

No. 548. "An Experimental Inquiry as to the Co-efficient of Labouring force in Overshot Water-wheels, whose diameter is equal to, or exceeds the total descent due to the fall; and of Water-wheels moving in circular channels." By Robert Mallet, M. Inst. C. E.

On the co-efficient of labouring force of water-wheels.

This paper is partly mathematical, and partly experimental. The investigation which it details, the results of which are given in ten tables of experiments, had in view principally to obtain the definite solution of the following questions.

1st. With a given height of fall and head of water, or in other words, a given descent and depth of water in the pentrough, will any diameter of wheel greater than that of the fall give an increase of labouring force (*i.e.* a better effect than the latter), or will a loss of labouring force result by so increasing the diameter?

2nd. When the head of water is necessarily variable, under what conditions will an advantage be obtained by the use of the larger wheel, and what will be the maximum advantage?

3rd. Is any increase of labouring force obtained by causing the loaded arc of an overshot wheel to revolve in a closely fitting circular race, or conduit; and if so, what is the amount of advantage, and what the conditions for maximum effect?

The author briefly touches upon the accepted theory of water-wheels, the experimental researches of Smeaton, and the recent improvements in theory, due to the analytic investigations of German and French Engineers.

Smeaton, in his Paper on Water-wheels, read to the Royal Society in May, 1759; and Dr. Robison, in his Treatise on Water-wheels, lay down as a fixed principle, that no advantage can be obtained by making the diameter of an overshot-wheel greater than that of the total descent, minus so much as is requisite to give the water, on reaching the wheel, its proper velocity.

The author, however, contends that while the reasoning of the latter is inconclusive, there are some circumstances which are necessarily in favour of the larger wheel, and that conditions may occur in practice, in which it is desirable to use the larger wheel, even at some sacrifice of power; and that hence it is important to ascertain its co-efficient of labouring force, as compared with that of the size assigned by Smeaton for maximum effect.

The author states, first, the general proposition, that the labouring force ("travail" of French writers), or "mechanical power" of Smeaton, of any machine for transferring the motive power of water

"is equal to that of the whole moving power employed—minus the half of the *vis viva* lost by the water on entering the machine, and minus the half of the *vis viva* due to the velocity of the water on quitting it." He deduces from the theory, the following results, coinciding with the conclusions obtained by experiment.

1st. If the portion of the total descent passed through by the water before it reaches the wheel be given, the velocity of the circumference should be one-half that due to this height.

2nd. If the velocity of the circumference be given, the water must descend through such a fraction of the whole fall before reaching the wheel, as will generate the above velocity.

3rd. The maximum of labouring force is greater, as the velocity of the wheel is less; and its limit theoretically approaches that due to the whole fall.

General equations are given, expressing the amount of labouring force in all the conditions considered, and their maxima.

One of the principal advantages of using an overshot wheel greater in diameter than the height of the fall, is the power thus afforded of rendering available any additional head of water occurring at intervals, from freshes or other causes, by admitting the water upon the wheel at higher levels.

The first course of experiments is dedicated to the determination of the comparative value of two water-wheels, one of whose diameter is equal to the whole fall, and the other to the head and fall, or to the total descent; by the head, being in every case understood the efficient head, or that due to the real velocity of efflux at the shuttle, as determined according to Smeaton's mode of experimenting.

The apparatus employed in this research consisted of two accurately made models of overshot wheels, with curved buckets; these were made of tin plate, the arms being of brass, and the axles of cast-iron. Special contrivances were adopted to measure the weight of water which passed through either wheel during each experiment, to preserve the head of water strictly constant, and to determine the number of revolutions, and the speed of the wheels.

One wheel was 25·5 inches diameter, the other, 33 inches diameter. The value of the labouring force was determined, directly by the elevation of known weights to a height, by a silken cord over a pulley; the altitude being read off, on a fixed rule placed vertically against a lofty chimney; and in other experiments, relatively by the speed of rotation given to a regulating fly or vane. The depth of the efficient head was in all cases 6 inches.

The weight of water passed through either wheel, in one experiment, was always 1000 pounds avoirdupoise.

All the principal results given in the tables accompanying the paper, are the average of five good experiments. From the large scale upon which these were conducted, the accurate construction of the apparatus, and the care bestowed upon the research, which was undertaken with reference to an actual case in the author's professional practice, he is disposed to give much confidence to the results.

The weight of water contained in the loaded arc of each wheel is accurately ascertained, and in the tables which accompany the paper, the results of the several experiments are given at length.

The velocity of the wheels, under different circumstances, is carefully noted and discussed with respect to the maximum force.

The author next ascertains the value of the circular conduits, and states that generally, in round numbers, there is an economy of labouring force, amounting to from 8 to 11 per cent. of the power of the fall, obtained by the use of a conduit to retain the water in the lower part of the buckets of an overshot wheel, whose diameter is equal to the fall. The velocity of a water-wheel working thus, may vary through a larger range without a material loss of power, and a steady motion is continued to a lower velocity than when it is working in a free race.

The author finally arrives at the following general practical conclusions:—

1st. When the depth of water in the reservoir is invariable, the diameter of the water-wheel should never be greater than the entire height of the fall, less, so much of it as may be requisite to give the water a proper velocity on entering the buckets.

2nd. Where the depth of water in the reservoir varies considerably and unavoidably, an advantage may be obtained by applying a larger wheel, dependant upon the extent of fluctuation and ratio in time, that the water is at its highest and lowest levels during a given prolonged period; if this be a ratio of equality in time, there will be no advantage; and hence, in practice, the cases will be rare when any advantage will be obtained by the use of an overshot wheel, greater in diameter than the height of fall—minus, the head due to the required velocity of the water reaching the wheel.

3rd. If the level of the water in the reservoir never fall below the mean depth of the reservoir, when at the highest and lowest, and the average depth be between an eighth and a tenth of the height of the fall, then the average labouring force of the large wheel will be

greater than that of the small one; and it will of course retain its increased advantage at periods of increased depth of the reservoir.

Dr. Robison's views, therefore, upon this branch of the subject, should, he contends, receive a limitation.

A positive advantage is obtained by the use of the conduit, varying with the conditions of the wheel and fall, of nearly 11 per cent. of the total power.

The value increases with the wheel's velocity up to  $4\frac{1}{2}$  feet per second, or to 6 feet per second, in large wheels. Hence, he argues, that it is practicable to increase the efficiency of the best overshot wheels, as now usually made, at least 10 per cent. by this application. The only objections urged against the use of the conduit are of a practical character, relating to the difficulty of making it fit close, of repair, &c.; but however these may have applied to the rude workmanship of the older wooden wheels, with wood or stone conduits, they are unimportant, as referring to modern water-wheels made of iron. The conduits may be also made of cast-iron, provided with adjusting screws, and are hence capable of being always kept fitting, readily repaired, and of being withdrawn from the circumference of the wheel in time of frost, &c.

The paper is illustrated by a drawing, giving the elevation and partial sections of the experimental apparatus, and by a diagram showing the full size of the loaded arc of each model.

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Mr. Farey observed, that the result arrived at by the experiments, Mr. Farey. appeared to correspond nearly with those recorded by Smeaton, who had experimented upon, and used practically both kinds of wheels. The buckets of the model wheels used in the experiments did not appear to be of the best form, and they were entirely filled with water; hence an apparent advantage had been obtained, by the use of the circular conduit to retain the water in the buckets. But that would not be realized in practice, for as the form of the bucket regulated the point at which the water quitted it, and it was the practice of the modern millwrights to make the wheels very broad, in order that the buckets should not be filled to more than one-third of their depth, the circular conduits became less useful, and in fact were now seldom used. Smeaton's practice was to entirely fill the buckets with water, but he never adhered to the slow velocity of revolution which he recommended theoretically, in his Paper to the Royal Society.

Mr. Fairbairn had adopted broad wheels with an improved form of bucket partially filled, and had obtained a more regular motion, particularly at high velocities.