fixed to the crank cheeks on the other side of the shaft. Steam is admitted to the back of the pistons only. It passes first through a throttle-valve, which is controlled by a centrifugal spring-governor (fig. 128), and is then distributed to the cylinders by three piston-

piston-rod is taken advantage of to open a supplementary exhaust port (B, fig. 129), which remains open during a sufficient portion of the back stroke. The flexible coupling C shown in fig. 128, in which the twisting moment of the shaft is transmitted through disks of leather, prevents straining of the shaft and bearings through any want of alignment between the shaft of the engine and that of the mechanism it drives. Besides its use as a steam-engine, Mr Brotherhood’s pattern has been extensively applied in driving torpedoes by means of compressed air. As a steam-engine it is compounded by placing a high-pressure cylinder outside of and tandem with each low-pressure cylinder.

204. In other engines of this type a pair of cylinders, or a high and a low pressure cylinder, are set vertically side by side, to work on cranks opposite each other. The cranks aud connecting-rods are completely enclosed, and are lubricated by dipping into a mixture of oil and water with which the lower part of the casing is filled. In the Westinghouse engine, where there are two vertical cylin­ders to which steam is admitted by a piston-valve, the crank-shaft is situated half a crank’s length out of the line of stroke, to reduce the effects of the connecting-rod’s obliquity during the working stroke.@@1 In Mr Willans’s latest form of engine the high and low pressure cylinders are tandem, and the space between the piston forms an intermediate receiver. The piston-rod is hollow, and has a piston-valve in it which controls the admission of steam to the high-pressure cylinder and its transfer to the low-pressure cylinder. The piston-valve within the rod takes its differential motion from an eccentric on the crank-pin. The crosshead is itself a piston working in a cylindrical guide, in which it compresses air as it rises during the back stroke in order to cushion the reciprocating parts.@@@2

205. In engines for pumping or for blowing air it is not essential to drive a revolving shaft, and in many forms the reciprocating motion of the steam-piston is applied directly or through a beam to produce the reciprocating motion of the pump-piston or plunger. On the other hand, pumping engines are frequently made rotative for the sake of adding a fly-wheel. When the level of the suction water is sufficiently high, horizontal engines, with the pump behind the cylinder and in line with it, are generally preferred ; in other cases a beam-engine or vertical direct-acting engine is more common. Horizontal engines are, however, employed to pump water from any depth by using triangular rocking frames, which serve as bell- crank levers between the horizontal piston and vertical pump-rods.@@3

Fig. 130 shows a compound inverted vertical pumping engine of the non-rotative class, by Messrs Hathorn, Davey, & Co. Steam is distributed through lift valves, and the engine is governed by the differential gear illustrated in fig. 107, in conjunction with a cataract, which makes the pistons pause at the end of each stroke. The pistons are in line with two pump-rods, and are coupled by an inverted beam which gives guidance to the crossheads by means of an approximate straight-line motion, which is a modification of that of fig. 120. Surface condensers are frequently used with pumping engines, the water w’hich the engine pumps serving as circulating water.

206. In a very numerous class of direct-acting steam-pumps, the steam-piston and the pump-piston or plunger are on the same piston-rod. In some of these a rotative element is introduced, partly to secure uniformity of motion, and partly for convenience of working the valves ; a connecting-rod is taken from some point in the piston-rod to a crank-shaft which carries a fly-wheel ; or a

valves A, worked by an eccentric, the sheave of which is made hollow so as to overhang one of the main bearings (fig. 128). Release takes place by the piston itself uncovering exhaust ports in the circumference of the cylinder, and the rocking motion of the

slotted crosshead fixed to the rod gives rotary motion to a crank- pin gearing into the slot, the line of the slot being perpendicular to that of the stroke. Many other steam-pumps are strictly non-rota­tive. In some the valve is worked by tappets from the piston-rod. In the Blake steam-pump a tappet worked by the piston as it reaches each end of its stroke throw’s over an auxiliary steam-valve, which

admits steam to one or other side of an auxiliary piston carrying the main slide-valve. In Cameron & Floyd’s form one of a pair of tappet-valves at the ends of the cylinder is opened by the piston as it reaches the end of the stroke, and puts one or other side of an auxiliary piston, which carries the slide-valve, into communication with the exhaust, so that it is thrown over. In the Worthington engine—a design which has had much success in America, and is now being introduced in England by Messrs Simpson—two steam cylinders are placed side by side, each working its own pump-piston. The piston-rod of each is connected by a short link to a swinging bar, which actuates the slide-valve of the other steam-cylinder. In this way one piston begins its stroke when the motion of the other is about to cease, and a smooth and continuous action is secured.

207. The Worthington engine has 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 it is made compound, each high-pressure cylinder having a low-pressure cylinder tandem with it on the same rod. Owing to the lightness of the reciprocating masses, and their comparatively slow accelera­tion, their inertia does not compensate, to any great extent, for tho inequality of pressure on the pump-piston that would be caused by an early cut-off in the steam cylinder (see § 186). To meet this difficulty, and make high expansion practicable, an ingen­ious addition has recently been made to the engine.@@4 A cross­head A (fig. 131) fixed to each of the piston-rods is connected to tho 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

@@@1 See *Engineering,* August 13, 1886.

@@@2 See “Discussion on High Speed Motors,” *Min. Proc. Inst.* C.E., Nov. 1885.

@@@3 For an account of beam and other forms of rotative pumping engines, see a

paper by Mr Rich, and remarks by Mr J. G. Mair, in *Min. Proc. Inst. C.E.,* April 1884.

@@@4 *Min. Proc. Inst. C.E.,* 1886, part iv. ; *Engineering,* August 20, 1886.