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Treatise on mills and millwork

On the principles of mechanism and on prime movers

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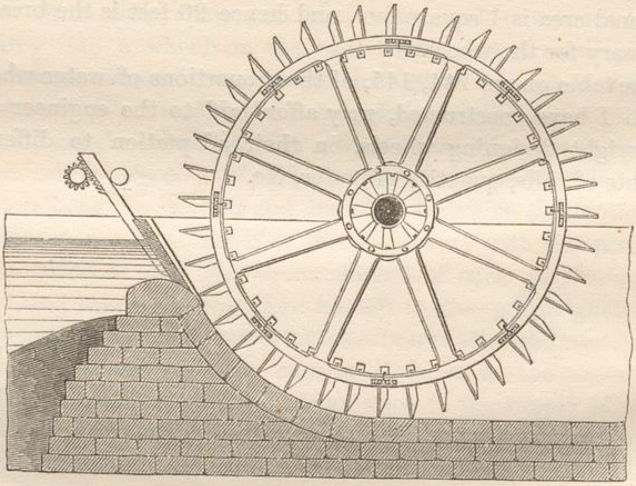
CHAP. IV.

ON THE UNDERSHOT WATER WHEEL.

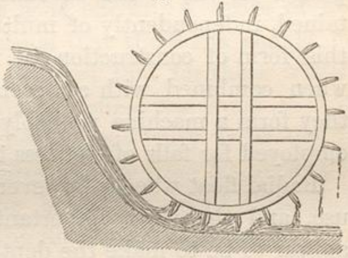
Before the introduction of iron, undershot water wheels were frequently employed, and were in almost every instance constructed with straight radial floats, as in the annexed sketch, the water being discharged against the float-boards, as it rushed with considerable velocity underneath the shuttle. This was the invariable practice down to Smeaton's time even, the principle being to employ the impulse of the fluid stream, and not its gravity or weight. Indeed, there appeared to be an impression that this was the more effective and economical mode of application, and probably arose out of the circumstances of the original employment of water as a moving power. The earliest wheels of which we read are undershot wheels placed

Fig. 123.



between two boats in a flowing stream, and driven by its impulse, and in Smeaton's own time the works for the supply of water to London obtained their power from some magnificent examples of precisely similar wheels, placed in the tidal stream rushing between the clumsy piers of the old London Bridge. In the old time it was no doubt an advantage to have the prime mover working at a considerable velocity, and an overshot wheel will not do this effectively. Hence wheels were sometimes built of the form shown in fig. 124, the water being carried down from the top of the fall so as to strike the radial floats of the wheel at a very high velocity. Such a wheel is described in Smeaton's Reports.

Fig. 124.



The earliest great advance in the perfecting of the water wheel was effected mainly by Smeaton, and we owe to him the first experimental inquiries on the effect and proper velocity and proportions of water wheels. In all the various applications of water, experimental researches have hitherto been the principal means of advance, and in no department has more labour and talent been expended in such inquiries; the result is, that our hydraulic machinery of the present day is as perfect, and yields as high a proportion of the power to the actual fall of water, as we can ever hope to obtain.

In my own practice I have been accustomed to employ water even for very low falls, solely by gravity, using the arrangement already described, as a low breast wheel, when treating of ventilation, and which is shown in detail in Plate III. This wheel is 16 feet in diameter, 17 feet 6 inches between the shrouds, and is adapted to a fall varying from 5 to 8 feet, according to the condition of the river. The water flows into the wheel at its highest level, over a sliding sluice of precisely the same construction as in high breast wheels; it is retained in the buckets to the bottom of the fall, by the cast-iron and stone breast fitting accurately to the edge of the buckets. The advantages of this construction are manifest, as the water expends its full force on the wheel from the very top of the fall, the buckets being well ventilated, and having a curvature adapted to the position in which they receive the water. By these means, a greatly increased duty is obtained as compared with the wheels with radial floats acted upon by impulse or gravity, or by both. Besides, with this form of wheel, the spider, or suspension principle of construction, may be adopted, and the power taken off at once from an internal segmental spur-wheel, placed on one of the shrouds, and a high velocity at once obtained, independently of multiplying gear. The advantages of this form of construction in iron wheels are very great, and, when combined with an economical application of the water, they form a machine probably as effective as any which can be employed for falls of not less than 5 feet.

Radial float wheels, however, constructed of wood are still in use, and the most important directions in respect to these appear to be to make the depth of the floats large, as compared with the thickness of the lamina of water which strikes them; to place the sluice as close as practicable to the floats; to contract somewhat the aperture of the sluice, and to expand the tail-race immediately beyond the vertical plane passing through the axis, to allow the water escaping from the floats to diffuse itself in the tail-race, and pass freely away. These directions, with the following practical formula for fixing the diameter of the wheel, we have from the dissertation on water wheels in the Engineer and Machinist's Assistant.

Let u = the velocity of the extremity of the floats; N the number of turns desired per minute; h = fall in feet. Assume $u = 2{\cdot}4 \sqrt{h}$ for a maximum effect, then the diameter expressed in terms of the velocity and height of fall will be $19{\cdot}1 \times \frac{2{\cdot}4 \sqrt{h}}{\text{N}} = \frac{46}{\text{N}} \sqrt{h}$ nearly. Thus supposing the height of fall $= h = 4$ feet; number of turns required per minute $= \text{N} = 8$; then the diameter $= \frac{46}{8} \sqrt{4} = 11\frac{1}{2}$ feet nearly. Twelve to twenty-five feet is the usual range of diameter for undershot wheels, and the same writer considers 12 to 16 feet to be the most effective; in my own practice, I have found from 14 to 18 feet perform the best duty. Feathering, or inclining the floats, does not appear to increase the useful effect.

The number of floats is usually equal to $\frac{4}{3}d + 12$, where d is the diameter in feet. The thickness of the vein of fluid striking the floats may be from 6 to 9 inches, and the depth of the floats from 18 inches to 2 feet.

M. Poncelet, one of the first authorities on Hydraulic Machines, and the first writer on Turbines, has contrived a very important modification of the undershot wheel, which has been used on the Continent with very good effect. A series of experiments led him to the conclusion that the floats should be curved instead of plane, and he deduced that for these wheels the velocity which gives a maximum effect was equal to 0·55 the velocity of the current, whilst it may vary from 0·5 to 0·6. He found the dynamic effect to vary from 50 to 60 per cent. of that of the water, being better for small falls with large openings at the bottom of the flood gate, and less for deep falls with small openings.

For describing the curve of Poncelet's floats, let $c\,c$ be the external circumference, and $a\,r$ the radius of the wheel; take $a\,b = \frac{1}{3}$ to $\frac{1}{4}$ the fall, and draw the inner circumference of the shrouding; let the water first strike the bucket at the point a and in the direction $d\,a$, draw $a\,e$ perpendicular to $d\,a$, so that the angle $e\,a\,r$ will be from 24° to 28°. Take on $a\,e$, $f\,g = \frac{1}{6}\,a\,f$, and from centre g, with radius $g\,a$, describe the curve of the float.

Fig. 125.

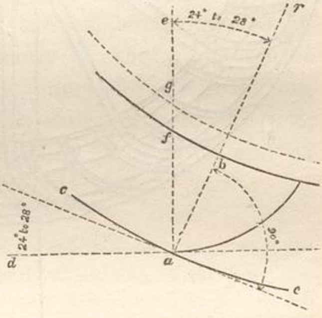
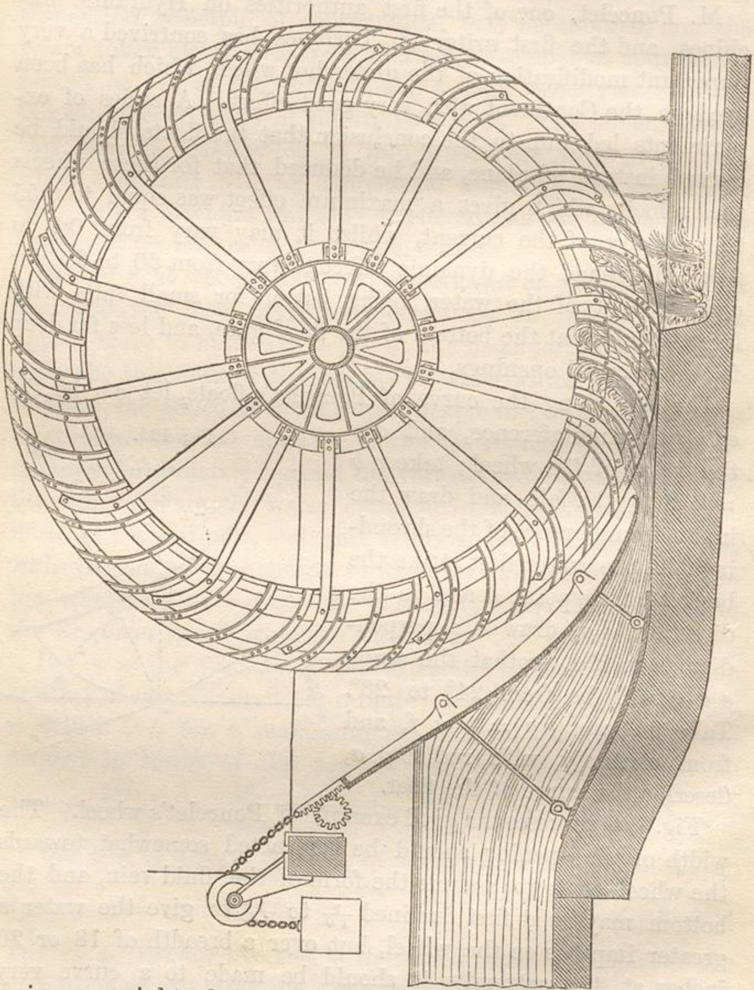


Fig. 125 represents a good example of Poncelet's wheel. The width of the opening should be contracted somewhat towards the wheel so as to assume the form of the fluid vein, and the bottom may be at first inclined $\frac{1}{10}$ to $\frac{1}{15}$, to give the water a greater impetus on the wheel, but over a breadth of 18 or 20 inches at the extremity it should be made to a curve very accurately fitting the periphery of the wheel.

So also the tail-race may be expanded in width and depth to keep the wheel clear of backwater. The buckets are made of wrought iron of the requisite curve, riveted to the shrouds on each side, and the sole plate is altogether dispensed with; as no resistance is opposed by the air, the buckets are made more numerous than in breast or undershot wheels, and as the wheel carries no weight of water, it may be made comparatively light. For the number of buckets for wheels of from 10 to 20 feet in diameter, we may take

Fig. 126.



$$n = \frac{8}{5}d + 16$$

Thus for a wheel 15 feet in diameter,

$$n = \frac{8 \times 15}{5} + 16 = 40$$

The wheel shown in the figure is 16 feet 8 inches in diameter, and 30 feet wide, and is driven by a fall 6 feet 6 inches high, yielding 20,000 cubic feet per minute. With a circumferential velocity of 11 or 12 feet per second, it afforded 140 horses' power.

This wheel gives a useful effect of 50 to 60 per cent. of the water power employed when well constructed, and may be used with advantage for falls not greater than about 6 feet. Above this the low breast wheel is certainly more advantageous and costs less.

Poncelet made some experiments on wheels of this class, with the friction break. The wheel was 11 feet diameter, 28 inches wide, and with 30 floats. He found the efficiency equal to 52 per cent. when the ratio of the velocity of the wheel to the water was 0·52. Morin has also experimented on these wheels, and for falls of from 3 to 4½ feet, with sluice openings of 6, 8, 10, and 11 inches, he found the efficiency 52, 57, 60, and 62 per cent. respectively.*

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* In a conversation with General Poncelet on this subject I found that the wheel which bears his name gives a duty of nearly 60 per cent. of the water employed. This is about the same as my own wheel with ventilated buckets for low falls, where the sole is entirely dispensed with. There is, however, this difference, namely, that in the Poncelet wheel the water is discharged upon the floats from *under* the sluice, whereas, in that of the ventilated wheel, it is discharged into buckets *over* the sluice from the upper surface of the fall.