valve-box of the low-pressure cylinder, and the pipe connecting the latter with the high-pressure exhaust passages, together with that ever-changing portion of the small cylinder which is not cut off by the exhaust face of its valve.

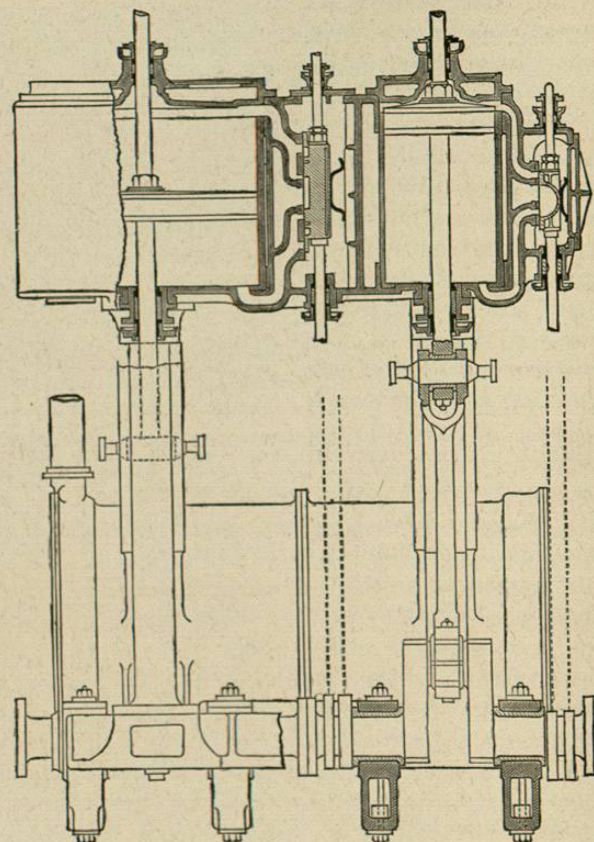

Fig. 195.

Whenever the power of the engines is so great that the low-pressure cylinder would become of very large diameter, it is usual to have two low-pressure cylinders, which draw

their steam from a common receiver. The cranks in such cases are usually at angles of 120° with one another, though sometimes, in order to secure a special distribution of the

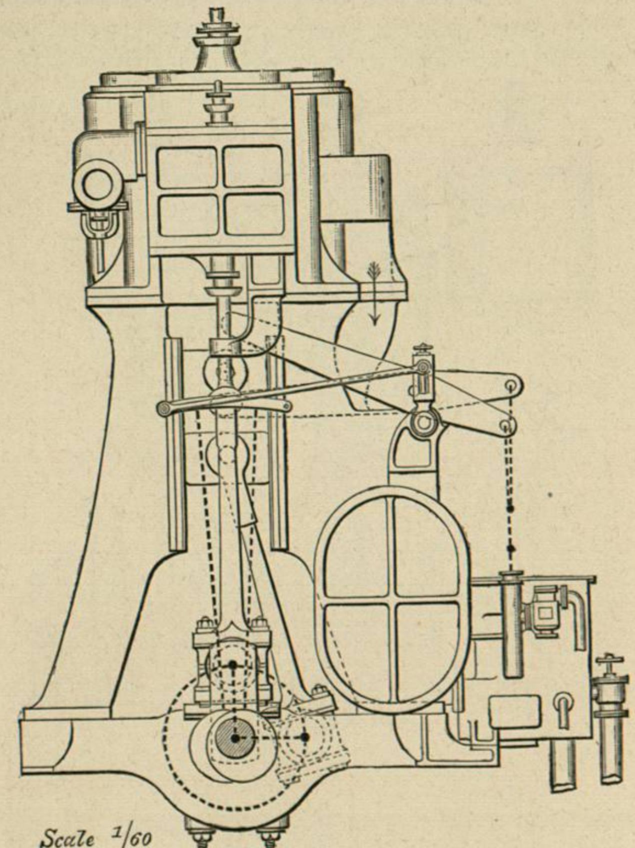

Fig. 196.

steam, or a more uniform curve of twisting moments on the shaft, the two low-pressure cranks are exactly opposite each other, while the high-pressure crank is at right angles to them, and occasionally the high-pressure crank makes a right angle with one low-pressure crank, the remaining one being at 135° with each of the others. Figs. 197, 198 show the general arrangements of a three-cylinder compound engine where two low-pressure cylinders are used, the valves being

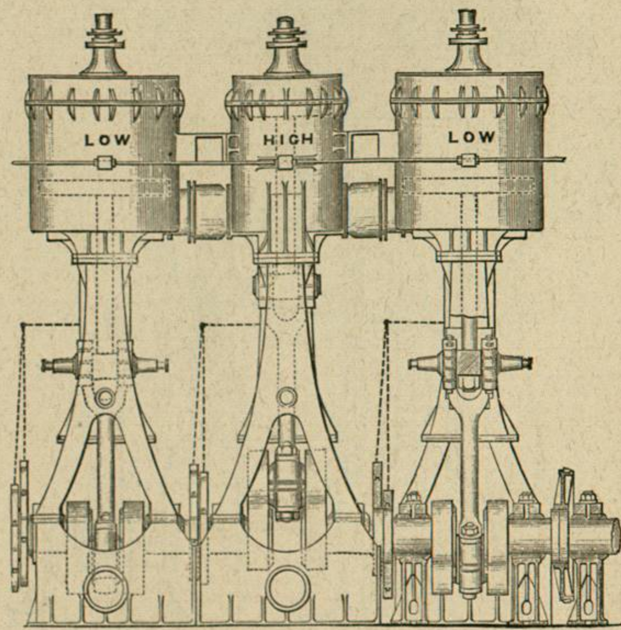

Fig. 197.

at the sides instead of between the cylinders. In this example the small cylinder is placed between the other two, though occasionally the two low-pressure cylinders are together, and the small cylinder outside.

Fig. 197 is a sketch of the front elevation, and fig. 198 a section through one of the low-pressure cylinders with its

piston valve. These engines belong to the well-known Transatlantic mail steamer, the 'Arizona.'

Triple Expansive Engines.—The same arguments which justify expansion in two cylinders successively, when the steam pressure lies between 60 and 90 lbs. per square inch, render it advisable to expand in three cylinders successively

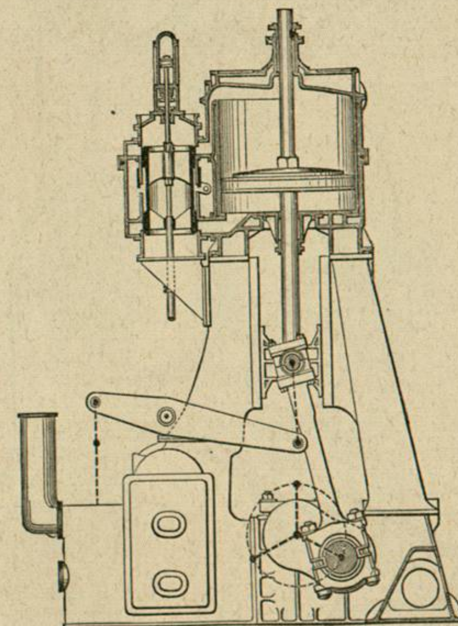

Fig. 198.

when still higher pressures are used. Such engines are called triple expansive, to distinguish them from three-cylinder ordinary compound engines. They were first introduced by Mr. A. C. Kirk.

The simplest arrangement of triple expansive engines is that illustrated in the frontispiece and figs. 199, 200, in which the high, intermediate, and low pressure cylinders are side by side, each working a separate crank. Sometimes the high-

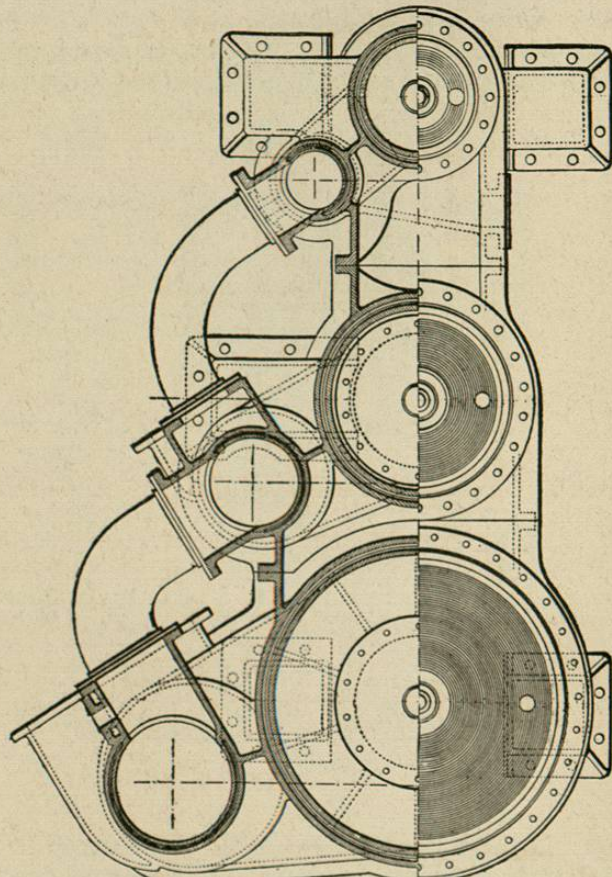

Fig. 199.

pressure is placed over the intermediate cylinder, tandem fashion, the two working on to one crank, while the low-pressure cylinder drives a separate crank. Occasionally, as

in the case of ordinary compound engines, the low-pressure cylinder is divided into two, in order to avoid excessive size.

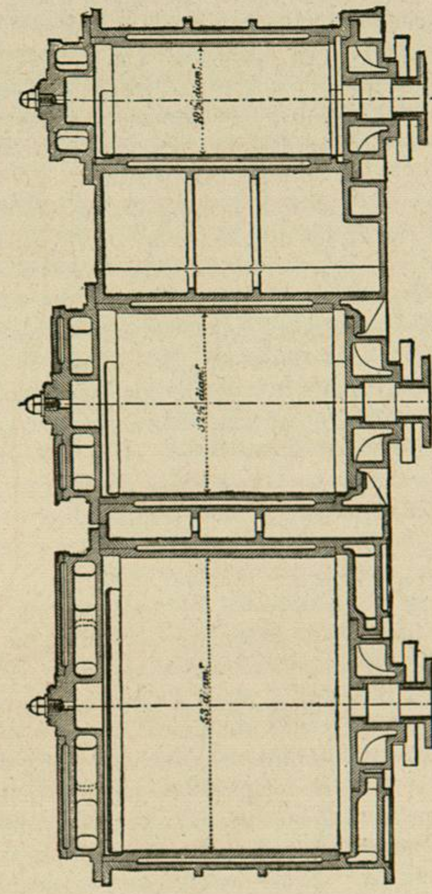

Fig. 200.

In this case the small cylinder is placed over one low-pressure cylinder, and the intermediate one over the other low-pressure, the engine resembling a double tandem with four cylinders and two cranks. The arrangement of the cylinders is, in fact, a matter of convenience, and depends upon the height and length available in the engine-room, and on the approximation to uniformity which it is desired to effect in the curve of twisting moments. Fig. 200 is a vertical longitudinal section through the cylinders, and fig. 199 a plan and half horizontal section through the cylinders, showing the positions of the piston valves, and the arrangement of the steam pipes connecting the cylinders.

Saving of Fuel effected by Compounding.—The saving of fuel effected by the use of steam of the pressure of from 120 to 150 lbs. worked in triple expansion engines may be put down as about fifteen to twenty per cent. over the expenditure in ordinary compound engines using steam of from 70 to 90 lbs. pressure. One of the first marine triple expansion engines ever made developed 1800 horse-power on the trial trip of four hours, with an expenditure of 1·28 lb. of coal per hour. The ordinary consumption at sea may be put down as about 1·5 to 1·6 lb. of coal per I.H.P. per hour. The corresponding consumption of the older type of engine with the lower pressures given above is generally from 1·8 to 2·2 lbs.

The saving of fuel effected by compounding is well illustrated by the table on page 453. Comparing the simple and compound engines when both working with jackets, it will be noticed that, with a ratio of expansion of between 5 and 6, the simple engine consumed 23·15 lbs. of water and the compound 20·36 lbs. per I.H.P. per hour, showing a saving in favour of the compound of 12½ per cent. For ratios of expansion of between 7 and 9 the saving in favour of the compound was about 15 per cent., showing, as might be expected, that the greater the difference of temperature in the cylinder, the greater the benefit to be derived from compounding. The difference in the consumption of steam between the simple engine without, and the compound engine with jacket, is still more marked. For instance, with a ratio of expansion of 7·6, the simple engine without jacket requires 9·3 lbs. of water per horse-power more than the compound with jacket, which shows that a saving of nearly 32 per cent. is in this particular instance due to the combination of the remedies of compounding and jacketing.

The distribution of the Steam in Compound Engines.—Before we examine the actual indicator diagrams of compound engines, or investigate their mechanical as distinguished from their thermal advantages, it is necessary to trace out the theoretical distribution of the steam in some of the types which occur in practice. In doing so, we will assume for the sake of simplicity that the steam is not released till the end of the stroke, that there is no compression of the exhaust steam, and that there is no resistance due to ports and passages.

Let v represent the volume of the small cylinder.

V „ „ volume of the large cylinder.
R „ „ ratio of the two cylinders.
V_R „ „ volume of the receiver.
ρ „ „ ratio of the volumes of the receiver and the small cylinder.
r „ „ rate of expansion in the small cylinder.
r' „ „ rate of expansion in the large cylinder.
E „ „ total rate of expansion.
p „ „ absolute initial pressure of the steam in the small cylinder.

Then we have the total rate of expansion $E = rR$.

The pressure of the steam at the end of the stroke in the large cylinder $= \frac{p}{E}$, and the volume which it occupies is V.

Hence, as the product of pressures and volumes is equal during hyperbolic expansion, we have

$$V \times \frac{p}{E} = \frac{v}{r} \times p \quad \therefore \quad \frac{V}{E} = \frac{v}{r}$$

Tandem Engines with a Receiver.—This is the first case which occurs in practice, because the passages between the face of the high-pressure valve and the back of the low-pressure valve, including the valve-box of the low-pressure cylinder, constitute in themselves a receiver the effect of which must not be neglected.

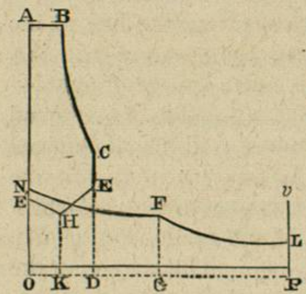

Fig. 201.

The steam is admitted into the small cylinder during the portion AB of the stroke, the length of the line AB being determined by the rate of expansion r. Its pressure at this point being p, and its volume $\frac{v}{r}$. It then expands to the end of the stroke C, when its volume is v and its pressure $CD = \frac{p}{r}$.

At this point communication is opened with the receiver, the volume of which is V_R, and which is filled from the last stroke with steam having the pressure p_R. Consequently we have now a total volume $v + V_R$ and two masses of steam, one having the pressure $\frac{p}{r}$ and the other the pressure p_R. These pressures at once equalise themselves and attain the value

$$\frac{\frac{p}{r}v + p_R V_R}{v + V_R}$$

Let this pressure be represented by DE. Hence we see that, unless at the moment of the opening of the exhaust the receiver is already filled with steam of the pressure in the small cylinder $\frac{p}{r}$, there will be a sudden drop in the diagram represented by CE. That is to say, expansion will take place

without any work being done, and the heat liberated in the process will be expended in superheating the steam in the receiver.

The pressure in the receiver is of course the initial pressure in the large cylinder. From the point O mark off ON′=DE. In drawing the low-pressure diagram it must be remembered that the volume of the large cylinder is R times that of the small cylinder; therefore on the line of volumes any given part of the stroke will be represented by a line R times as long as the same part of the stroke in the high-pressure diagram. Thus, for instance, the whole stroke is represented by $OP = OD \times R$.

The steam now expands in the low-pressure cylinder and receiver together till the point of cut-off, which is $\frac{1}{r'}$ of the stroke. At this point the volume of the steam is made up of three parts—viz.

The portion of the large cylinder up to the cut-off point $= \frac{V}{r'}$.

The volume of the receiver $= V_R$.

The portion of the small cylinder which yet remains to be traversed $= v - \frac{v}{r'} = v\left(1 - \frac{1}{r'}\right)$.

The pressure is got, as usual, by remembering that the product of the pressure and volume at all points is constant. At the commencement of the stroke of the large cylinder this product was

$$\frac{\frac{pv}{r} + p_R V_R}{v + V_R} \times (v + V_{R'})$$

Therefore at the point of the stroke now under consideration, the pressure $FG = \dfrac{\frac{pv}{r} + p_R V_R}{\frac{V}{r'} + V_R + v\left(1 - \frac{1}{r'}\right)}$