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

crosshead has advanced so that the

cylinders stand at right angles to

the line of stroke. Then for the re­

mainder of the stroke the compen­

sating cylinders 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. One advantage which this method of equalizing the effort of a steam-engine piston has (as compared with making use of the inertia of the reciprocating masses) is that the effort, when adjusted to be uniform at one speed, remains uniform although the speed be changed, provided the inertia of the recipro­cating parts be small. In the Worthington “high-duty” engine, where this plan is in use, the high and low pressure cylinders are each provided with a separate expansion-valve of the rocking- cylinder type, as well as a slide-valve ; the cut-off is early, and the efficiency is as high as in other pumping engines of the best class.

208. Mr Hall’s “pulsometer” is a peculiar pumping engine without cylinder or piston, which may be regarded as the modern representative of tho engine of Savery (§ 6). The sectional view, fig. 132, 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 pas­

sage 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 suc­

tion-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-con­

ducting 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.

209. We have seen that the tendency of modern steam prac­tice is towards higher pressures, and that this means a gain both in efficiency and in power for a given weight of engine. High pressure, or indeed any pressure materially above that of the atmosphere, is out of the question when engine and boiler are to work without the regular presence of an attendant. Mr Davey has recently introduced a domestic motor which deserves notice from the fact that it employs steam at atmo­spheric pressure. One form of this successful little engine is shown in fig. 133. The boiler—which serves as the frame of the engine —is of cast-iron, and is fitted with a cast-iron internal fire-box, with a vertical flue which is traversed by a water-bridge. The

cylinder, which is enclosed within the upper part of the boiler, and the piston are of gun-metal, and work without lubrication. Steam is admitted by an ordinary slide-valve, also of gun-metal, worked by an eccentric in the usual way. The condenser stands behind the boiler ; it consists of a number of upright tubes in a box, through which a current of cold water circulates from a supply-pipe at the bottom to an overflow-pipe at the top. In larger sizes of the motor the cylinder stands on a distinct frame, and the boiler has a hopper fire-box, which will take a charge of coke sufficient to drive the engine for several hours without attention. About 6 or 7 lb of coke are burned per horse-power per hour.

210. 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.@@1

In a more modern wheel-engine (Dudgeon’s) 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.@@2 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 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.

211. A recent interesting and successful example of the rotary type is the spherical engine of Mr Beauchamp Tower,@@3 which, like several of its predecessors,@@4 is based on the kinematic relations of the moving pieces in a Hooke’s joint. Imagine a Hooke’s joint, uniting two shafts set obliquely to one another, to be made up of a central disk to which the two shafts are hinged by semicircular plates, each plate working in a hinge which forms a diameter of the central disk, the two hinges being on opposite sides of the disk and at right angles to one another. Further, let the disk and the hinged pieces be enclosed in a spherical chamber through whose walls the shafts project. As the shafts revolve each of the four spaces bounded by the disk, a hinged piece, and the chamber wall will suffer a periodic increase and diminution of volume, between limits which depend on the angle at which the shafts are set. In Mr Tower’s engine this arrangement is modified by using spherical sectors, each a quarter sphere, in place of semicircular plates, for the pieces in which the shafts terminate. The shafts are set at 135°. Each of the four enclosed cavities then alters in volume from zero to a quarter sphere, back to zero, again to a quarter sphere, and again back to zero, in a complete revolution of the shafts. In practice the central disk is a plate of finite thickness, whose edge is kept steam-tight in the enclosing chamber by spring-packing, and the sectors are reduced to an extent corresponding to the thickness of the central disk. One shaft is a dummy and runs free, the other is the driving-shaft. Steam is admitted and exhausted by ports in the spherical sectors, whose backs serve as revolving slide-valves. It is admitted to each cavity during the first part of each periodical increase of the cavity’s volume. It is then cut off and allowed to expand as the cavity further enlarges, and is exhausted as the cavity contracts. If the working shaft, to which the driven mechanism serves as a fly-wheel, revolves uni­formly, the dummy shaft is alternately accelerated and retarded. Apart from this, the only reciprocating motion is the small amount of oscillation which the comparatively light central disk undergoes.

Another rotary engine of the Hooke’s-joint family is Mr Field-

@@@1 See Farey's *Treatise on the Steam Engine,* p. 676.

@@@2 A large number of proposed rotary engines are described, and their kine­matic relations to one another are discussed, in Reuleaux’s *Kinematics of Machinery,* translated by Prof. Kennedy.

@@@3 *Proc. Inst. Mech. Eng.,* March 1885.

@@@4 One of these, the disk-engine of Bishop, was used for a time in the printing office of *The Times,* but was discarded in 1857.