smooth and continuous action is secured. These engines have been extensively applied, on a large scale, to raise water for the supply of towns and to force oil through “ pipe-lines” in the United States. In the larger sizes they are made compound, each high-pressure cylinder having a low-pressure cylinder tandem with it on the same rod. To allow of expansive working a device is added which compensates for the inequality of effort resulting from an early cut-off. A cross-head *A* (fig. 49) fixed to each of the piston-rods is connected to the piston-rods of a pair of oscillat­ing cylinders B, B, which contain water and communicate with a reservoir full of air compressed to a pressure of about 300 lb per square inch. When the stroke (which takes place in the direction of the arrow) begins the pistons are at first forced in, and work is at first done by the main piston-rod, through the compensating cylinders B, B, on the compressed air in the reservoir. This continues until the cross-head has advanced so that the cylinders stand at right angles to the line of stroke. Then for the remainder of the stroke the compensating cyb\*nders assist in driving the main piston, and the compressed air gives out the energy which it stored in the earlier portion. The volume of the air reservoir is so much greater than the volume of the cylinders, B, B, that the air pressure remains nearly constant throughout the stroke. Any leakage from the cylinder or reservoir is made good by a small pump which the engine drives.

99. *Pulsometer.—*Hall’s “pulsometer” is a peculiar pump­ing engine without cylinder or piston, which may be regarded as the modern representative of the engine of Savery. The sectional view, fig. 50, shows its principal parts. There are two chambers A, A', narrowing towards the top, where the steam-pipe B enters. A ball-valve C allows steam to pass into one of the chambers and closes the other. Steam entering (say) the right-hand chamber forces water out of it past the clack-valve V into a delivery passage D, which is connected with an air-vessel. When the water level in A sinks so far that steam begins to blow through the delivery passage, the water and steam are disturbed and so brought into intimate contact, the steam in A is condensed, and a partial vacuum is formed. This causes the ball-valve C to rock over and close the top of A, while water rises from the suction-pipe E to fill that chamber. At the same time steam begins to enter the other chamber A', discharging water from it, and the same series of actions is repeated in either chamber alternately. While the water is being driven out there is comparatively little condensation of steam, partly because the shape of the vessel does not promote the formation of eddies, and partly because there is a cushion of air between the steam and the water. Near the top of each chamber is a small air-valve opening inwards, which allows a little air to enter each time a vacuum is formed. When any steam is condensed, the air mixed with it remains on the cold surface and forms a non-conducting layer. The pulsometer is, of course, far from efficient as a thermodynamic engine, but its suitability for situations where other steam-pumps cannot be used, and the extreme simplicity of its working parts, make it valuable in certain cases.

100. *Rotary Engines.—*From the earliest days of the rota­tive engine attempts have been made to avoid the intermittent reciprocating motion which an ordinary piston engine first produces and then converts into motion of rotation. Murdoch, the contemporary of Watt, proposed an engine consisting of a pair of spur-wheels gearing with one another in a chamber through which steam passed by being carried round the outer sides of the wheels in the spaces between successive teeth.

In Dudgeon’s wheel engine the steam was admitted by ports in side-plates into the clearance space behind teeth in gear with one another, just after they had passed the line of centres. From that point to the end of the arc of contact the clearance space increased in volume; and it was therefore possible, by stopping the admission of steam at an intermediate point, to work expansively. The difficulty of maintaining steam-tight connexion between the teeth and the side-plates on which the faces of the wheels slide is obvious; and the same difficulty has prevented the success of many other forms of rotary engine. These have been devised in immense variety, in many cases, it would seem, with the idea that a distinct mechanical advantage was to be secured by avoiding the reciprocating motion of a piston. In point of fact, however, very few forms entirely escape having pieces with reciprocating motion. In all rotary engines, with the exception of steam turbines—where work is done not by pressure but by the kinetic impulse of steam— there are steam chambers which alternately expand and con­tract in volume, and this action usually takes place through a more or less veiled reciprocation of working parts. So long as engines work at a moderate speed there is little advantage in avoiding reciprocation; the alternate starting and stopping of piston and piston-rod does not affect materially the frictional efficiency, throws no deleterious strain on the joints, and need not disturb the equilibrium of the machine as a whole. The case is different when very high speeds are concerned ; it is then desirable as far as possible to limit the amount of reciprocating motion and to reduce the masses that partake in it.

101. *Types of Marine Engines.—*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” 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 cross-tail, 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. 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. 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.

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