movement of the crank. Steam is admitted through the trunnions to slide-valves on the sides of the cylinders. In some instances the mean position of the cylinders is inclined instead of vertical; and oscillating engines have been arranged with one cylinder before and another behind the shaft, both pistons working on one crank. The oscillating cylinder type is best adapted for what would now be considered comparatively low pres­sures of steam. (2) *Diagonal engines* are direct-acting engines of the ordinary connecting-rod type, with the cylinders fixed on an inclined bed and the guides sloping up towards the shaft.

216. When the screw-propeller began to take the place of paddle-wheels in ocean-steamers, the increased speed which it required was at first supplied by using spur-wheel gearing in conjunction with one of the forms of engines then usual in paddle steamers. After a time types of engine better suited to the screw were introduced, and were driven fast enough to be connected directly to the screw-shaft. The smallness of the horizontal space on either side of the shaft formed an obstacle to the use of horizontal engines, but this difficulty was overcome in several ways. In Penn’s trunk-engine, still used in the

navy, the engine is shortened by attaching the connecting- rod directly to the piston, and using a hollow piston-rod, called a trunk, large enough to allow the connecting-rod to oscillate inside it. The trunk extends through both ends of the cylinder and forms a guide for the piston. It has the drawback of requiring very large stuffing-boxes, of wasting cylinder space, and of presenting a large surface of metal to alternate heating by steam and cooling by con­tact with the atmosphere. The use of high-pressure steam is likely to make the trunk-engine obsolete.

217. The return-connecting-rod engine is another hori­zontal form much used in the navy. It is a steeple-engine placed horizontally, with two, and in some cases four, piston-rods in each cylinder. The piston-rods pass clear of the shaft and the crank, and are joined beyond it in a guided crosshead, from which a connecting-rod returns.

Ordinary horizontal direct-acting engines with a short stroke and a short connecting-rod are also common in war­ships, where the horizontal is frequently preferred to the vertical type of engine for the sake of keeping the machinery below the water-line. In horizontal marine engines the air-pump and condenser are generally placed on the oppo­site side of the shaft from the cylinder, which balances the weight and allows the air-pump to be driven direct.

218. In merchant ocean-steamers one general type of en­gine is universal, and the same type is now to an increasing extent adopted in naval practice. This is the inverted verti­cal direct-acting engine, generally with two or more cylinders placed side by side directly over the shaft. In exceptional cases a single cylinder has been used, with a fly-wheel on the shaft. Two, three, and four cylinders are common.

The most usual form of existing marine engine is the two- cylinder compound arrangement, with cranks at right angles or nearly at right angles, of which figs. 135, 136, 137 (pp. 518-20) show a characteristic example (the engines of the s.s. “Tartar,” by Messrs John & James Thomson, Glasgow).

Fig. 135 is an end elevation, fig. 136 a longitudinal section through the centre of the engines, and fig. 137 a thwart-ship section through the condenser and air-pump. The cylinders are 50 and 91 inches in diameter, and the stroke is 5 feet. Both cylinders are fitted with liners, and are steam-jacketed. Double-ported slide- valves are used on both, and the high-pressure valve has a relief­ring. The crosshead guides are fitted on the side on which the crosshead bears when the engines are going ahead, with a hollow box behind the guiding surface, and cold water is kept circulating in this to prevent the guides from heating.

The crank-shaft is of Vicker’s steel, 171/2 inches in diameter. The condenser is in the place it usually has in engines of this type,— in the lower part of the backframe, with its tubes running horizon­tally from end to end of the engine. There are 1400 tubes, of 1 inch diameter and 11/2 inch pitch. The air-pumps are of the single- acting bucket kind, and are driven by a lever from the crosshead.

Centrifugal circulating pumps are used, driven by a pair of independent small vertical engines. The link-motion is worked by steam starting and reversing gear, which appears on the left side of the engine in fig. 135. These engines work with a boiler pressure of 90 lb, and indicate 3560 horse-power. Fig. 134 shows, on a larger scale, the piston packing, which consists of a pair of floating rings, pressed out by a spiral spring behind them.

219. Two other arrangements of double compound (as distin­guished from triple-expansion) marine engines of the inverted vertical type require notice. One is the tandem arrangement, largely adopted in the steamers of the “White Star” line. In these each crank is operated by an independent pair of compound cylinders, the high-pressure cylinder being on top of the low- pressure cylinder, with one piston-rod common to both, The valves of both are worked by a single pair of eccentrics with a link-motion ; the valve-rod of the low-pressure cylinder extends through the top of its valve-chest, and is joined either directly or by a short lever with the valve-rod of the high-pressure cylinder. Generally two pairs of tandem cylinders are placed side by side, one pair abaft the other, to work on cranks at right angles. In exceptionally large engines three pairs have been used, working on

@@@1 *Min. Proc. Inst. C.E.,* November 1885.