CHAPTER III.

EXPANSION OF STEAM AND ACTION OF THE VALVES.

177. *Q.*—What is meant by working engines expansively?

A.—Adjusting the valves, so that the steam is shut off from the cylinder before the end of the stroke, whereby the residue of the stroke is left to be completed by the expanding steam.

178. *Q.*—And what is the benefit of that practice?

A.—It accomplishes an important saving of steam, or, what is the same thing, of fuel; but it diminishes the power of the engine, while increasing the power of the steam. A larger engine will be required to do the same work, but the work will be done with a smaller consumption of fuel. If, for example, the steam be shut off when only half the stroke is completed, there will only be half the quantity of steam used. But there will be more than half the power exerted; for although the pressure of the steam decreases after the supply entering from the boiler is shut off, yet it imparts, during its expansion, *some* power, and that power, it is clear, is obtained without any expenditure of steam or fuel whatever.

179. *Q.*—What will be the pressure of the steam, under such circumstances, at the end of the stroke?

A.—If the steam be shut off at half stroke, the pressure of the steam, reckoning the total pressure both below and above the atmosphere, will just be one-half of what it was at the beginning of the stroke. It is a well known law of pneumatics, that the pressure of elastic fluids varies inversely as the spaces into which they are expanded or compressed. For example, if a cubic foot of air of the atmospheric density be compressed into the compass of half a cubic foot, its elasticity will be increased from 15 lbs. on the square inch to 30 lbs. on the square inch; whereas, if its volume be enlarged to two cubic feet, its elasticity will be reduced to 7½ lbs. on the square inch, being just half its original pressure. The same law holds in all other proportions, and with all other gases and vapors, provided their temperature remains unchanged; and if the steam valve of an engine be closed, when the piston has descended through one-fourth of the stroke, the steam within the cylinder will, at the end of the stroke, just exert one-fourth of its initial pressure.

180. *Q.*—Then by computing the varying pressure at a number of stages, the average or mean pressure throughout the stroke may be approximately determined?

A.—Precisely so. Thus in the accompanying figure, (fig. 32), let E be a cylinder, J the piston, *a* the steam pipe, *c* the upper port, *f* the lower port, *d* the steam pipe, prolonged to *e* the equilibrium valve, *g* the eduction valve, M the steam jacket, N the cylinder cover, O stuffing box, *n* piston rod, P cylinder bottom; let the cylinder be supposed to be divided in the direction of its length into any number of equal parts, say twenty, and let the diameter of the cylinder represent the pressure of the steam, which, for the sake of simplicity, we may take at 10 lbs., so that we may divide the cylinder, in the direction of its diameter, into ten equal parts. If now the piston be supposed to descend through five of the divisions, and the steam valve then be shut, the pressure at each subsequent position of the piston will be represented by a series, computed according to the laws of pneumatics, and which, if the initial pressure be represented by 1, will give a pressure of ·5 at the middle of the stroke, and ·25 at the end of it. If this series be set off on the horizontal lines, it will mark out a hyperbolic curve—the area of the part exterior to which represents the total efficacy of the stroke, and the interior area, therefore, represents the diminution in the power of a stroke, when the steam is cut off at one-fourth of the

Fig. 32.

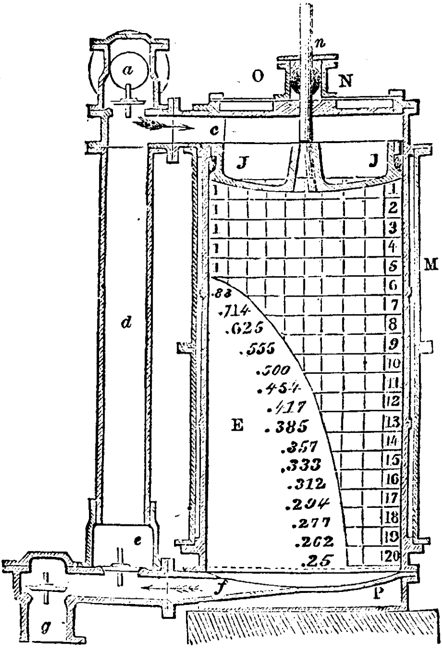


Diagram showing law of expansion of steam in a cylinder.

descent. If the squares above the point, where the steam is cut off, be counted, they will be found to amount to 50; and if those beneath that point be counted or estimated, they will be found to amount to about 69. These squares are representative of the power exerted; so that while an amount of power represented by 50 has been obtained by the expenditure of a quarter of a cylinder full of steam, we get an amount of power represented by 69, without any expenditure of steam at all, merely by permitting the steam first used to expand into four times its original volume.

181. *Q.*—Then by working an engine expansively, the power of the steam is increased, but the power of the engine is diminished?

A.—Yes. The efficacy of a given quantity of steam is more than doubled by expanding the steam four times, while the efficacy of each stroke is made nearly one-half less. And, therefore, to carry out the expansive principle in practice, the cylinder requires to be larger than usual, or the piston faster than usual, in the proportion in which the expansion is carried out. Every one who is acquainted with simple arithmetic, can compute the terminal pressure of steam in a cylinder, when he knows the initial pressure and the point at which the steam is cut off; and he can also find, by the same process, any pressure intermediate between the first and the last. By setting down these pressures in a table, and taking their mean, he can determine the effect, with tolerable accuracy, of any particular measure of expansion. It is necessary to remark, that it is the total pressure of the steam that he must take; not the pressure above the atmosphere, but the pressure above a perfect vacuum.

182. *Q.*—Can you give any rule for ascertaining at one operation the amount of benefit derivable from expansion?

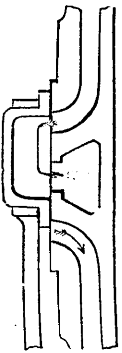
A.—Divide the length of stroke through which the steam expands, by the length of stroke performed with full pressure, which last call 1; the hyperbolic logarithm of the quotient is the increase of efficiency due to expansion. According to this rule it will be found, that if a given quantity of steam, the power of which working at full pressure is represented by 1, be admitted into a cylinder of such a size that its ingress is concluded when one-half the stroke has been performed, its efficacy will be raised by expansion to 1·69; if the admission of the steam be stopped at one-third of the stroke, the efficacy will be 2·10; at one-fourth, 2·39; at one-fifth, 2·61; at one-sixth, 2·79; at one-seventh, 2·95; at one-eighth, 3·08. The expansion, however, cannot be carried beneficially so far as one-eighth, unless the pressure of the steam in the boiler be very considerable, on account of the inconvenient size of cylinder or speed of piston which would require to be adopted, the friction of the engine, and the resistance of vapor in the condenser, which all become relatively greater with a smaller urging force.

183. *Q.*—Is this amount of benefit actually realized in practice?

A.—Only in some cases. It appears to be indispensable to the realization of any large amount of benefit by expansion, that the cylinder should be enclosed in a steam jacket, or should in some other way be effectually protected from refrigeration. In some engines not so protected, it has been found experimentally that less benefit was obtained from the fuel by working expansively than by working without expansion—the whole benefit due to expansion being more than counteracted by the increased refrigeration due to the larger surface of the cylinder required to develop the power. In locomotive engines, with outside cylinders, this condition of the advantageous use of expansion has been made very conspicuous, as has also been the case in screw steamers with four cylinders, and in which the refrigerating surface of the cylinders was consequently large.

184. *Q.*—The steam is admitted to and from the cylinder by means of a slide or sluice valve?

Fig. 33.



A.—Yes; and of the slide valve there are many varieties; but the kinds most in use are the D valve,—so called from its resemblance to a half cylinder or D in its cross section—and the three ported valve, shown in fig. 33, which consists of a brass or iron box set over the two ports or openings into the cylinder, and a central port which conducts away the steam to the atmosphere or condenser; but the length of the box is so adjusted that it can only cover one of the cylinder ports and the central or eduction port at the same time. The effect, therefore, of moving the valve up and down, as is done by the eccentric, is to establish a connection alternately between each cylinder port and the central passage whereby the steam escapes; and while the steam is escaping from beneath the piston, the position of the valve is such, that a free communication exists between the space above the piston and the steam in the boiler. The piston is thus urged alternately up and down—the valve so changing its position before the piston arrives at the end of the stroke, that the pressure is by that time thrown on the reverse side of the piston, so as to urge it into motion in the opposite direction.

185. *Q.*—Is the motion of the valve, then, the reverse of that of the piston?

A.—No. The valve does not move down when the piston moves down, nor does it move down when the piston moves up; but it moves from its mid position, to the extremity of its throw, and back again to its mid position, while the piston makes an upward or downward movement, so that the motion is as it were at right angles to the motion of the piston; or it is the same motion that the piston of another engine, the crank of which is set at right angles with that of the first engine, would acquire.

186. *Q.*—Then in a steam vessel the valve of one engine may be worked from the piston of the other?

A.—Yes, it may; or it may be worked from its own connecting rod; and in the case of locomotive engines, this has sometimes been done.

187. *Q.*—What is meant by the lead of the valve?

A.—The amount of opening which the valve presents for the admission of the steam, when the piston is just beginning its stroke. It is found expedient that the valve should have opened a little to admit steam on the reverse side of the piston before the stroke terminates; and the amount of this opening, which is given by turning the eccentric more or less round upon the shaft, is what is termed the lead.

188. *Q.*—And what is meant by the lap of the valve?

A.—It is an elongation of the valve face to a certain extent over the port, whereby the port is closed sooner than would otherwise be the case. This extension is chiefly effected at that part of the valve where the steam is admitted, or upon the *steam side* of the valve, as the technical phrase is; and the intent of the extension is to close the steam passage before the end of the stroke, whereby the engine is made to operate to a certain extent expansively. In some cases, however, there is also a certain amount of lap given to the escape or eduction side, to prevent the eduction from being performed too soon when the lead is great; but in all cases there is far less lap on the eduction than on the steam side, very often there is none, and sometimes less than none, so that the valve is incapable of covering both the ports at once.

189. *Q.*—What is the usual proportional length of stroke of the valve?

A.—The common stroke of the valve in rotative engines is twice the breadth or depth of the port, and the length of the valve face will then be just the breadth of the port when there is lap on neither the steam nor eduction side. Whatever lap is given, therefore, makes the valve face just so much longer. In some engines, however, the stroke of the valve is a good deal more than twice the breadth of the port; and it is to the stroke of the valve that the amount of lap should properly be referred.

190. *Q.*—Can you tell what amount of lap will accomplish any given amount of expansion?

A.—Yes, when the stroke of the valve is known. From the length of the stroke of the piston subtract that part of the stroke which is intended to be accomplished before the steam is cut off; divide the remainder by the length of the stroke of the piston, and extract the square root of the quotient, which multiply by half the stroke of the valve, and from the product take half the lead; the remainder will be the lap required.

191. *Q.*—Can you state how we may discover at what point of the stroke the eduction passage will be closed?

A.—To find how much before the end of the stroke the eduction passage will be closed:—to the lap on the steam side add the lead, and divide the sum by half the stroke of the valve; find the arc whose sine is equal to the quotient, and add 90° to it; divide the lap on the eduction side by half the stroke of the valve, and find the arc whose cosine is equal to the quotient; subtract this arc from the one last obtained, and find the cosine of the remainder; subtract this cosine from 2, and multiply the remainder by half the stroke of the piston; the product is the distance of the piston from the end of the stroke when the eduction passage is closed.

192. *Q.*—Can you explain how we may determine the distance of the piston from the end of the stroke, before the steam urging it onward is allowed to escape?

A.—To find how far the piston is from the end of its stroke when the steam that is propelling it by expansion is allowed to escape to the atmosphere or condenser—to the lap on the steam side add the lead; divide the sum by half the stroke of the valve, and find the arc whose sine is equal to the quotient; find the arc whose sine is equal to the lap on the eduction side, divided by half the stroke of the valve; add these two arcs together and subtract 90°; find the cosine of the residue, subtract it from 1, and multiply the remainder by half the stroke of the piston; the product is the distance of the piston from the end of its stroke when the steam that is propelling it is allowed to escape into the atmosphere or condenser. In using these rules, all the dimensions are to be taken in inches, and the answers will be found in inches also.

193. *Q.*—Is it a benefit or a detriment to open the eduction passage before the end of the stroke?

A.—In engines working at a high rate of speed, such as locomotive engines, it is very important to open the exhaust passage for the escape of the steam before the end of the stroke, as an injurious amount of back pressure is thus prevented. In the earlier locomotives a great loss of effect was produced from inattention to this condition; and when lap was applied to the valves to enable the steam to be worked expansively, it was found that a still greater benefit was collaterally obtained by the earlier escape of the steam from the eduction passages, and which was incidental to the application of lap to the valves. The average consumption of coke per mile was reduced by Mr. Woods from 40 lbs. per mile to 15 lbs. per mile, chiefly by giving a free outlet to the escaping steam.

194. *Q.*—To what extent can expansion be carried beneficially by means of lap upon the valve?

A.—To about one-third of the stroke; that is, the valve may be made with so much lap, that the steam will be cut off when two thirds of the stroke have been performed, leaving the residue to be accomplished by the agency of the expanding steam; but if more lap be put on than answers to this amount of expansion, a very distorted action of the valve will be produced, which may impair the efficiency of the engine. If a further amount of expansion than this is wanted, it may be accomplished by wire drawing the steam, or by so contracting the steam passage that the pressure within the cylinder must decline when the speed of the piston is accelerated, as it is about the middle of the stroke.

195. *Q.*—Will you explain how this result ensues?

A.—If the valve be so made as to shut off the steam by the time two thirds of the stroke have been performed, and the steam be at the same time throttled in the steam pipe, the full pressure of the steam within the cylinder cannot be maintained except near the beginning of the stroke where the piston travels slowly; for, as the speed of the piston increases, the pressure necessarily subsides, until the piston approaches the other end of the cylinder, where the pressure would rise again but that the operation of the lap on the valve by this time has had the effect of closing the communication between the cylinder and steam pipe, so as to prevent more steam from entering. By throttling the steam, therefore, in the manner here indicated, the amount of expansion due to the lap may be doubled, so that an engine with lap enough upon the valve to cut off the steam at two-thirds of the stroke, may, by the aid of wire drawing, be virtually rendered capable of cutting off the steam at one-third of the stroke.

196. *Q.*—Is this the usual way of cutting off the steam?

A.—No; the usual way of cutting off the steam is by means of a separate valve, termed an expansion valve; but such a device appears to be hardly necessary in ordinary engines. In the Cornish engines, where the steam is cut off in some cases at one-twelfth of the stroke, a separate valve for the admission of steam, other than that which permits its escape, is of course indispensable; but in common rotative engines, which may realize expansive efficacy by throttling, a separate expansion valve does not appear to be required.

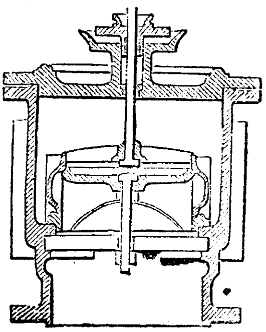
197. *Q.*—That is, where much expansion is required, an expansion valve is a proper appendage, but where not much is required, a separate expansion valve may be dispensed with?

A.—Precisely so. The wire drawing of the steam causes a loss of part of its power, and the result will not be quite so advantageous by throttling as by cutting off. But for moderate amounts of expansion it will suffice, provided there be lap upon the slide valve.

198. *Q.*—Will you explain the structure or configuration of expansion apparatus of the usual construction?

A.—The structure of expansion apparatus is very various; but all the kinds operate either on the principle of giving such a motion to the slide valve as will enable it to cut off the steam, at the desired point, or on the principle of shutting off the steam by a separate valve in the steam pipe or valve casing. The first class of apparatus has not been found so manageable, and is not in extensive use, except in that form known as the link motion. Of the second class, the most simple probably is the application of a cam giving motion to the throttle valve, or to a valve of the same construction, which either accurately fits the steam pipe, or which comes round to a face, which, however, it is restrained from touching by a suitable construction of the cam. A kind of expansion valve, often employed in marine engines of low speed, is the kind used in the Cornish engines, and known as the equilibrium valve. This valve is represented in fig. 34. It consists substantially of

Fig. 34.



an annulus or bulging cylinder of brass, with a steam-tight face both at its upper and lower edges, at which points it fits accurately upon a stationary seat. This annulus may be raised or lowered without being resisted by the pressure of the steam, and in rotative engines it is usually worked by a cam on the shaft. The expansion cam is put on the shaft in two pieces, which are fastened to each other by means of four bolts passing through lugs, and is fixed to the shaft by keys. A roller at one end of a bell-crank lever, which is connected with the expansion valve, presses against the cam, so that the motion of the lever will work the valve. The roller is kept against the cam by a weight on a lever attached to the same shaft, but a spring is necessary for high speeds. If the cam were concentric with the shaft, the lever which presses upon it would remain stationary, and also the expansion valve; but by the projection of the cam, the end of the lever receives a reciprocating motion, which is communicated to the valve.

199. *Q.*—The cam then works the valve?

A.—Yes. The position of the projection of the cam determines the point in relation to the stroke at which the valve is opened, and its circumferential length determines the length of the time during which the valve continues open. The time at which the valve should begin to open is the same under all circumstances, but the duration of its opening varies with the amount of expansion desired. In order to obtain this variable extent of expansion, there are several projections made upon the cam, each of which gives a different degree, or *grade* as it is usually called, of expansion. These grades all begin at the same point on the cam, but are of different lengths, so that they begin to move the lever at the same time, but differ in the time of returning it to its original position.

200. *Q.*—How is the degree of expansion changed?

A.—The change of expansion is effected by moving the roller on to the desired grade; which is done by slipping the lever carrying the roller endways on the shaft or pin sustaining it.

201. *Q.*—Are such cams applicable in all cases?

A.—In engines moving at a high rate of speed the roller will be thrown back from the cam by its momentum, unless it be kept against it by means of springs. In some cases I have employed a spring formed of a great number of discs of India rubber to keep the roller against the cam, but a few brass discs require to be interposed to prevent the India rubber discs from being worn in the central hole.

202. *Q.*—May not the percussion incident to the action of a cam at a high speed, when the roller is not kept up to the face by springs, be obviated by giving a suitable configuration to the cam itself?

A.—It may at all events be reduced. The outline of the cam should be a parabola, so that the valve may be set in motion precisely as a falling body would be; but it will, nevertheless, be necessary that the roller on which the cam presses should be forced upward by a spring rather than by a counterweight, as there will thus be less inertia or momentum in the mass that has to be moved.

203. *Q.*—An additional slide valve is sometimes used for cutting off the steam?

A.—Yes, very frequently; and the slide valve is sometimes on the side or back of the valve casing, and sometimes on the back of the main or distributing valve, and moving with it.

204. *Q.*—Are cams used in locomotive engines?

A.—In locomotive engines the use of cams is inadmissible, and other expedients are employed, of which those contrived by Stephenson and by Cabrey operate on the principle of accomplishing the requisite variations of expansion by altering the throw of the slide valve.

205. *Q.*—What is Stephenson's arrangement?

A.—Stephenson connects the ends of the forward and backward eccentric rods by a link with a curved slot in which a pin upon the end of the valve rod works. By moving this link so as to bring the forward eccentric rod in the same line with the valve rod, the valve receives the motion due to that eccentric; whereas if the backward eccentric rod is brought in a line with the valve rod, the valve gets the motion proper for reversing, and if the link be so placed that the valve rod is midway between the two eccentric rods, the valve will remain nearly stationary. This arrangement, which is now employed extensively, is what is termed "the link motion." It is represented in the annexed figure, fig. 35, where *e* is the valve rod, which is

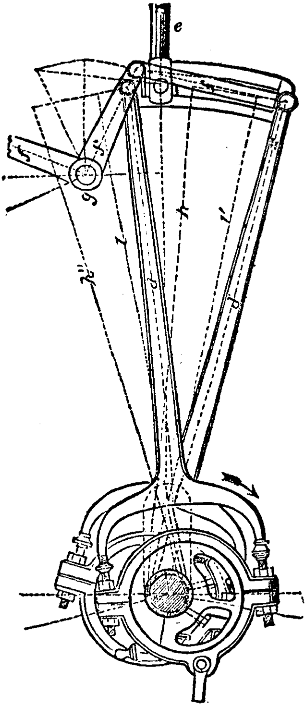


Fig. 35.

attached by a pin to an open curved link susceptible of being moved up and down by the bell-crank lever *f'' f''*, supported on the centre *g*, and acting on the links *f*, while the valve rod *e* remains in the same horizontal plane; *d d'* are the eccentric rods, and the link is represented in its lowest position. The dotted lines *h' h''* show the position of the eccentric rods when the link is in its highest position, and *l l'* when in mid position.

206. *Q.*—What is Cabrey's arrangement?

A.—Mr. Cabrey makes his eccentric rod terminate in a pin which works into a straight slotted lever, furnished with jaws similar to the jaws on the eccentric rods of locomotives. By raising the pin of the eccentric rod in this slot, the travel of the valve will be varied, and expansive action will be the result.

207. *Q.*—What other forms of apparatus are there for working steam expansively?

A.—They are too numerous for description here, but a few of them may be enumerated. Fenton seeks to accomplish the desired object by introducing a spiral feather on the crank axle, by moving the eccentric laterally against which the eccentric is partially turned round so as to cut off the steam at a different part of the stroke. Dodds seeks to attain the same end by corresponding mechanical arrangements. Farcot, Edwards, and Lavagrian cut off the steam by the application of a supplementary valve at the back of the ordinary valve, which supplementary valve is moved by tappets fixed to the valve casing. Bodmer, in 1841, and Meyer, in 1842, employed two slides or blocks fitted over apertures in the ordinary slide valve, and which blocks were approximated or set apart by a right and left handed screw passing through both.* Hawthorn, in 1843, em-

* In 1838 I patented an arrangement of expansion valve, consisting of two movable plates set upon the ordinary slide valve, and which might be drawn together or asunder by means of a right and left handed screw passing through both plates. The valve spindle was hollow, and a prolongation of the screw passed up through it, and was armed on the top with a small wheel, by means of which the plates might be adjusted while the engine was at work. In 1839 I fitted an expansion valve in a steam vessel, consisting of two plates, connected by a rod, and moved by tappets up against the steam edges of the valve. In another steam vessel I fitted the same species of valve, but the motion was not derived from tappets, but from a moving part of the engine, though at the moderate speed at which these engines worked I found tappets to operate well and make little noise. In 1837 I employed, as an expansion valve, a rectangular throttle valve, accurately fitting a bored out seat, in which it might be made to revolve, though it did not revolve in working. This valve was moved by a pin in a pinion, making two revolutions for every revolution of the engine, and the configuration of the seat deter-

ployed as an expansion valve a species of frame lying on the ordinary cylinder face upon the outside of the valve, and working up against the steam side of the valve at each end so as to cut off the steam. In the same year Gonzenbach patented an arrangement which consists of an additional slide valve and valve casing placed on the back of the ordinary slide valve casing, and through this supplementary valve the steam must first pass. This supplementary valve is worked by a double ended lever, slotted at one end for the reception of a pin on the valve link, the position of which in the slot determines the throw of the supplementary valve, and the consequent degree of expansion.

208. *Q.*—What is the arrangement of expansion valve used in the most approved modern engines?

A.—In modern engines, either marine or locomotive, it is found that if they are fitted with the link motion, as they nearly all are, a very good expansive action can be obtained by giving a suitable adjustment to it, without employing an expansion valve at all. Diagrams taken from engines worked in this manner show a very excellent result, and most of the modern engines trust for their expansive working to the link motion and the throttle valve.

mined the amount of the expansion. In 1855 I have again used expansion valves of this construction in engines making one hundred revolutions per minute, and with perfectly satisfactory results.—J. B.