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On the principles of mechanism and on prime movers

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Chap. V. On turbines.

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CHAP. V.

ON TURBINES.

It will be impossible in the present work to enter into details on the theory and construction of the immense variety of prime-movers known under the name of turbines, the development of the principles of which we owe chiefly to continental mathematicians. Two varieties of horizontal wheels or turbines have long been employed on the Continent, which although ill-devised and ineffective, yet presented evident advantages in their small size, cheapness, and simplicity of construction. These are known in France as *roues à cuves* and *rouets volants*, the former being a small wheel revolving on a vertical axis, and having inclined curved vanes or buckets arranged radially. It is placed in a pit so that the water passing vertically through it should act by pressure and reaction on the buckets. The *rouet volant* differs from this in having the water applied to the wheel at a small part only of the periphery, so as to drive the wheel by impulse. These wheels of from 3 to 5 feet in diameter with nine to twelve buckets are usually made of cast-iron, and fixed upon a lever foot bridge, so that they can be slightly raised or depressed. The running millstone is fixed on the upper extremity of the vertical axis, so as to obviate the use of any gearing or belting. In regard to efficiency, the *roues à cuves* yield about 27 per cent. and the *rouets volants* about 30 to 40 per cent. of the water used.

General Poncelet was the first to demonstrate the principle and superior advantages of the turbine, and in 1827 M. Fourneyron recalled public attention in France very forcibly to the construction of the horizontal wheels by a turbine very happily conceived and executed. For this invention he received in 1833 a prize of 6000 francs; and the principles of his machine

have been investigated, and its superiority proved, by the ablest continental experimenters on hydraulics. In its present form it is equal in efficiency to the best hydraulic machines, and in many circumstances is very advantageously employed. Since then the manufacture of these turbines in countries where water power is much depended upon has assumed considerable importance, and very numerous modifications of its form and construction have been adopted.

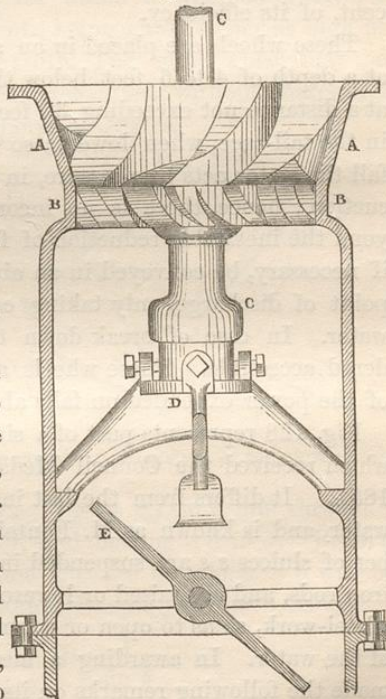
1. *Turbines in which the water passes vertically through the wheel.*

Wheels of this class are composed of two annular cylinders, the upper fixed and the lower revolving on a vertical axis. The upper is fitted with guides to direct the water most effectively against similar curved vanes or buckets, turned in the opposite direction, in the lower wheel. The water passes from the reservoir or cistern placed over the upper cylinder, vertically downwards, acting on the revolving wheel by pressure as it glides over the surface of the vanes.

Burdin about 1826 invented a turbine of this description (*turbine à évacuation alternative*), the efficiency of which was as much as 67 per cent. of the water power expended.

Fig. 127 represents Feu Jonval's turbine (known also as the Koechlin turbine). The fixed wheel is shown at *AA*, the revolving wheel at *BB*. The wheels consist of cast-iron rims having wrought-iron guides grooved and riveted to them. The running wheel is keyed on the shaft *cc*, which is supported on a step *d*, firmly fixed by screws on the cast-iron bridge attached to the

Fig. 127.



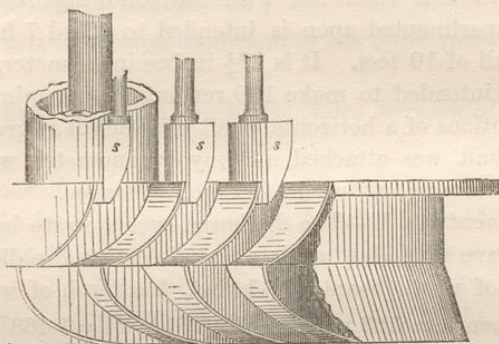
cylinder forming the tail-race. The regulation of the water is effected partly by a valve *e* resembling the throttle-valve of a steam-engine and placed beneath the wheel, or in some cases by a sluice at the opening of the conduit into the tail-race. This method, when much variation of power is required, reduces the efficiency of the wheel, but it has the merit of great simplicity and facility of construction. In the construction represented the vane carries outside the cylinder in which it is placed a wheel, acted on by a worm from a hand-wheel placed at any convenient point above the upper cistern. There are also employed movable divisions by which part of the inner periphery of the revolving wheel is enclosed, and the water passes through a narrower annular aperture on the external periphery. This arrangement is said to have operated effectively in America, so that a wheel giving 60 H. P. in wet seasons can work at 40 H. P. in dry seasons, without losing more than 15 or 16 per cent. of its efficiency.

These wheels are placed in an air-tight cylinder, for low falls at a depth of 4 to 6 feet below the surface, and for high falls at a distance not exceeding 30 feet above the level of the water in the tail-race, when lowest; so that in the upper part of the fall the water acts by pressure, in the part below the wheel by suction; hence, there is no inconvenience from backwater beyond the inevitable reduction of fall, and the waste water may, if necessary, be conveyed in an air-tight pipe to any convenient point of discharge, only taking care that its mouth be under water. In case of break down the wheel is very easily rendered accessible. These wheels are said to yield 75 per cent. of the power expended on falls above 12 feet.

Fig. 128 represents part of a similar turbine by M. Fromont, which received the Council Medal at the Great Exhibition of 1851. It differs from the last in the method of regulating the water, and is known as M. Fontaine Baron's turbine. A number of sluices *s s* are suspended in the fixed wheel by wrought-iron rods, and are raised or lowered simultaneously by means of wheel-work, so as to open or contract the orifices for the passage of the water. In awarding a medal to this turbine, the jury made the following remarks on its merits:—"1st. It occupies a small space; 2nd. Turning very rapidly, it may, when used for

grinding flour, be made to communicate the motion directly to the millstones; 3rd. It works equally well under great and

Fig. 128.



small falls of water; 4th. It yields, when properly constructed, and with the supply of water for which it was constructed, a useful effect of 68 to 70 per cent., being an efficiency as high as any other hydraulic machine; 5th. The same wheel may be made to work at very different velocities, without materially altering its useful effect."—*Reports of Juries.*

In designing a wheel of this description, we must take a distance $a b$ equal to the distance between the floats, or $\frac{6.29 \times \text{radius}}{\text{No. of vanes}}$.

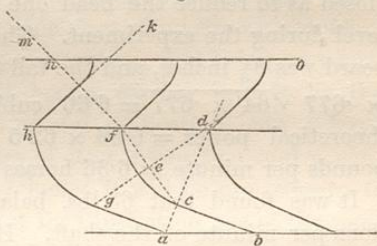
Take the angle $a b c = 15^\circ$ to 20° , and draw $a c$ perpendicular to $c b$. Lay off $d c f$

equal to $\frac{\delta + \beta}{2}$ where δ is the angle $a b c$, and β is taken arbitrarily equal to 100° to 110° . Bisect $c f$ in e , and through e draw $g d$ perpendicular to $c f$, and cutting $c d$ in d . From d with radius $d c$, or $d f$, draw the arc to which $c b$ will be a tangent. For the guides, take the angle $f h k = a$, so that

$$\cot a = \cot \beta + \frac{1}{\sin \delta}$$

draw $f m$ perpendicular to $h k$, cutting the top of the guide

Fig. 129.



wheel $n o$ in n ; from n draw arc, touching $h k$. These directions are from Weisbach.

In America the Koechlin turbine has been experimented upon by the Franklin Institute, with the following results:—The turbine experimented upon is intended to afford 7 horse power under a fall of 10 feet. It is $21\frac{1}{4}$ inches in diameter, $3\frac{1}{2}$ inches deep, and intended to make 190 revolutions per minute, giving $63\frac{1}{3}$ revolutions of a horizontal shaft to which it is geared 3 to 1. To this shaft was attached a Prony dynamometer, whose lever was 7.96 feet long, giving 50 feet circumference.

Experiment No. 1.—The discharge over a waste board in the tail-race gave the following data for calculating the discharge:— L = width of waste board = 3.83 feet, h = depth of water on it, 0.74. Then $q = .383 \times 3.83 \times .74 \sqrt{64} \times .74 = 7.468$ cubic feet per second. Hence the theoretical power = $7.468 \times 62.5 \times 9.34 \times 60 = 261,537$ foot-pounds per minute, = 7.92 horses power.

It was found that at 63 revolutions per minute of the horizontal shaft 63 lbs. balanced the lever. Hence the power developed by the wheel was $63 \times 63 \times 50 = 198,450$ lbs. = 6.014 horses power.

Experiment 2.—The gates from the head race were so far closed as to reduce the head one foot, and maintain it at that level during the experiment. The depth of water on the waste board was $8\frac{1}{8}$ inches, and the fall 8.41 feet. $\therefore q = 0.39 \times 3.83 \times .677 \sqrt{64} \times .677 = 6.66$ cubic feet per second. Hence theoretical power = $6.66 \times 62.5 \times 8.41 \times 60 = 210,000$ foot-pounds per minute = 6.36 horses power.

It was found that 63 lbs. balanced the lever at 49 revolutions per minute of the shaft. Hence the power developed by the wheel was $49 \times 63 \times 50 = 164,350$ lbs. = 4.98 horses power.

The coefficients are then for No. 1, $\frac{6.014}{7.92} = 0.76$.

” ” ” ” 2, $\frac{4.98}{6.66} = 0.78$.

And making allowance for leakage round the waste board, the experimenters conclude that the wheel yielded 75 per cent. of the power expended.

Another experiment on a 60-horse power turbine gave the following results:—

$$\left. \begin{array}{l} \text{Effective power } 56\cdot30 \\ \text{Theoretical power } 63\cdot92 \end{array} \right\} 0\cdot88.$$

Perhaps this very large coefficient is not quite reliable.

2. *Turbines in which the water flows horizontally and outwards.*

In turbines of this class the revolving wheel is placed outside of the fixed wheel, so that the water directed by guide plates on the inner wheel strikes the curved vanes of the outer wheel, and forces them round by pressure and reaction. The water is regulated by a cylindrical sluice fitting between the fixed and movable wheels.

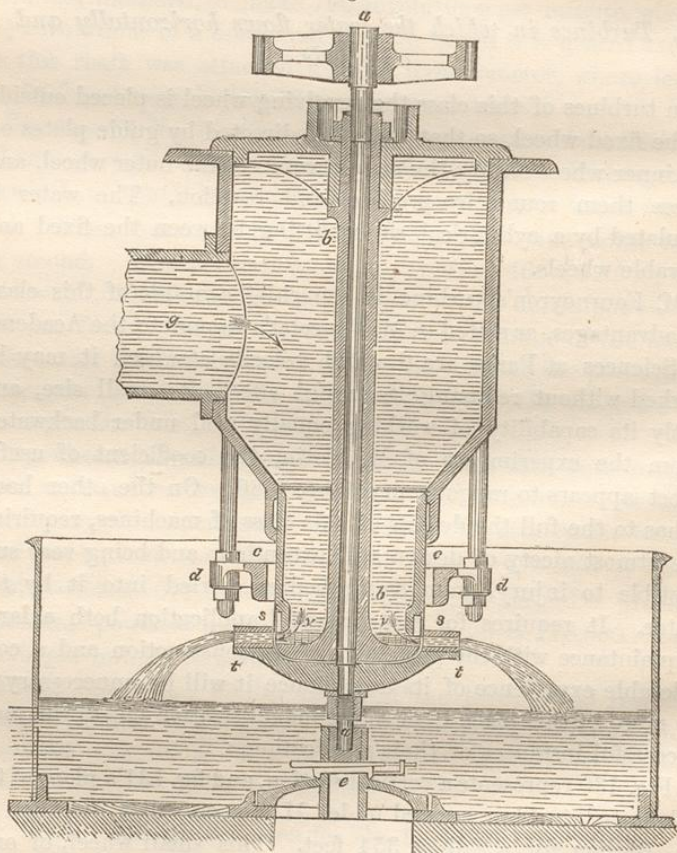
M. Fourneyron's turbine is the chief example of this class. Its advantages, as stated in M. Poncelet's Report to the Academy of Sciences at Paris, are the high velocity at which it may be worked without reducing its useful effect, its small size, and lastly its capability of working equally well under backwater. From the experiments of M. Morin, the coefficient of useful effect appears to range from 0·60 to 0·80. On the other hand it has to the full the defects of this class of machines, requiring the utmost nicety of design and execution, and being very susceptible to injury, from small bodies carried into it by the water. It requires for its successful application both a large acquaintance with the principles of its construction and a considerable experience of its use: hence it will be unnecessary to do more in this place than select for illustration one of the most successful instances of their application.

Fig. 130 represents a vertical section, and fig. 131 a plan, of the celebrated turbine erected under M. Fourneyron's direction at St. Blazien for a fall of 354 feet. This small wheel, of only about 26 inches diameter, is employed in driving the machinery of a spinning factory of 8000 throstle-spindles, with the necessary preparing apparatus. In comparison with the work it has to perform, it is therefore of a size altogether unique.

The wheel consists of a cast-iron concave plate *t t*, keyed on the main axis *a a*; on this is fixed the annular wheel *s s*, con-

sisting of an upper and lower plate of wrought iron, in which are fixed the 36 curved diaphragms seen in the plan, fig. 131. Opposite each of these curved plates on the outer revolving wheel, there is a similar guide on the inner fixed wheel *v v*, which are carried on a massive cast-iron plate attached to the

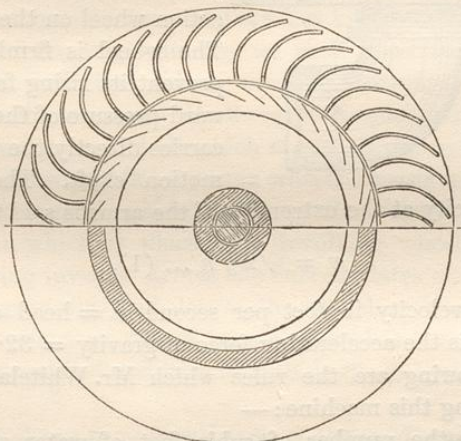
Fig. 130.



hollow tube *b b*, in which is placed the main axis. This plate not only sustains the guide plates, but takes off from the main axis the weight of the water, and thus reduces the friction on the foot step. The cylinder *cc* slides up and down in the larger water cistern, and forms a circular sluice between the revolving and fixed wheel, by which, within certain limits, the

discharge of water and velocity of the turbine can be regulated. This sluice is raised or lowered by 4 rods, *dd*, which are screwed above into the eyes of 4 pinions (not shown). These pinions all gear into one larger wheel, and in this way the 4 rods may be raised or lowered simultaneously. The supply of water is brought to the cistern by a pipe *g* of $16\frac{1}{2}$ inches

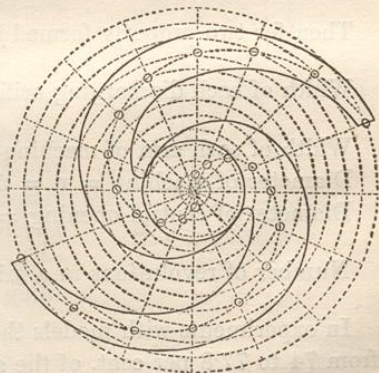
Fig. 131.



diameter, and 1200 feet in length. The spindle works on a steel pivot in a footstep adjusted by gibs and cotters *e*. This turbine makes from 2200 to 2300 revolutions per minute.

Another form of turbine, in which the flow is horizontally outwards, has been made to some extent in this country by Messrs. Whitelaw and Stirrat, and is sometimes called the Scotch turbine or reaction wheel. It is precisely on the principle of Barker's mill, and works by reaction. The principal improvement effected by Mr. Whitelaw is the form of the arms, which are curved in an archimedean spiral. Fig. 132 shows the method of striking these curves, the centre line of the arm being first drawn

Fig. 132.



ing these curves, the centre line of the arm being first drawn

and half the breadth set off on each side of it, so that the capacity of the arm increases from the extremity towards the centre in the inverse ratio of the velocity at each point.

Fig. 133.

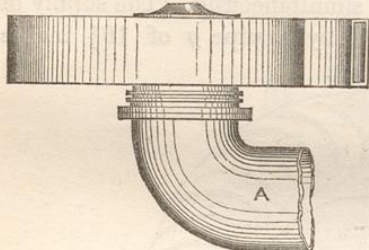


Fig. 133 shows the arrangement of this wheel, the water being brought in a pipe A, curved at bottom, so as to enter the reaction wheel on the under side. The wheel is firmly stayed to prevent its rising from the upward pressure of the water, and carries directly the vertical first motion shaft. The most effective velocity at the extremity of the arms is said to be nearly

$$v = \sqrt{2gh} \dots (1),$$

where v = velocity in feet per second, h = head of water in feet, and g is the accelerating force of gravity = 32.19.

The following are the rules which Mr. Whitlaw gives for proportioning this machine:—

Let q be the number of cubic feet of water supplied per minute,

H , the height of the fall or head of water.

E , the useful work in units of horse-power.

$$\therefore E = \frac{q H}{696.73} \dots (1).$$

Then for two properly formed jets:—

$$\text{Width of each discharging orifice} = w_1 = \sqrt{\frac{135 E}{1000 H \sqrt{H}}}.$$

$$\text{Width of each arm of machine} = 4 w_1 = w_2.$$

$$\text{Diameter of machine} = D = 50 w_1.$$

$$\text{Diameter of central opening} = 10 w_1.$$

$$\text{Number of revolutions in a minute} = \frac{149.4338 \sqrt{H}}{D}.$$

In experiments with models the wheel is said to have realised from 74 to 77.8 per cent. of the available power.

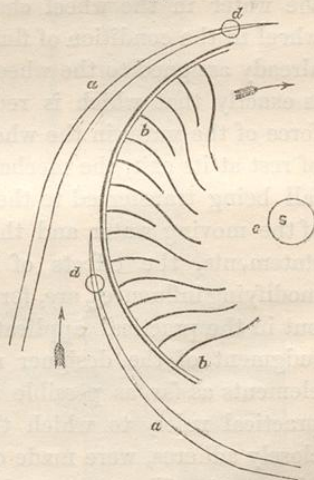
3. *Turbines in which the water flows horizontally inwards; vortex wheels.*

We owe the invention of this class of turbines to one of my own pupils, Mr. James Thomson, C. E. of Belfast, and probably no turbines are more efficient or capable of more general application to every variety of fall than the vortex wheels which he has constructed. For this reason, and also because from their recent introduction they are less known than the varieties which have been longer in use, we shall illustrate them rather more fully with the aid of working drawings, supplied by Messrs. Williamson and Brothers of Kendal, who we believe have at present erected all which are employed in this country.

The peculiarity of these vortex wheels consists in the arrangement of the fixed guide blades on the outside of a circular chamber in which is placed the revolving wheel, so that the water flowing inwards strikes the curved plates of the revolving wheel tangentially, and leaves the wheel at the centre at a minimum velocity; the whirlpool created in the wheel chamber giving to this description of turbine its designation of vortex wheel.

Fig. 134 shows the general form of the guides and passages of a vortex wheel; *a, a* are the fixed guides, four in number, which direct the water tangentially into the passages of the wheel *b b*; after having done its work in these, the water leaves the wheel at the open passage at the centre *c*; *s* is the vertical shaft carrying the wheel and communicating its motion to the mill. The chamber in which the guide blades *a, a* are fixed, forms part of the supply chamber, and the supply of water to the wheel may be regulated by altering the position of the guide blades, and thus diminishing or increasing the area of opening between them. For this purpose the guide blades are fixed on

Fig. 134.

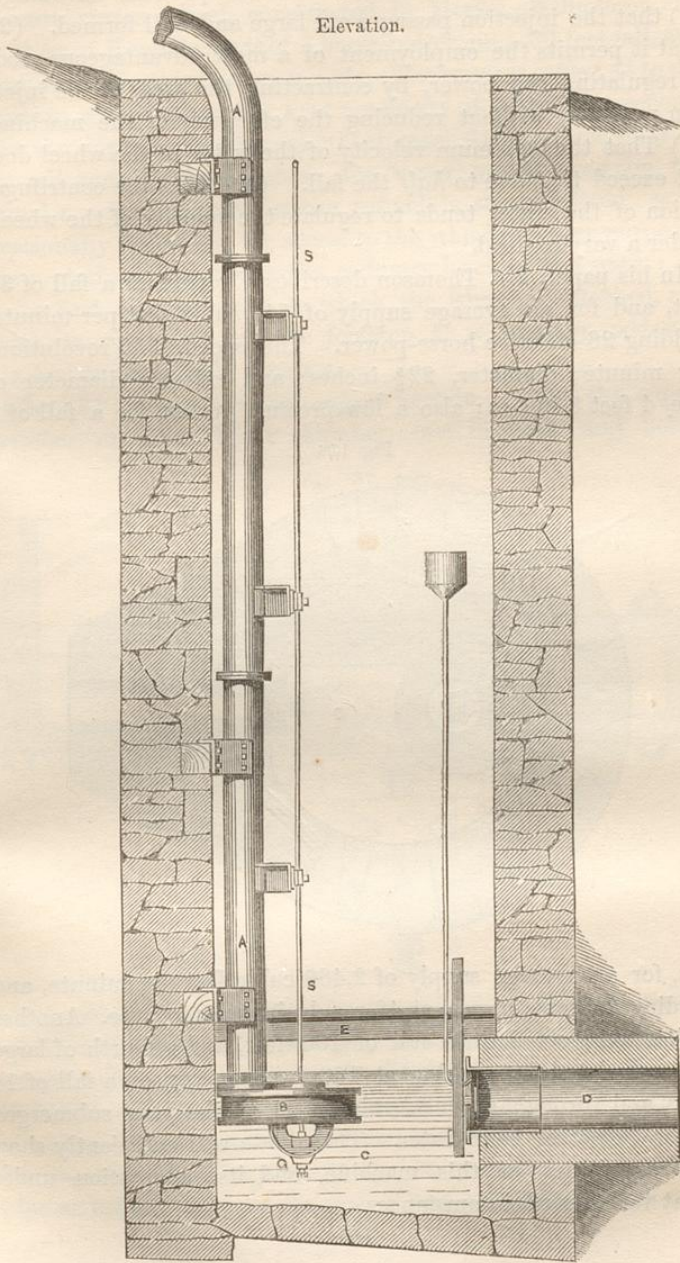


gudgeons d, d , near their extremities, and are connected by levers and links so that they may be shifted simultaneously by a spindle. The inner radius of the wheel is usually half the external radius, and the obliquity of the inner ends of the vanes 30° to 45° .

The general principles of these turbines Mr. Thomson thus explained at the meeting of the British Association in 1852:—
“The velocity of the circumference is made the same as that of the entering water, and thus there is no impact between the water and the wheel; but, on the contrary, the water enters the radiating conduits of the wheel gently, that is to say, with scarcely any motion in relation to their mouths. In order to attain the equalisation of these velocities, it is necessary that the circumference of the wheel should move with the velocity which a heavy body would attain in falling through a vertical space equal to half the vertical fall of water, or, in other words, with a velocity due to half the fall, and that the orifices through which the water is injected into the wheel chamber should be conjointly of such area, that when all the water required is flowing through them it may also have a velocity due to half the fall. Thus one half only of the fall is employed in producing velocity in the water, and therefore the other half still remains acting on the water in the wheel chamber at the circumference of the wheel in the condition of fluid pressure. Now, with the velocity already assigned to the wheel, it is found that this fluid pressure is exactly that which is requisite to overcome the centrifugal force of the water in the wheel, and to bring the water to a state of rest at its exit, the mechanical work due to both halves of the fall being transferred to the wheel during the combined action of the moving water and the moving wheel. In the foregoing statements, the effects of fluid friction, and of some other modifying influences, are, for simplicity, left out of consideration; but in the practical application of the principles, the skill and judgment of the designer must be exercised in taking all such elements as far as possible into account. To aid in this, some practical rules, to which the author (Mr. Thomson) as yet closely adheres, were made out by him previously to the date of his patent. These are to be found in the specification of the patent, published in the *Mechanics' Magazine* for January 18 and January 25, 1851.”

Fig.135.

Elevation.

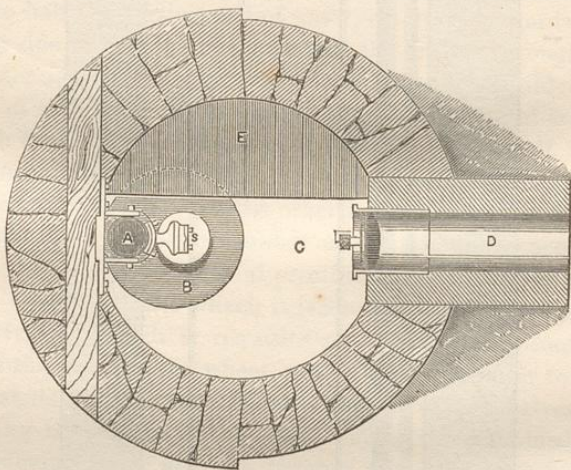


$\frac{1}{4}$ in. = 1 ft.

Mr. Thomson claims for his wheel the peculiar advantages (1.) that the injection passages are large and well formed. (2.) That it permits the employment of a most advantageous mode of regulating the power, by contracting the areas of the injection passages, without reducing the efficiency of the machine. (3.) That the maximum velocity of the water in the wheel does not exceed that due to *half* the fall. (4.) That the centrifugal action of the water tends to regulate the velocity of the wheels under a varying load.

In his paper, Mr. Thomson describes a vortex for a fall of 37 feet, and for an average supply of 540 cubic feet per minute, yielding 28 effective horse-power. The speed, 355 revolutions per minute; diameter, $22\frac{5}{8}$ inches; and extreme diameter of case, 4 feet 8 inches; also a low-pressure vortex for a fall of 7

Fig. 136.

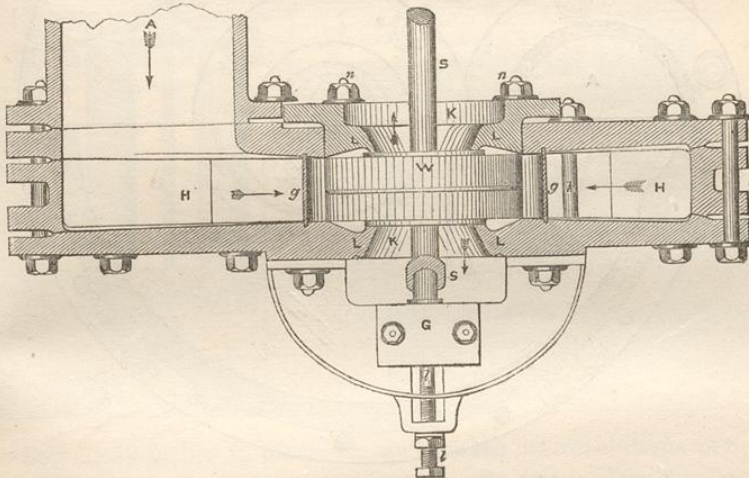


feet, for an average supply of 2,460 cubic feet per minute, and yielding 24 horse-power, at 48 revolutions per minute. Another he has constructed for a fall of 100 feet, and a fourth of large size, calculated for working at 150 horse-power, on a fall of 14 feet, and through a considerable part of the year submerged under 7 feet of back-water. These data will sufficiently show the capabilities of this machine, and its adaptation under great varieties of circumstances.

Figs. 135 and 136 exhibit an elevation and plan of a high-pressure vortex wheel, constructed by Messrs. Williamson and Brothers of Kendal. It is of 5 horse-power, on a 30 feet fall, and consumes 118 cubic feet per minute. The water is conveyed to the wheel in the 9-inch pipe $\Delta \Delta$, at a velocity of 4.4 feet per second. B is the supply chamber, or wheel case, fixed on masonry in the tail race c , from which the water passes away by the tunnel d . In the drawing the tunnel is shown closed, as is occasionally necessary, for access to the wheel or other purposes. E is a platform just above the ordinary level of the water; $s s$ is the first motion shaft, to which the wheel is attached, and which is supported on the footstep at G , and by pedestals attached to the supply pipe $\Delta \Delta$.

Fig. 137 shows the wheel case in section. $\Pi \Pi$ is the supply chamber or guide blade chamber, cast in parts and bolted

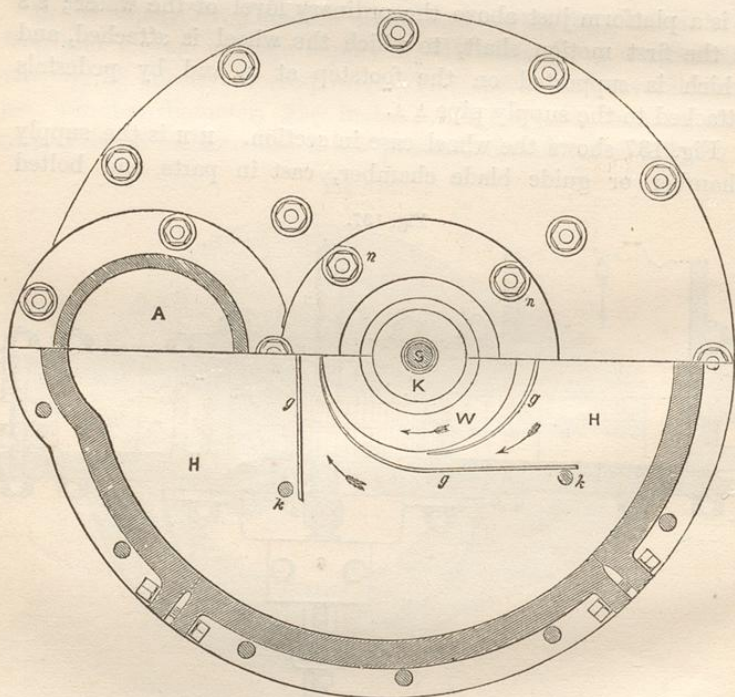
Fig. 137.



together as shown. w , the wheel itself, about 10 inches in diameter, and composed of wrought iron plates with wrought iron curved vanes; g, g the four guide blades, in this wheel fixed and let into grooves cast in the cover and bottom of the chamber; k, k , four bolts tying the cover and bottom of the supply chamber together to strengthen it against pressure. Δ the supply pipe as before, and k, k the openings in the centre of the wheel

for the escape of the waste water after it has done its work on the wheel. The joint between the wheel and its case is made by means of the accurately fitting annular parts *L, L*, adjusted for the wheel to run without friction by bolts *n, n* in the upper piece. *ss* is the first motion shaft resting on a lignum vitæ pivot firmly fixed in the foot bridge *G*, which is bolted on below the supply chamber, the height of the pivot as it wears being adjusted by the screw *l l*. The pivot is lubricated by the water

Fig. 138.



in which it works spread over it by a radial groove. In other cases Mr. Thomson makes the shaft to terminate in an inverted cup containing a concave brass disc working on a fixed steel pivot, with a radial groove for spreading the water. He does not consider the lubrication with oil so essential as other engineers insist, and believes the cases in which turbine pivots have been rapidly destroyed to be attributed to the absence of a

proper provision for the escape of the air between the rubbing surfaces. Fig. 138 represents a half-plan and half-horizontal section of the same wheel, the same letters of reference being used as in fig. 137.

Fig. 139 exhibits the arrangement, in sectional elevation, of a low-pressure vortex wheel with its pentrough and tail race. This wheel is of 34 horse-power, with an effective fall of 14 feet 3 inches, and a supply of 1680 cubic feet per minute. The

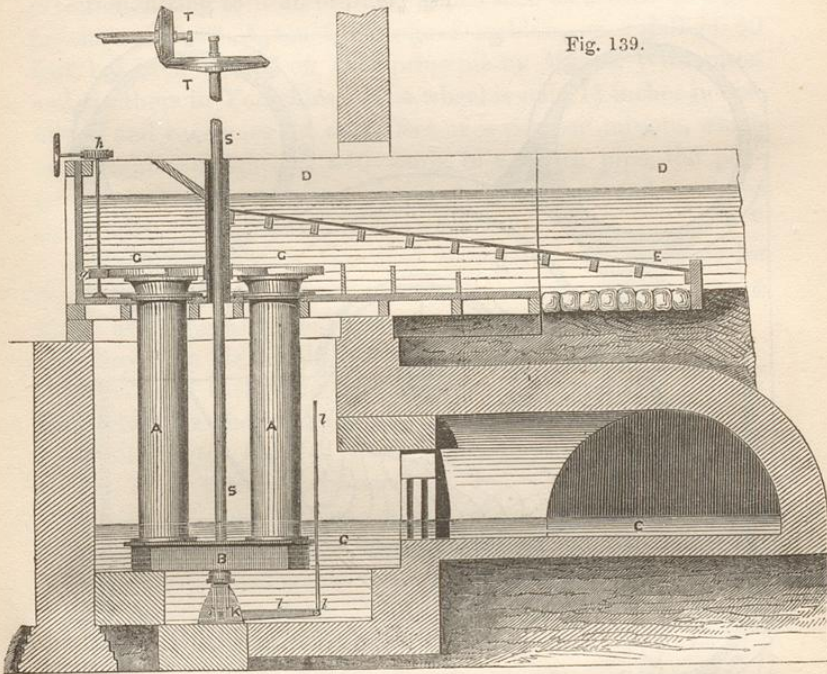
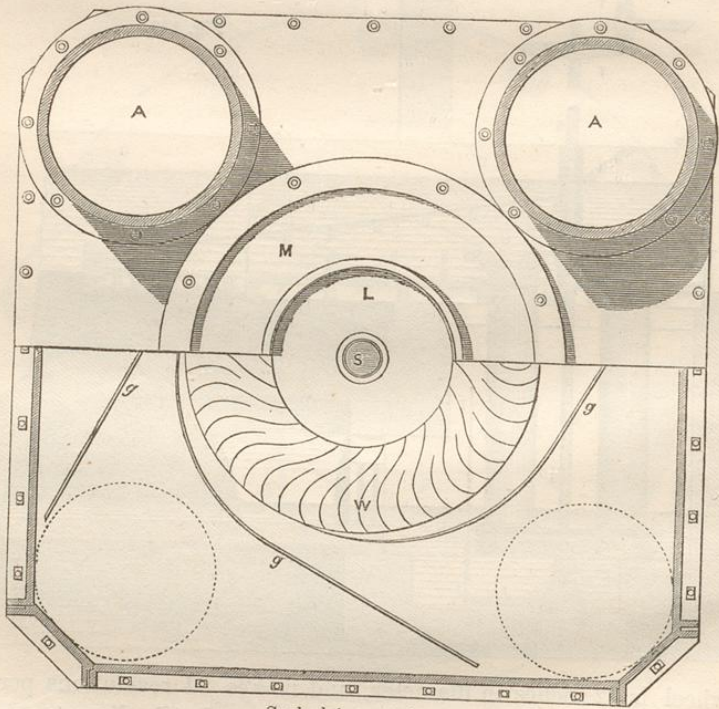


Fig. 139.

wheel is 52 inches in diameter, and makes 94 revolutions per minute. A, A are the four supply pipes, two feet in diameter, so that the water in them has a velocity of about 2.3 feet per second. B is the square supply chamber, c c the tail race, and d d the conduit and pentrough. The water as it arrives passes through a perforated metal strainer E E, to prevent the choking of the narrow passages of the wheel by floating leaves, &c. Over the four supply pipes A, A, is fixed a circular cast iron plate G G, with four holes corresponding in one position with the trumpet

mouths of the supply pipes. On the edge of this plate is a rack into which the pinion *g* gears, so that by moving the worm and wheel *h* the sluice plate *g g* may be revolved and the entrance for the admission of the water to the wheel more or less closed or opened. This is an effective and inexpensive means of regulating the power of the wheel, where the supply of water is abundant and it is not necessary to economise its

Fig. 140.



Scale $\frac{1}{2}$ in. = 1 ft.

expenditure to the utmost extent. *s s* is the first motion shaft, and *t, t* the bevel wheels by which it gives off the power of the wheel to the mill. *k* is the footbridge carrying a step which can be raised by the lever *l l* as it wears away. Fig. 140 exhibits a half-plan and half-section of the wheel and supply chamber. *A, A*, as before, supply pipes, *w*, the wheel itself, *g, g, g*,

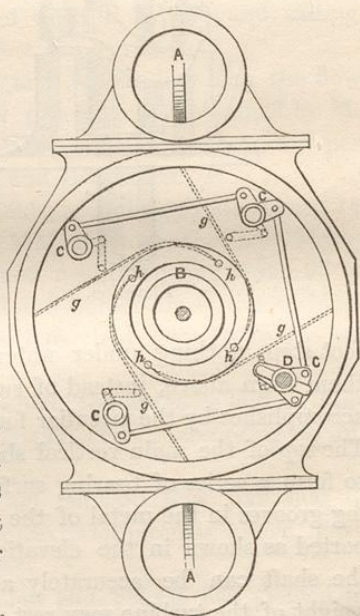
fixed guide blades, the regulation of the wheel being effected by the sluice as before described. *s*, first motion shaft, *L* central opening for the escape of the water, *M* wheel cover, forming at its inner periphery a close and accurate joint with the revolving wheel.

Another plan which has been adopted with these wheels for regulating the speed, when they are applied to high falls, is to bring the supply pipe when near the wheel into a horizontal direction, fitting to it an ordinary sluice such as is used in high-pressure mains. A ten horse-power turbine, on a fall of 80 feet, has been erected on this principle by Messrs. Williamson and Brothers in Yorkshire. The wheel is only 13 inches in diameter, and consumes 44 cubic feet of water per minute, which is brought a distance of 340 yards, in a 9-inch pipe, the pentrough and strainer being placed at the upper end, and the sluice at the bottom, close to the wheel.

But beyond question the most economical arrangement for regulating the expenditure of water, although somewhat more complicated in its details, is the adjustment of the guide blades themselves in the manner already alluded to. Fig. 141 shows a plan of a turbine, arranged with *movable* guide blades. *A*, *A*, two supply pipes, *B*, wheel cover; *c*, *c*, *c*, *c*, bell cranks connected together by links. The whole of these bell cranks are worked by a vertical spindle, *D*, and worm and wheel in the mill; they carry in the supply chamber links shown by the dotted lines, by which the guide blades *g*, *g*, *g*, *g*, movable on centres at *h*, *h*, *h*, *h*, can be opened or closed.

These turbines yield 75 per cent. of the power expended, and are therefore as efficient as the

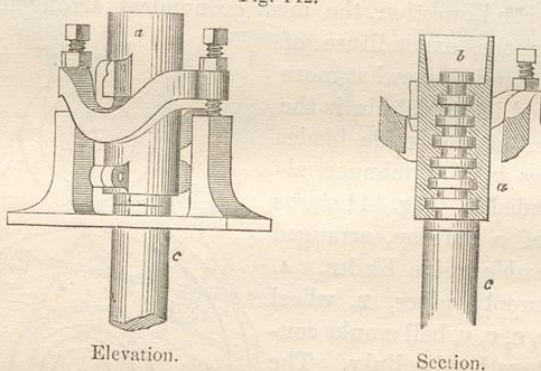
Fig. 141.



best water wheels or turbines. They work equally well under backwater, and if it be necessary they can be placed at any height less than 30 feet above the water in the tail race, the lower part of the fall being made to do its work on the wheel by suction in pipes descending from the central discharge orifice, and terminating in the water of the tail race.

In America, turbines of various kinds have come into extensive use, and some erected there are of unprecedentedly large size. The better forms have been copied in their main features, from European machines already described, with some variation in the constructive details. Thus Mr. Boyden has introduced a diffuser, or annular mouth-piece, round the outer or revolving wheel of the Fourneyron turbine, instead of permitting the water to escape into the free space of the tail water. He has also, to avoid the difficulties arising from the rapid wear of the

Fig. 142.



foot-step working under water in large turbines, suspended them from above, instead of supporting them below. This he accomplishes by the peculiar form of bearing shown in fig. 142. The top of the main vertical shaft of the turbine *c*, is cut so as to form a series of bearing surfaces; these fit into corresponding grooves in the metal of the suspension box *a*, which is supported as shown in the elevation by gimbals. The height of the shaft can be accurately adjusted by screws, so that the weight of the turbine may rest on the collars in the suspension shaft and the lower bearing beneath the water serve merely to

retain the shaft in its place. By lining the suspension box *a* with a soft metal, principally tin, melted and poured in with the necks in place, sufficient accuracy can be attained to prevent any undue strain on particular collars. This form of bearing is said to have been successfully employed, and to obviate the difficulties of oiling beneath the water.

Efficiency of Turbines.—It may be useful to revert here for a moment to the experiments which have been made upon different forms of turbine to ascertain their relative efficiency. In all these machines, the useful work rendered, is less than the entire force of the fall of water which acts upon them by the loss of work expended in overcoming the friction and inertia of the machine, together with the loss from the *vis viva* expended in shocks and impact and passing away in the water of the tail race, and from other causes in special cases. The fraction which expresses the ratio of the total work expended by the water to the useful work returned by the machine is the *efficiency* of the machine. Commonly we express this ratio in a percentage, taking the work of the fall as 100, and calling the work accomplished useful effect or return.

For the turbines of Fontaine and Jonval, in which the flow is vertical, a return of 70 to 72 per cent. was obtained by M. Morin; 67 per cent. by MM. Alcau and Grouvelle; 74·5 per cent. by MM. Hulze, Borneman, and Bruckman.

The turbine of Fourneyron yields, according to M. Morin, 74 per cent.; but $64\frac{1}{2}$ according to MM. Redtenbacher and Marozeau; M. Fourneyron has obtained results varying from 65 to 80 per cent. according to the fall and immersion of the turbine. The turbine of St. Blazier is said to yield from 70 to 75 per cent.

The turbine of Poncelet, in which the water is laid on tangentially, yields from 65 to 75 per cent.; according to M. Hulze, 70 per cent.

The turbine of Cadiat, with an outward flow like that of Fourneyron, but regulated by an exterior circular sluice, gave 65 per cent. to M. Redtenbacher.

The reaction wheel of Whitelaw and Stirrat has yielded in experiments with models 70 to 78 per cent.

Mr. Thomson's vortex wheel yields according to his experiments 75 per cent.

All these returns appear to approximate closely to the duty performed by water wheels; probably not so high as that given by a well-constructed iron water wheel, but the difference is inconsiderable. Smeaton's experiments gave, on his overshot wheels, as much as 76 per cent., and the results obtained from experiments on the breast wheel, with ventilated buckets on a large scale, gave nearly 78 per cent. of the actual power of the water employed.

Certain advantages, it must be admitted, are obtained by the turbine in certain localities under certain conditions; but it is very doubtful whether they are equal, either on the score of expense or ultimate efficiency, to well-constructed water wheels. In some situations favourable for their reception they are doubtless preferable in effecting a reduction of the original cost, but taking to account the conveyance of the water in pipes and other charges, it will be found as a general rule that the difference is not considerable, and that a well-constructed water wheel of 50 years' duration is an effective and excellent substitute for the turbine.

4. *Water Pressure Engines.*

In the water pressure engine the power obtained from the *pressure* of a column of water is employed in generating a reciprocating instead of a rotatory motion. Engines of this description have long been employed in the mining districts of the Continent, but in England their use appears to date from 1765, when a single-acting water pressure engine was erected for draining a mine in Northumberland by Mr. Westgarth.

For the most successful application of these engines, as regards efficiency, it is necessary that the motion of the water should be slow, and as far as possible without shock. Three to six strokes per minute, or a velocity for the piston of one foot per second, is about the ordinary speed. The stroke also should be long, and therefore "the most advantageous use to which a water pressure engine can be put is the pumping of water, to which slow motion and a long stroke are well adapted, because they are favourable to efficiency, not only in the engine but in the pump which it works."—*Rankine.*

The valves now usually employed in these engines are solid pistons working in the supply pipe, with leather or metal packings. Figs. 143 and 144 showing

the valves for a single-acting engine will sufficiently indicate the principle. $\Delta \Delta$ is the supply pipe, $B B$ the entrance to the cylinder, and $C C$ the eduction pipe. When the cylinder is being filled, fig. 144,

the valve D is below the entrance and closes the eduction pipe. When, however, the cylinder is emptying, fig. 143, the valve is raised and then closes the supply pipe. Deep notches are cut in these valves in order that they may very gradually open and close the passages to prevent shock.

These valves are usually worked by a small water pressure engine, acting in the reverse direction to the general engine, and worked from it by tappets. Fig. 145 shows such an arrangement, from the single-acting engine of M. Junker.

In this drawing c represents the upper edge of the main cylinder, s the supply pipe, d the port connecting the main cylinder with the valve chest, g the discharge pipe: e is the valve, which when above d , as in fig. 145, permits the water to escape from the cylinder, and when below d , closes the discharge pipe and opens a passage from the supply pipe. The area of the valve e , is made less than that of the piston f , with which it is connected by a rigid rod. Hence the pressure of the water between e and f tends to raise them both.

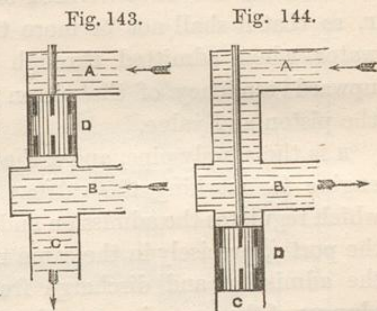
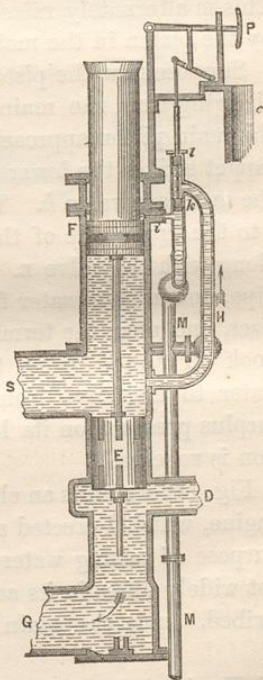


Fig. 145.



The upper side of r is provided with a trunk working in a stuffing box in the top of the valve cylinder. The use of this is to diminish the effective area of the upper side of the piston r , so that it shall not be more than is requisite to enable the water when admitted through the port i to overcome the upward tendency of the piston together with the friction of the piston and valve.

n is the supply pipe, and m the discharge pipe of the auxiliary engine for working the valves; k is the valve of this engine which regulates the admission and discharge of the water through the port i , precisely in the same manner as the valve e regulates the admission and discharge from the main cylinder. l is a plunger of the same size as k , that the pressure between them may be equalised and not tend to move k upwards or downwards. The rod to which k and l are fixed is connected by means of a train of levers and link work with a lever carrying the crutch p . This is alternately raised and depressed by a tappet rod carried by the piston in the main cylinder c .

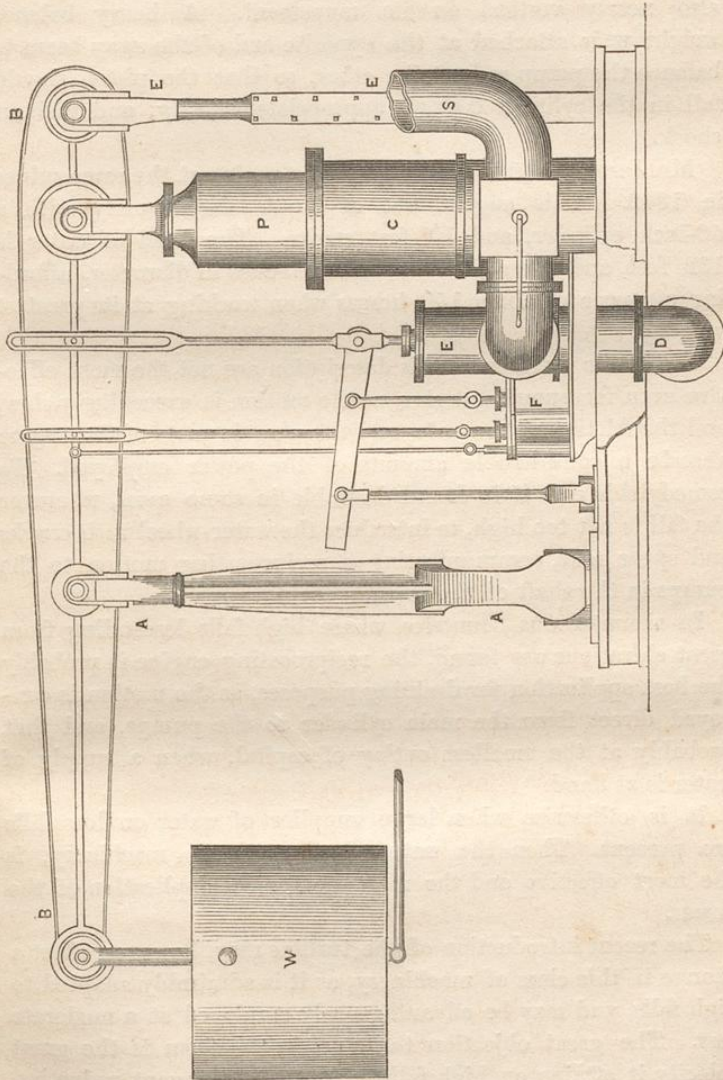
Suppose now the piston valve e is raised, and the water discharging from the main cylinder, as shown in fig. 145. When the main piston approaches the bottom of its stroke, the upper tappet strikes the lower hook on p and depresses it, along with the auxiliary valve k . This admits water from s through n and i to the upper side of the counter piston r , so as to depress it along with the valve e . The valve e then closes the discharge pipe, and admits water from s to the main cylinder; the piston rises, and near the termination of its stroke strikes the upper hook on p , and raises the auxiliary valve k . This allows the water to discharge from the upper side of r , and then the surplus pressure on its lower side lifts it with e , and the operation is repeated.*

Fig. 146 exhibits an elevation of a single-acting water pressure engine, which I erected some years since in Derbyshire for the purpose of raising water from the Alport lead mines. It does not widely differ in its action from that of M. Junker just described. c is the main cylinder, and p its piston or plunger.

* The description of this valve is abridged from Mr. Rankine's and Prof. Weisbach's Treatises.

s the supply pipe, and d the discharge pipe, connected with the valve apparatus E. F is the cataract or auxiliary engine for

Fig. 146.



working the valves. The piston P is connected with the sway beam BB, which at its other extremity is attached to the oscil-

lating connecting rod $\Delta \Delta$, which is fixed on a pivot or joint at its lower extremity. By this arrangement the piston is permitted to rise vertically, and the spear rod of the pumps E is also nearly vertical in its movement. A heavy balance weight w is attached at the opposite end of the sway beam to balance the pump rods at the other, so that the piston should fall in the cylinder c at an appropriate velocity, and without shock.

Mr. Joseph Glynn erected a similar engine at the same mines in 1842. This engine was of larger size, namely with a 50-inch cylinder, and 10 feet stroke. The head of water is 132 feet, and lifts a plunger rod 42 inches in diameter, affording a power of about 150 horses when working at its greatest velocity.

Hydraulic engines of this description are not the most effective even for pumping water, as the motion is exceedingly slow, and the friction of the water and the organic parts of the engine absorbs a considerable amount of the power employed. To remedy this evil it is found desirable in some cases, wherever the fall is not too high, to introduce the water-wheel with cranks and spear rods, communicating a reciprocating motion to the pumps in the shaft of the mine.

In mountainous countries, where high falls descending from great elevations are found, the reciprocating engine is probably the best application for draining purposes, as the motion is conveyed direct from the main cylinder to the pumps, and that probably at the smallest outlay of capital, when a supply of water is at hand.

It is otherwise when large supplies of water on low falls are present. Then the water-wheel, with its machinery, is the most effective and the most economical application of the power.

The recent introduction of the turbine may, however, effect a change in this class of machinery, as it is admirably adapted to high falls, and may be advantageously employed at a moderate cost. The great objection to its use in this form is the great velocity it attains on high falls, and the consequent reduction which would be requisite to work pumps at 10 to 12 strokes per minute, when the machine itself is moving at the rate of 400 to

500 revolutions per minute. This appears to be the only drawback, and it is not improbable that the simple cylinder here described may, under certain conditions, be best adapted to meet all the requirements of raising water from deep mines with the aid of convenient streams on high falls.