CHAPTER IX

WATER WHEELS AND TURBINES

Water wheels can be divided into two classes as follows.

(*a*) Wheels upon which the water does work partly by impulse but almost entirely by weight, the velocity of the water when it strikes the wheel being small. There are two types of this class of wheel, Overshot Wheels, Figs. 285 and 286, and Breast Wheels, Figs. 288 and 290.

(*b*) Wheels on which the water acts by impulse as when the wheel utilises the kinetic energy of a stream, or if a head h is available the whole of the head is converted into velocity before the water comes in contact with the wheel. In most impulse wheels the water is made to flow under the wheel and hence they are called Undershot Wheels.

It will be seen that, in principle, there is no line of demarcation between impulse water wheels and impulse turbines, the latter only differing from the former in constructional detail.

177. Overshot water wheels.—This type of wheel is not suitable for very low or very high heads, as the diameter of the wheel cannot be made greater than the head, neither can it conveniently be made much less.

Figs. 285 and 286 show two arrangements of the wheel, the only difference in the two cases being that in Fig. 286, the top of the wheel is some distance below the surface of the water in the up-stream channel or penstock, so that the velocity v with which the water reaches the wheel is larger than in Fig. 285. This has the advantage of allowing the periphery of the wheel to have a higher velocity, and the size and weight of the wheel is consequently diminished.

The buckets, which are generally of the form shown in the figures, or are curved similar to those of Fig. 289, are connected to a rim M coupled to the central hub of the wheel by suitable spokes or framework. This class of wheel has been considerably used for heads varying from 6 to 70 feet, but is now becoming obsolete, being replaced by the modern turbine, which for the same head and power can be made much more compact, and can be run at a much greater number of revolutions per unit time.

The direction of the tangent to the blade at inlet for no shock

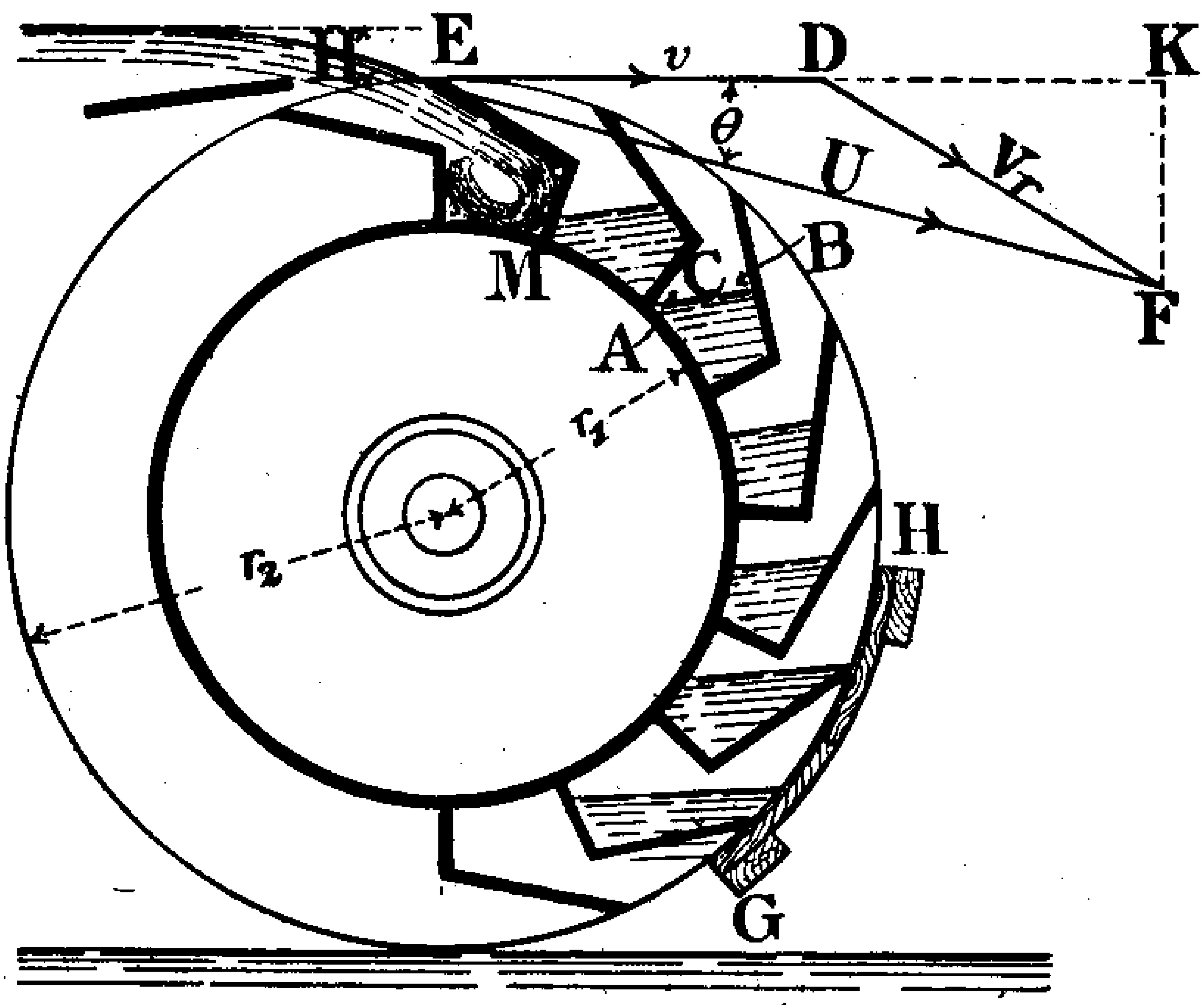

Fig. 285. Overshot Water Wheel.

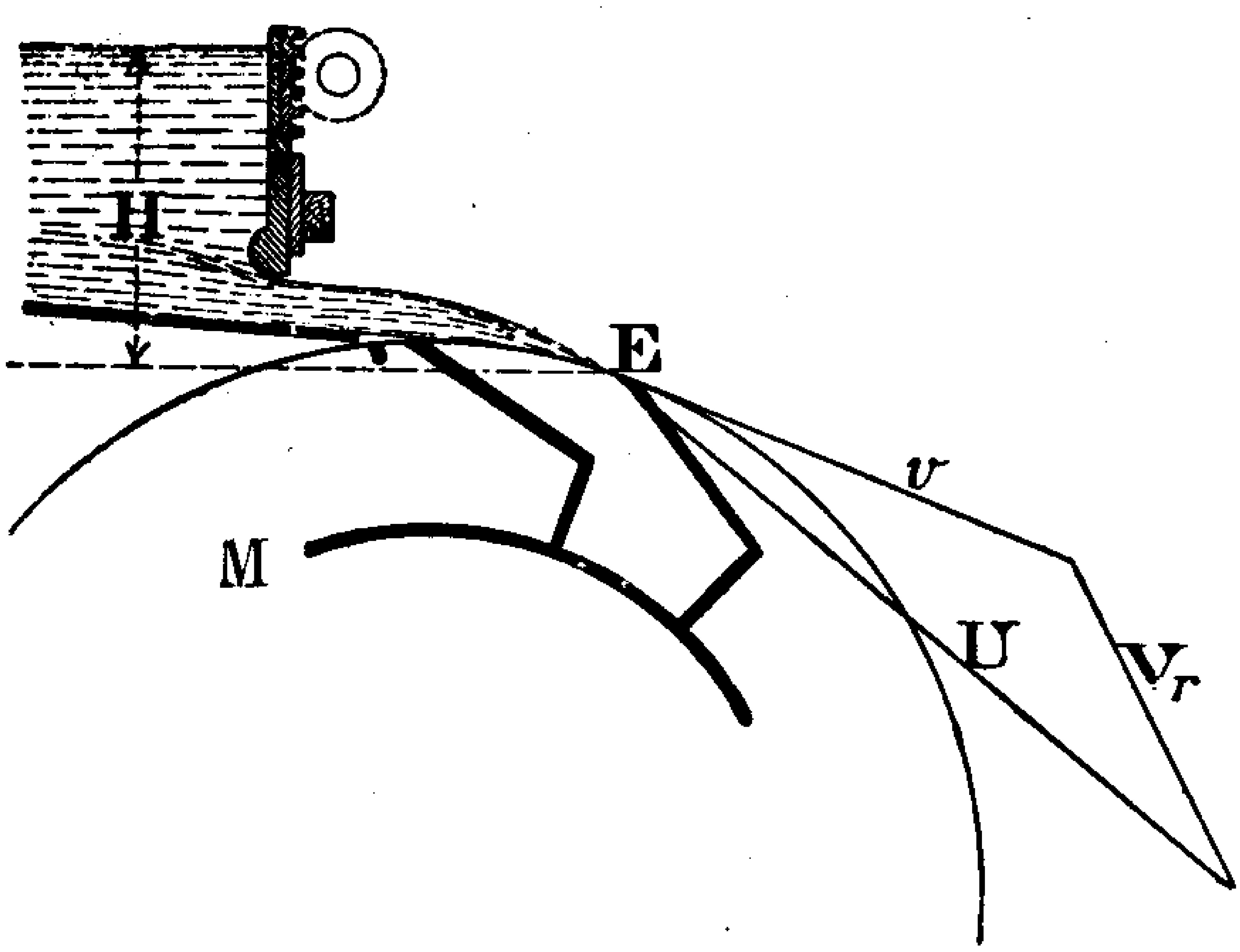

Fig. 286. Overshot Water Wheel.

can be found by drawing the triangle of velocities as in Figs. 285 and 286. The velocity of the periphery of the wheel is v and the velocity of the water U. The tip of the blade should be parallel to V_r. The mean velocity U, of the water, as it enters the wheel in Fig. 286, will be $v_0+k\sqrt{2gH}$, v_0 being the velocity of approach of the water in the channel, H the fall of the free surface and k a coefficient of velocity. The water is generally brought to the wheel along a wooden flume, and thus the velocity U and the supply to the wheel can be maintained fairly constant by a simple sluice placed in the flume.

The best velocity v for the periphery is, as shown below, theoretically equal to $\frac{1}{2}U\cos\theta$, but in practice the velocity v is frequently much greater and experiment * shows that the best velocity v of the periphery is about 0·9 of the velocity U of the water.

If U is to be about $1{\cdot}1v$ the water must enter the wheel at a depth not less than

$$H=\frac{U^2}{2g}=\frac{1{\cdot}2v^2}{2g}$$

below the water in the penstock.

If the total fall to the level of the water in the tail race is h, the diameter of the wheel may, therefore, be between h and

$$h-\frac{1{\cdot}2v^2}{2g}.$$

Since U is equal to $\sqrt{2gH}$, for given values of U and of h, the larger the wheel is made the greater must be the angular distance from the top of the wheel at which the water enters.

With the type of wheel and penstock shown in Fig. 286, the head H is likely to vary and the velocity U will not, therefore, be constant. If, however, the wheel is designed for the required power at minimum flow, when the head increases, and there is a greater quantity of water available, a loss in efficiency will not be important.

The horse-power of the wheel. Let D be the diameter of the wheel in feet which in actual wheels is from 10 to 70 feet.

Let N be the number of buckets, which in actual wheels is generally from $2\frac{1}{2}$ to 3D.

Let Q be the volume of water in cubic feet of water supplied per second.

Let ω be the angular velocity of the wheel in radians, and n the number of revolutions per sec.

Let b be the width of the wheel.

Let d, which equals r_2-r_1, be the depth of the shroud, which on actual wheels is from 10″ to 20″.

Whatever the form of the buckets the capacity of each bucket is

$$bd.\frac{\pi D}{N}, \text{ nearly.}$$

* Theory and test of an Overshot Water Wheel, by C. R. Weidner, Wisconsin, 1913.

The number of buckets which pass the stream per second is

$$\frac{N\omega}{2\pi}=N.n.$$

If a fraction k of each bucket is filled with water

$$Q=kbd\frac{\pi D}{N}.\frac{N\omega}{2\pi}$$

$$=\frac{kbdD\omega}{2}$$

or

$$k=\frac{2Q}{bdD\omega}$$

The fraction k in actual wheels is from $\frac{1}{5}$ to $\frac{1}{3}$.

If h is the fall of the water to the level of the tail race and e the efficiency of the wheel, the horse-power is

$$HP=\frac{62{\cdot}4.e.hQ}{550},$$

and the width b for a given horse-power, HP, is

$$b=\frac{1100HP}{62{\cdot}4ekdD\omega h}=17{\cdot}6\frac{HP}{ekdD\omega h}.$$

Effect of centrifugal forces. As the wheel revolves, the surface of the water in the buckets, due to centrifugal forces, takes up a curved form.

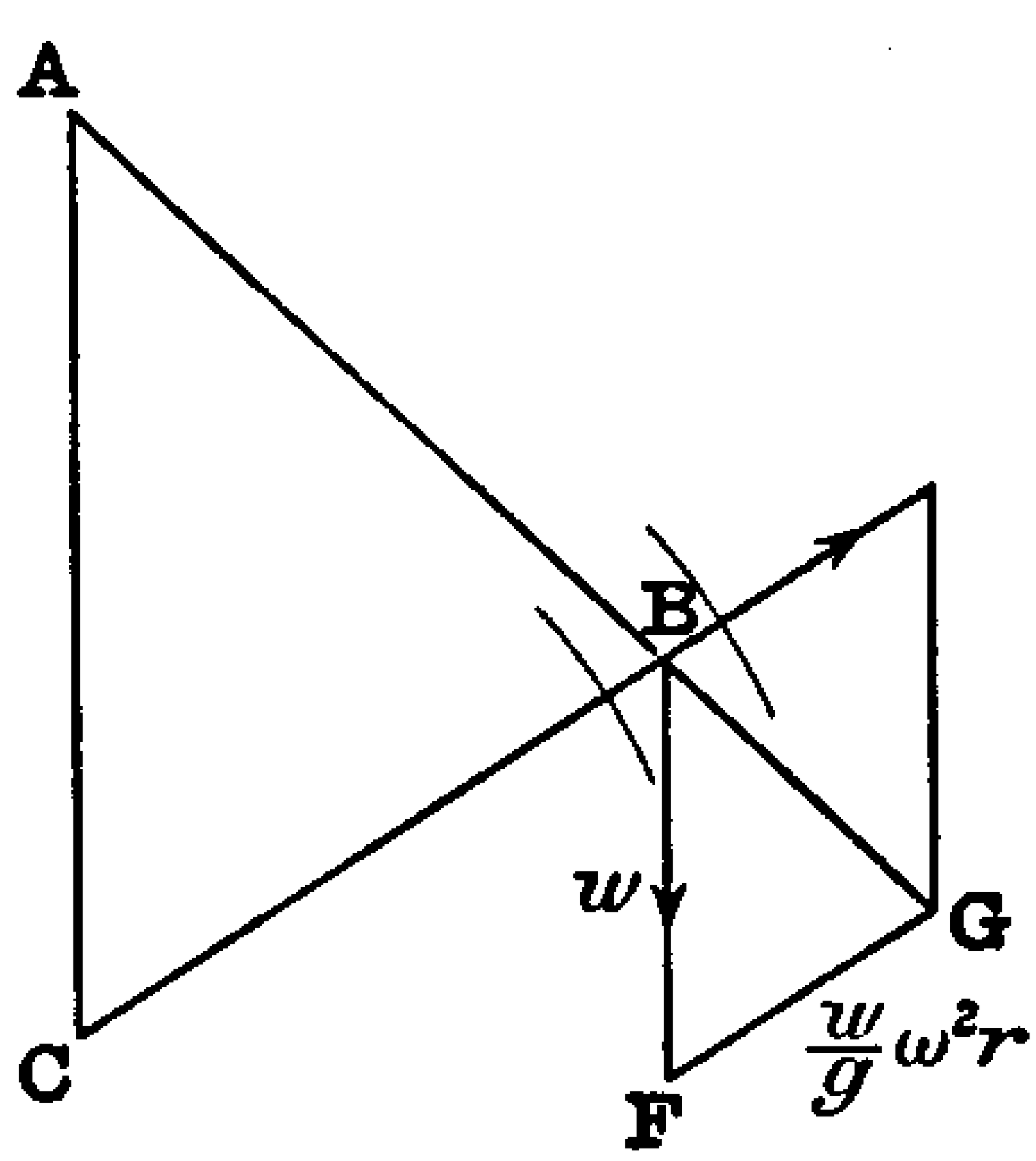

Fig. 287.

Consider any particle of water of mass w lbs. at a radius r equal to CB from the centre of the wheel and in the surface of the water. The forces acting upon it are w due to gravity and the centrifugal force $\frac{w}{g}\omega^2 r$ acting in the direction CB, ω being the angular velocity of the wheel. The resultant BG (Fig. 287) of these forces must be normal to the surface. Let BG be produced to meet the vertical through the centre in A. Then

$$\frac{AC}{CB}=\frac{AC}{r}=\frac{w}{\frac{w}{g}\omega^2 r}$$

or

$$AC=\frac{g}{\omega^2}.$$

That is the normal AB always cuts the vertical through C in a fixed point A, and the surface of the water in any bucket lies on a circle with A as centre.

Losses of energy in overshot wheels.

(*a*) The whole of the velocity head $\frac{V_r^2}{2g}$ is lost in eddies in the buckets.

In addition, as the water falls in the bucket through the vertical distance EM, its velocity will be increased by gravity, and the velocity thus given will be practically all lost by eddies.

Again, if the direction of the tip of the bucket is not parallel to V_r the water will enter with shock, and a further head will be lost. The total loss by eddies and shock may, therefore, be written

$$h_1 + k\frac{V_r^2}{2g},$$

or

$$h_1 + k_1\frac{U^2}{2g},$$

k and k_1 being coefficients and h_1 the vertical distance EM.

(*b*) The water begins to leave the buckets before the level of the tail race is reached. This is increased by the centrifugal forces, as clearly, due to these forces, the water will leave the buckets earlier than it otherwise would do. If h_m is the mean height above the tail level at which the water leaves the buckets, a head equal to h_m is lost. By fitting an apron GH in front of the wheel the water can be prevented from leaving the wheel until it is very near the tail race.

(*c*) The water leaves the buckets with a velocity of whirl equal to the velocity of the periphery of the wheel and a further head $\frac{v^2}{2g}$ is lost.

(*d*) If the level of the tail water rises above the bottom of the wheel there will be a further loss due to, (1) the head h_0 equal to the height of the water above the bottom of the wheel, (2) the impact of the tail water stream on the buckets, and (3) the tendency for the buckets to lift the water on the ascending side of the wheel.

In times of flood there may be a considerable rise of the down-stream, and h_0 may then be a large fraction of h. If, on the other hand, the wheel is raised to such a height above the tail water that the bottom of the wheel may be always clear, the head h_m will be considerable during dry weather flow, and the greatest possible amount of energy will not be obtained from the water, just when it is desirable that no energy shall be wasted.

If h is the difference in level between the up- and down-stream surfaces, the maximum hydraulic efficiency possible is

$$e=\frac{h-\left(h_m+\frac{V_r^2}{2g}+\frac{v^2}{2g}\right)}{h} \quad . \quad . \quad . \quad . \quad (1),$$

and the actual hydraulic efficiency will be

$$e=\frac{h-\left(k_1h_1+k_0h_0+h_m+k\frac{V_r^2}{2g}+\frac{v^2}{2g}\right)}{h},$$

k, k_1 and k_0 being coefficients.

The efficiency as calculated from equation (1), for any given value of h_m, is a maximum when

$$\frac{V^2}{2g}+\frac{v^2}{2g} \text{ is a minimum.}$$

From the triangles EKF and KDF, Fig. 285,

$$(U \cos \theta - v)^2+(U \sin \theta)^2=V_r^2.$$

Therefore, adding v^2 to both sides of the equation,

$$V_r^2+v^2=U^2 \cos^2 \theta - 2Uv \cos \theta + 2v^2 - U^2 \sin^2 \theta,$$

which is a minimum for a given value of U, when $2Uv \cos \theta - 2v^2$ is a maximum. Differentiating and equating to zero this, and therefore the efficiency is seen to be a maximum when

$$v=\frac{U}{2} \cos \theta.$$

The actual efficiencies obtained from overshot wheels vary from 60 to 89 * per cent.

178. Breast wheel.—This type of wheel, like the overshot wheel, is becoming obsolete. Fig. 288 shows the form of the wheel, as designed by Fairbairn.

The water is admitted to the wheel through a number of passages, which may be opened or closed by a sluice as shown in the figure. The directions of these passages may be made so that the water enters the wheel without shock. The water is retained in the bucket, by the breast, until the bucket reaches the tail race, and a greater fraction of the head is therefore utilised than in the overshot wheel. In order that the air may enter and leave the buckets freely, they are partly open at the inner rim. Since the water in the tail race runs in the direction of the motion of the bottom of the wheel there is no serious objection to the tail race level being 6 inches above the bottom of the wheel.

* Theory and Test of Overshot Water Wheel. *Bulletin* No. 529, *University of Wisconsin.*