# PRINCIPLES OF CONSTRUCTION AND EFFICIENCY OF WATER-WHEELS

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BY

WILLIAM DONALDSON, M.A.,

ASSOC. INST. C.E.,

AUTHOR OF "A TREATISE ON OBLIQUE ARCHES," "SWITCHES AND CROSSINGS," "TABLES FOR PLATELAYERS," AND "NEW FORMULAS FOR THE LOADS AND DEFLECTIONS OF SOLID BEAMS."



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## PRINCIPLES OF CONSTRUCTION

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### INTRODUCTION.

The use of water as a motive power has been so well known from the earliest ages of which we have any record, and the best mode of its application has formed the subject of so many scientific treatises, that the Author feels he cannot advance any new views, or establish any new rules of construction of the more ancient forms of wheels. Modern inventions for utilising the impulsive power of water, such as turbines, do not seem, however, to have been thoroughly investigated; at least, the Author has not been able to meet with any treatise, in which detailed rules of construction have been given; or if detailed rules of construction have been given, no scientific reason has been laid down for their adoption.

Part I. is devoted to the investigation of the effect of the impulse of water against vanes, the general principles of construction, and the efficiency of the different classes of vertical wheels.

Part II. treats of the efficiency, principles, and details of construction of the working parts of the three classes of turbines—outward, inward, and parallel flow.

Smeaton and the older writers on this subject use the word *power* to express the product of the weight of water falling during any interval by the height through which it falls, the units of time, weight, and space generally adopted being a second, a pound, and a foot respectively. Professor Rankine in his work on "Prime Movers" uses the word *energy* to express the same thing. Neither according to its strictly etymological, nor any acknowledged derivative meaning, can the word energy be rightly used to express the idea. It is more nearly synonymous with efficiency. Perhaps the difference between the two, and the reasons for preferring the word "power" cannot be better illustrated than by saying, you may be powerful without being energetic, and energetic without being powerful.

To utilise this power, water-wheels of different kinds have been invented. They may all, however, be divided into two classes.

(1.) Those which are driven partly by the statical weight of the water acting through a portion of the whole fall, partly by the momentum acquired by the water before it strikes the wheel.

(2.) Those which are driven by momentum acquired by the water only.

Wheels of the first class are designated "weight and impulse," those of the second "impulse" wheels.

The power which the wheel is capable of transmitting to the machinery is called by Smeaton the effective power of the wheel. This, owing to the friction of the bearings and other resistances, and the impossibility of utilising the whole power of the fall, whether it acts partly by weight, partly by impulse, or wholly by impulse, is always less than the gross power of the fall. The ratio, effective power ÷ gross power of fall, is called the co-efficient of efficiency of the wheel.

The efficiency can only be determined by actual experiment. Co-efficients determined by calculations, based upon assumptions which, although more nearly true in some cases than in others, never exactly represent the actual state of the case, are never sufficiently near the truth to determine the absolute power of any wheel, even when this is considered apart from the efficiency lost by friction of the bearing surfaces or by contact with external resistances, such as the tail water in a vertical wheel race, or the water surrounding a submerged horizontal wheel.

Such co-efficients will, however, enable us to compare with sufficient exactness the relative efficiency of different wheels, and of the same wheel under different circumstances, and the theoretical investigation into their value will show us how to determine the form of the wheel of each class, which will, in practice, develop the highest efficiency.

The co-efficient of efficiency of turbines is usually stated to be equal to that of high breast wheels, viz., about ·75. The investigations of the Author have led him to the conclusion that this efficiency cannot much exceed ·5. The argument of those who uphold the higher co-efficient is simply this. The power lost by the water must have been communicated by the machine; if not, what has become of it? If such an argument be applicable to the case of one hydraulic machine, it must be applicable to all. Thus the water in the tail race of an undershot wheel with flat vanes moving at its best velocity, moves with only half the original velocity. Seventy-five per cent. of the original power of the current has been lost, therefore ·75 is the co-efficient of efficiency of undershot wheels.

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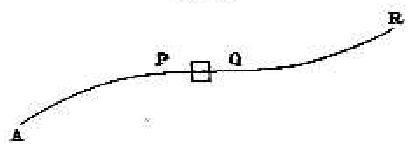
## PART I.

### Impulsive Action of Water and Vertical Water-wheels.

The simplest case of the impulsive action of water is that of a flat vane immersed in a stream at right angles to its direction. The following investigation of the effective power exerted by the stream on such a vane is given in Mosely's "Hydrostatics."

Let the curve A P Q R represent the direction of the motion of the stream between the points A and R. Let us consider the

Fig. 1.




motion of a small cylindrical element of the fluid P Q. Let K be the area of either end of the cylinder, S the distance of P from A and P Q = $\delta s$. Since the pressure may vary from A to R, but is always of the same value at the same distance from A, if $p$ be the pressure at P, the pressure at Q will be $p + \delta p$. Let S be the accelerating force on the end P, $\rho$ the density of the liquid, then the moving force on the element P Q will manifestly be

$$K \rho \delta s S - K \delta p;$$

if, therefore, $v$ be the velocity of the point P, the equation of motion of the point P, when $\delta s$ is indefinitely diminished, will be

$$v \frac{dv}{ds} = S - \frac{1}{\rho} \frac{dp}{ds},$$

whence

$$\tfrac{1}{2} v^2 = \int S \, ds - \frac{p}{\rho} \text{ (A)},$$

we may apply equation (A) in the two following ways for determining the moving force of the water on the vane.

(1.) Let the vane be stationary.

Let $p'$ be the pressure in front of the vane after immersion, since the motion of the water in direction A P Q R is wholly destroyed, we have

$$o = \int S\, ds - \frac{p'}{\rho},$$

and therefore K $(p' - p)$ the moving force exerted on the vane is equal to

$$\tfrac{1}{2} K \rho v^2 = K g \rho . \frac{v^2}{2g},$$

or the moving force is equal to the weight of a column of water whose height is equal to that due to the velocity of the current and base equal to the area immersed.

(2.) Let the immersed vane have a velocity $u$.

The effort of the stream on the vane may be viewed in two lights.

(*a*.) Since the moving force on the vane when stationary is equal to the weight of a column of water whose height is equal to that due to the velocity of the current, we might infer that when the vane is in motion the moving force would be equal to the weight of a column of water whose height is equal to that due to the difference between the velocities of the water and the vane, or to

$$K g \rho \frac{(v - u)^2}{2g},$$

in which case effective power exerted per second would be

$$K g \rho . \frac{(v - u)^2 u}{2g},$$

from which we get these theoretical values of the ratios.

$$\frac{\text{Best velocity of vane}}{\text{Velocity of current}} = \frac{1}{3} = \cdot 34$$

$$\frac{\text{Moving force at best velocity}}{\text{Moving force when stationary}} = \frac{4}{9} = \cdot 45$$

$$\frac{\text{Effective power}}{\text{Gross power}} = \frac{4}{27} = \cdot 15$$

$$\frac{\text{Effective power}}{\text{Power lost}} = \frac{1}{6} = \cdot 17$$

the gross power being equal to the product of the weight of water passing in one second, viz.: $K g \rho v$ multiplied by the height due to the velocity of the stream, and the power lost to the product of the same weight of water multiplied by the difference between the heights due to the initial and final velocity, viz.: $\frac{8v^2}{9g}$.

($b$.) Referring to equation (A), if $p'$ represent the pressure, when the vane is immersed on the front of the vane, since the velocity in the direction A P R must be equal to that of the vane, we have

$$\tfrac{1}{2}u^2 = \int S\,ds - \frac{p'}{\rho},$$

and therefore the moving force on the vane will be equal to

$$K\,g\,\rho.\ \frac{(v^2 - u^2)}{2g},$$

and the effective work done per second

$$\frac{K\,g\,\rho\,(v^2 - u^2)\,u}{2g},$$

whence

$$\frac{\text{Best velocity of vane}}{\text{Velocity of current}} = \sqrt{\frac{1}{3}} = \cdot 58$$

$$\frac{\text{Moving force at best velocity}}{\text{Moving force when stationary}} = \frac{2}{3} = \cdot 67$$

$$\frac{\text{Effective power}}{\text{Gross power}} = \frac{2}{3\sqrt{3}} = \cdot 385$$

$$\frac{\text{Effective power}}{\text{Power lost}} = \sqrt{\frac{1}{3}} = \cdot 58$$

In the above investigations, it has been assumed that the pressure in rear of the vane is equal to the pressure of the fluid before the immersion of the vane. Since the pressure before immersion exceeds very little that of the atmosphere, because the depth of immersion is small, this assumption must be looked upon as practically correct.

The solution given in ($b$) is rigorously exact on these data. That given in ($a$) is a mere deduction from the calculated moving force on the vane when stationary, and has only been given because the theoretical co-efficients obtained by that mode of solution are the same as those adopted by Smeaton in comparing the results of his experiments with those of theoretical investigation.

The following table gives values selected from the results of twenty-seven experiments made by Smeaton to determine the