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, now obsolete, the engine was 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 *return-connecting-rod* engine was another horizontal form at one time used in the British navy. It was a steeple engine placed horizontally, with two, and in some cases four, piston- rods in each cylinder. The piston-rods passed clear of the shaft and the crank, and were joined beyond it in a guided crosshead, from which a connecting-rod returned.

102. *Inverted Vertical Engines.—*Both in the navy and in merchant ocean steamers one general type of engine is universal, where the reciprocating engine has not yet been displaced by the steam turbine. This is the inverted vertical direct-acting engine, with two or more cylinders placed side by side directly over the shaft. Two, three and four cranks are employed, the arrangement with four cranks being specially suitable, as has already been pointed out, when the balance of the engine at high speeds has to be secured. As a rule naval engines are triple compound, and those of merchant vessels either triple or quadruple. In vessels of high speed and power the engines are arranged in twin sets, on two shafts with twin screw propellers.

The marine engine is always furnished with a surface con­denser, consisting of a multitude of brass tubes about 3/4 in. in diameter cooled by sea-water which is caused to circulate through the condenser by means of a circulating pump. This pump and also the air pump are often driven independently of the main engine.

103. It is in marine practice that the largest examples of engines are to be found. The triple expansion engines of the “ Campania ” and "Lucania,” which develop 30,000 h.p., consist of twin sets, on two shafts, each set having three cranks and five cylinders, two of 37 in., one of 79 in. and two of 98 in. diameter, with a stroke of 69 in. In the "Kaiser Wilhelm der Grosse ” engines of the same power are arranged in twin sets, each set consisting of four cylinders, one of 52 in. diameter, one of 89 and two of 96∙4, the four giving triple expansion and working on four cranks. The "Deutschland ” develops 36,000 h.p. with twin sets, each of which comprises two 36∙6-in. cylinders, one 73·6-in., one 103∙9-in. and two 106∙3-in. with a stroke of 72∙8 in. In the “ Kaiser Wilhelm II.” each of the twin shafts is driven by two 3-crank 4-cylinder quadruple expan­sion engines, the diameters being 37·4, 49,2, 74·8 and 112∙2 in. and a stroke of 70·9 in. With a working pressure of 225 lb per square inch these engines develop in all 40,000 h.p. These are examples of the most powerful reciprocating engines used in the propulsion of ships, but the successful application of the Parsons turbine to marine use has enabled even these powers to be greatly surpassed.

104. *Locomotive Engines.—*The ordinary locomotive consists of a pair of direct-acting horizontal or nearly horizontal engines, fixed in a rigid frame under the front end of the boiler, and coupled to the same shaft by cranks at right angles, each with a single slide-valve worked by a link-motion, or by a form of radial gear. The engine is non-condensing, except in a very few special cases, and the exhaust steam, delivered at the base of the funnel through a blast-pipe, serves to produce a draught of air through the furnace. In some instances a portion of the exhaust steam, amounting to about one-fifth of the whole, is diverted to heat the feed-water. In tank engines the feed-water is carried in tanks on the engine itself; in other engines it is carried behind in a tender.

On the shaft are a pair of driving-wheels, whose frictional adhesion to the rails furnishes the necessary tractive force. In some engines a single pair of driving-wheels are used; in many more a greater tractive force is secured by having two equal driving-wheels on each side, connected by a coupling-rod be­tween pins on the outside of the wheels. In some engines a still greater proportion of the whole weight is utilized to give tractive force by coupling three or more wheels on each side.

It is now general to have under the front of the engine two or four smaller wheels which do not form part of the driving system. These are carried in a *bogie,* that is, a small truck upon which the front end of the boiler rests by a swivel-pin or plate which allows the bogie to turn, so as to adapt itself to curves in the line, and thus obviate the grinding of tyres and danger of derailment which would be caused by using a long rigid wheel base. The bogie appears to have been of English origin;@@1 it was brought into general use in America, and is now common in English as well as in American practice. Instead of a four-wheeled bogie, a single pair of leading wheels are also used, carried by a Bissel *pony* truck, which has a swing-bolster pivoted by a radius bar about a point some distance behind the axis of the wheels. This has the advantage of combining lateral with radial movement of the wheels, both being required if the wheel base is to be properly accommodated to the curve. Another method of getting lateral and radial freedom is the plan used by F. W. Webb of carrying the leading axle in a box curved to the arc of a circle, and free to slide laterally for a short distance, under the control of springs, in curved guides.@@2

In *inside-cylinder* engines the cylinders are placed side by side within the frame of the engine, and their connecting-rods work on cranks in the driving shaft. In *outside-cylinder* engines the cylinders are spread apart far enough to lie outside the frame of the engine, and to work on crank-pins on the outsides of the driving wheels. This dispenses with the cranked axle, which is the weakest part of a locomotive engine. Owing to the frequent alternation of strain to which it is subject, a locomotive crank axle is peculiarly liable to rupture, and has to be removed after a certain amount of use.

The outside-cylinder type is adopted by several British makers; in America it is almost universal. There the cylinders are in castings which are bolted together to form a saddle on which the bottom of the smoke-box sits. The slide-valves are on the tops of the cylinders, and are worked through rock­ing levers from an ordinary link-motion. Fig. 51, which is a half section through one cylinder of an American locomotive, by the Baldwin Company of Philadelphia, shows the position of the cylinders and valves.

In inside-cylinder engines the slide- valves are frequently placed back to back in a single valve-chest between the cylinders. the width of the engine within the frame leaves little room for them there, and they are reduced to the flattest possible form, in some cases with split ports, half above and half below a partition in a central horizontal plane. In some engines the valves are below the cylinders: in many others the valves work on horizontal planes above the cylinders; this position is specially suitable when some\* form of radial gear is used instead of the link-motion. Radial valve-gears have the advantage, which is of considerable moment in inside-cylinder engines, that a part of the shaft’s length which would otherwise be needed for eccentrics is available to increase the width of main bearings and crank-pins, and to strengthen the crank-cheeks.

The principle of compounding has often been applied to locomotive engines, but without much advantage. On this subject the reader should refer to the article Railway: *§ Locomotive Power.* A more important modern departure is the use of highly superheated steam, which in many locomotives has been attended with conspicuous success.

*@@@1 Proc. Inst. Civ. Eng.,* liii. 3, p. 50.

*@@@2 Proc. Inst. Mech. Eng.* (1883).