VI. Compound Expansion.

111. In the original form of compound engine, invented by Hornblower and revived by Woolf, steam passed directly from the first to the second cylinder ; the exhaust from the first and admission to the second went on together throughout the whole of the back stroke. This arrangement is possible only when the high and low pressure pistons begin and end their strokes together, that is to say, when their movements either coincide in phase or differ by half a revolution. Engines of the “tandem” type satisfy this condition—engines, namely, whose high and low pressure cylinders are in one line, with one piston-rod common to both pistons. Engines in which the high and low pressure cylinders are placed side by side, and act either on the same crank or on cranks set at 180° apart, may also discharge steam directly from one to the other cylinder; the same remark applies to beam engines, whether of the class in which both pistons act on one end of the beam, or of the class introduced by M'Naught, in which the high and low pressure cylinders stand on opposite sides of the centre. By a convenient usage which is now pretty general the name “Woolf engine” is restricted to those compound engines which discharge steam directly from the high to the low pressure cylinders without the use of an intermediate receiver.

112. An intermediate receiver becomes necessary when the phases of the pistons in a compound engine do not agree. With two cranks at right angles, for example, a portion of the discharge from the high-pressure cylinder occurs at a time when the low-pressure cylin­der cannot properly receive steam. The receiver is in some cases an entirely independent vessel connected to the cylinders by pipes ; very often, however, a sufficient amount of receiver volume is afforded by the valve casings and the steam-pipe which connects the cylinders. The receiver, when it is a distinct vessel, is frequently jacketed.

The use of a receiver is of course not restricted to engines in which the “Woolf” system of compound working is impracticable. On the contrary, it is frequently applied with advantage to beam and tandem compound engines. Communication need not then be maintained between the high and low pressure cylinders during the whole of the stroke; admission to the low-pressure cylinder is stopped before the stroke is completed ; the steam already admitted is allowed to expand independently ; and the remainder of the discharge from the high-pressure cylinder is compressed into the intermediate re­ceiver. Each cylinder has then a definite point of cut-off, and by varying these points the distribution of work between the two cylin­ders may be adjusted at will. In general it is desirable to make both cylinders of a compound engine contribute equal quantities of work. If they act on separate cranks this has the effect of giving the same value to the mean twisting moment on both cranks.

113. Wherever a receiver is used, care should be taken that there is no unresisted expansion into it; in other words, the pressure in the receiver should be equal to that in the high-pressure cylinder at the moment of release. If the receiver pressure is less than this there will be what is termed a “drop” in the steam pressure between the high-pressure cylinder and the receiver, which will show itself in an indicator diagram by a sudden fall at the end of the high-pressure expansion. This “drop” is, from the thermodynamic point of view, irreversible, and therefore wasteful. It can be avoided by selecting a proper point of cut-off in the low- pressure cylinder. When there is no “drop’’the expansion that occurs in a compound engine has precisely the same effect in doing work as the same amount of expansion in a simple engine would have, provided the law of expansion be the same in both and the waste of energy which occurs by the friction of ports and passages in the transfer of steam from one to the other cylinder be negligible. The work done in either case depends merely on the relation of pressure to volume throughout the process; and so long as that relation is unchanged it is a matter of indifference whether the expansion be performed in one vessel or in more than one. It has, however, been fully pointed out in chap. IV. that in general a compound engine has a thermodynamic advantage over a simple engine using the same pressure and the same expansion, inasmuch as it reduces the exchange of heat between the working substance and the cylinder walls and so makes the process of expansion more nearly adiabatic. The compound engine has also a mechanical advantage which will be presently described. The ultimate ratio

of expansion in any com­pound engine is the ratio of the volume of the low- pressure cylinder to the volume of steam admitted to the high-pressure cylin­der. Fig. 29 illustrates the combined action of the two cylinders in a hypothetical compound engine of the Woolf type, in which for simplicity the effect of clearance is neglected and also the loss of pressure which the steam undergoes in transfer from one to the other cylinder. ABCD is the indicator diagram of the high-pressure cylinder. The exhaust line CD shows a falling

pressure in consequence of the increase of volume which the steam is then undergoing through the advance of the low-pressure piston. EFGH is the diagram of the low-pressure cylinder drawn alongside of the other for convenience in the construction which follows. It has no point of cut-off ; its admission line is the continuous curve of expansion EF, which is the same as the high-pressure exhaust line CD, but drawn to a different scale of volumes. At any point K, the actual volume of the steam is KL + MN. By drawing OP equal to KL + MN, so that OP represents the whole volume, and repeating the same construction at other points of the diagram, we may set out the curve QPR, the upper part of which is identical with BC, and so complete a single diagram which exhibits the equivalent expansion in a single cylinder.

In a tandem compound engine of the receiver type the diagrams resemble those shown in fig. 30. During CD (which corresponds to FG) expansion is taking place into the large or low- pressure cylinder. D and G mark the point of cut-off in the large cylinder, after which GH shows the independent expansion of the steam now shut within the large cylinder, and DE shows the compression of steam by continued discharge from the small cylinder into the receiver. At the end of the stroke the receiver pressure is OE, and this must be the same as the pressure at C, if there is to be no “drop.” Dia­grams of a similar kind may be sketched without difficulty for the case of a receiver engine with

any assigned phase relation between the pistons.@@1

114. By making the cut-off take place earlier in the large cylinder we increase the mean pressure in the receiver ; the work done in the small cylinder is consequently diminished. The work done in the large cylinder is correspondingly increased, for the total work (depending as it does on the initial pressure and the total ratio of expansion) is unaffected by the change. The same adjustment serves, in case there is “drop,” to remove it. By selecting a suitable ratio of cylinder volumes to one another and to the volume of the receiver, and also by choosing a proper point for the low- pressure cut-off, it is possible to secure absence of drop along with equality in the division of the work between the two cylinders.

To determine that point of cut-off in the low-pressure cylinder which will prevent drop when the ratio of cylinder and receiver volumes is assigned is a problem most easily solved by a graphic process. The process consists in drawing the curve of pressure during admission to the low-pressure cylinder until it meets the curve of expansion which is common to both cylinders.@@2 Thus in fig. 31 (where for the sake of simplicity the effects of clearance are neglected) AB represents the admission line and BC the ex­pansion line in the small cylin­der. Release occurs at C, and from C to D steam is being taken by the large cylinder.

D corre­sponds to the cut­off in the large cylin­der, which is the point

to be found. From D to E steam is being compressed into the receiver. To avoid drop the receiver pressure at E is to be the same as the pressure at C. E is therefore known, and may be employed as the starting-point in drawing a curve EF which is the admission line of the low-pressure diagram EFGHI. This line is drawn by considering at each point in the low-pressure piston’s stroke what is then the whole volume of the steam. The place at which EF intersects the continuous expansion curve BCG determines the proper point of cut-off. The sketch (fig. 31) refers to the case of a tandem receiver engine ; but the process may also be applied to an engine with any assumed phase relation between the cranks. Fig. 32 shows a pair of theoretical indicator diagrams determined in the same way for an engine with cranks at right angles, the high-pres­sure crank leading. In using the graphic method any form may be assigned to the curve of expansion. Generally this curve may be treated without serious inaccuracy as a common hyperbola, in which the pressure varies inversely as the volume.

115. If this simple relation between pressure and volume be assumed, it is practicable to find algebraically the low-pressure cut­off which will give no drop, with assigned ratios of cylinder and

@@@1 An intermediate receiver lias the thermodynamic advantage that it reduces the range of temperature in the high-pressure cylinder, and so helps to prevent initial condensation of the steam. This will he made obvious by a comparison of fig. 29 and fig. 30. The lowest temperature reached in the high-pressure cylinder is that corresponding to the pressure at D, and is materially higher in fig. 30 than in fig. 29.

@@@2 See a paper by Prof. R. H. Smith, “Οn the Cut-off in the Large Cylinder of Compound Engines,” *The Engineer,* November 27, 1885.