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Turbine wheels and water power

Herman N. Van Devander

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THESIS

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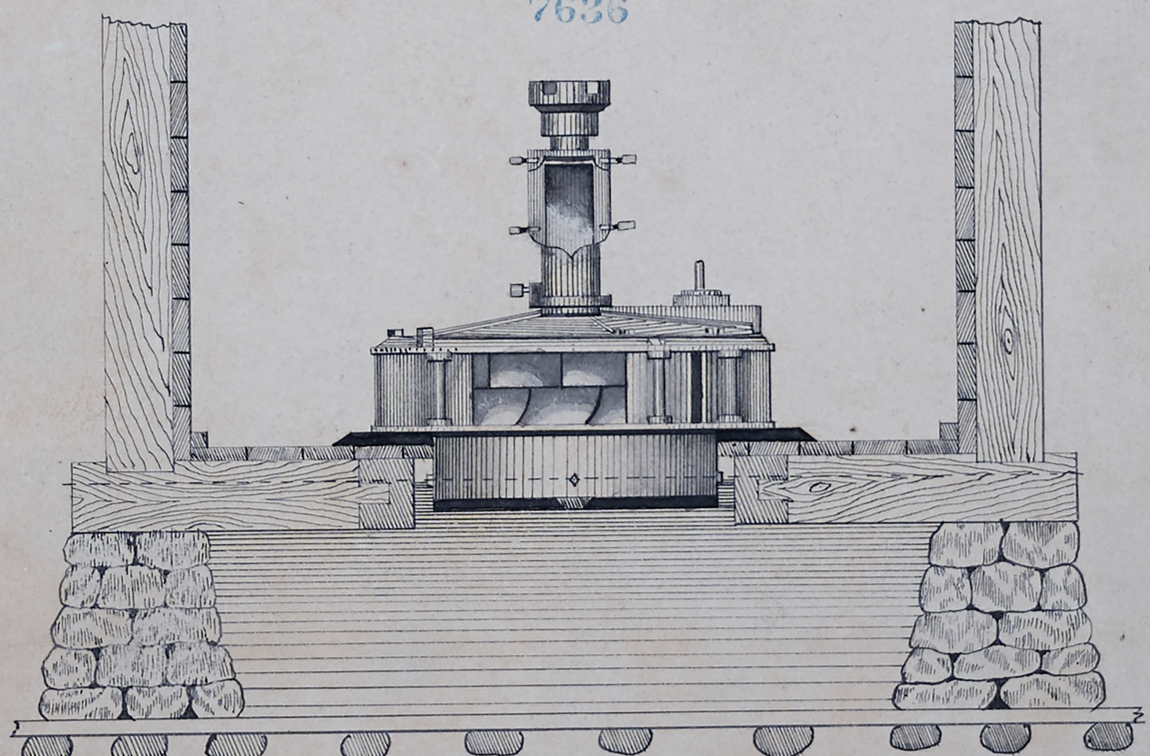

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Turbine Wheels & Water Power

The utilization of the power resident in natural water falls, ranks among the oldest of mans efforts to escape animal power, and particularly the expenditure of his own muscular energy: and its natural cheapness has rendered this one of the most promising fields for the exercise of his inventive genius. From the crude apparatus used to furnish the blast for the old Catalan Iron Furnace (a column of water was allowed to fall through a perpendicular box, perforated near the top to admit the air, which becoming entangled in the water, was carried downward to a pressure chamber at the bottom, and thence to the tuyeres) — and this is probably the least efficient of any method ever attempted, of obtaining work from water to the most perfect turbine of to-day, men have labored, experimented, and invented, with a slow but gradual improvement through generations, until now they have succeeded in bringing out of the rough Catalan machinery, which gave but an insignif-icant fraction of the theoretical power

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A turbine water-wheel is one through which the water passes, guided by channels either interior or exterior to the wheel its self, and the walls of these channels or guides as they are termed, are placed in such positions, as to impinge the water on to the blades or wheel buckets at such an angle as will insure the greatest efficiency. The guides and buckets are usually curved in opposite directions, and are so placed, with regard to each other, that the water enters the wheel with the least possible shock, and leaves it with the least possible velocity. Turbines may be placed in any position, from a horizontal to a perpendicular, and another advantage they possess over the old style of wheel is, the higher the fall, the smaller the wheel required, whereas with the over-shot wheel (the best form of old style) the reverse is the case.

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The velocity of a small turbine under a high fall is necessarily very great, and this proves to be an advantage too, for it permits of the doing away with the heavy and expensive gearing which was necessarily used in connection with the old style wheels of great power; and it also gives a greater regularity of motion. The turbine was first introduced into general use by Fourneyron in France, in 1827 and shortly after, it was used in England, and later it was introduced into the United States, by Boyden. Turbines are termed inward-flow, outward-flow and parallel-flow wheels, &etc. according to the direction the water takes in passing through them. The modulus of a wheel is found as follows: The amount of water flowing through the wheel is found by guaging, and its weight is measured by the height of fall; The actual amount of power exerted by the wheel is ascertained by means of a dynamometer. Now if we let R, represent the resistance, and, V, the velocity with which the wheel

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over comes it: then RV will represent the work done in a unit of time. If we let W represent the weight of water flowing per second, h, the height of fall, and, M, the modulus, we will have $RV=WhM$ or $M=\frac{RV}{Wh}$ which gives us the modulus or coefficient of efficiency. Turbines are found to give their greatest power when their velocity is between 5/10 and 7/10 of that due to the height of the fall. The velocity of the water as it passes through the wheel should be kept as nearly uniform as possible, and the passages should have such a form and area of cross-section as will insure the greatest uniformity. The velocity of the whirl should be made equal to the velocity of the wheel, and thus allow the water to glide over the buckets, without sudden change in velocity, and finally, having spent all its force, merely drop from the wheel.

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view of utilizing the enormous heat that daily comes to us from the sun, for the purpose of power, and in view of the fact, that our steam engines are so rapidly consuming the vast stores of the past energy of that luminary, as potentially represented in the coal fields, to think, that the most wasteful form of water wheel, was a more perfect machine than the highest type of our modern steam engine, while as a sun engine or any contrivance where by we may convert solar heat to power for our own use, the modern water wheel far exceeds in perfection, any thing man can ever hope to devise or discover. The existing energy of a body of water at any level, represents exactly the equivlant of the heat of the sun expended in raising it to that level, from some other, by evaporation, and the instrument or machine by which 90 per cent of this latent power can be utilized, in the descent from this level to

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that at which it was evaporated, is about six times more efficient, and consequently that much nearer perfection, than the most efficient steam engine ever constructed.

The old device, the over-shot wheel, for a long time, stood alone, as the best means of utilizing water power, and it is only within comparatively few years that its efficiency has been approached by any other, but the turbine has reached that state of perfection, when the probabilities of its being surpassed almost entirely disappear. The principle objections to the over-shot wheel, are, its size, space required, cost, inapplicability to high and low falls &etc. whereas the turbine is small, requires but little space, is cheap, comparatively much stronger and is capable of utilizing either high or low falls; and so near theoretical perfection has this machine been brought, that now the best turbine wheel gives us very nearly all that can come from the water in shape

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The principle field for improvement now, is in such things as relate to cost, durability, prevention of clogging from sundry substances in the water, service in freezing, as well as in warm weather, government of speed under variations of load, and others of less importance; while perhaps the direction open to greatest improvement, is its efficiency under a diminished flow of water or a partial gate. Of course it is not intended, here, to convey the idea, that there is no difference in turbines, and that they all reach the greatest perfection: even while working under a full gate, the results, which are given farther on, will show, that the wheel that, ~~gives~~ under the most favorable circumstances gives 80 per cent of

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Gate leakage is a question that demands attention, and shows considerable room for improvement.

In the arrangement of Machinery Hall at the Centenial Exhibition, in 1876 at Philadelphia, quite extensive preparations were made for testing the wheels, placed on exhibition; and as this class of motors is now so universally in use, it may be well to give a dis-cription of the apparatus used in testing them. A few figures will enable us to better understand it- Fig. 1 is an end elevation of the arrangements for supplying and maintaining the necessary head of water. It consists of a boiler iron tank, supported on six iron columns, three of which are placed on a pier built in the main basin. This tank when full contains about 19000 gallons. The side of the tank which extends over the main basin, has a curved form which provides for the escape of the surplus water, thus allowing the experiments to be conducted under

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Fig. 1. The water was forced up to
the tank by two of Wm D. Andrew's
centrifugal pumps, B, Fig. 2, each having
a discharge pipe 15 inches in diameter,
and are seen in part at, c, Fig. 1;
on the left of these is seen the
penstock, D, which is 4 feet in diameter,
extending downward from the bottom
of the tank, and terminating at its
lower end in a right angle curve
where it enters a cylindrical case
8.5 feet in diameter, and which is
supported on a circular brick wall.
In this case the wheels were placed
for testing. Fig. 2 shows in horizontal
projection, the position of the race,
weir, wheel &etc. From the wheel
pit it will be seen, the tail race
, E, leads out to the channel between
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pier, f, therein erected. One side
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built in the main basin, and
increased in width from the
wheel toward the weir, to a point
about 30 feet from the wheel pit,
where it was 15 feet wide, and
15 feet farther on was placed the
overflow, H, which consisted of a
cast iron plate, accurately plained
and bevelled at an angle of 45° until
the edge was but 1/8 of an inch
thick. The inside of this plate was
verticle, and the incline was placed
in the direction the water was
flowing. It was exactly 9 feet long,
which left 3 feet of the end wall
of the weir, on each side, this
caused a contraction of the vein,
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calculations. At each end of the
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a correct level. This guage was supplyed with a vernier so as to read to 1/1000 of a foot, and the whole was placed back of the weir, a distance of six feet, so as to be beyond the point at which the depression of the surface began, and the vernier was set with reference to the edge of the weir plate as a datum plane. The head of water on the wheel, was determined by a guage placed in the tail race, and provided with a box, similar to the other, but this one carried a wooden rod, which extended upward, and was furnished with a vernier at the top, which read to 1/100 of a foot. Along side of this vernier was a glass tube guage, which was connected with the case in which the wheels were placed, and the reading of the vernier at the level of the water in the tube gave the exact difference of level, between that and the head of water on the wheel, and the tail race, or the true head of water on the wheel. The water

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The velocities of the wheels
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in a dial point. This indicator
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The time principally depended on
the number of fractional gate
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brake. A hollow cylinder, C, is keyed
to the shaft of the water wheel,
and is 37.44 inches in diameter, with
a face of 18 inches; this runs
within two semi-circular straps,
one of which terminates in the
lever arm, L, The straps were
arranged for perfect lubrication,
and the pressure was regulated
by the tension screws, G.
Fig. 4 is a frame upon which is
supported a horizontal lever, L',
pivoted at its center, f. The pivot
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U.S. standard and were furnished by Fairbanks &Co. The weight of the apparatus was calculated to be about the same as the gearing usually attached to the wheel when in use, and was therefor omitted in the determination of power. The length of the arm, L, was 10.5 feet or equal to the radius of a circle whose circumference was 66 feet, and was made of this length to facilitate computation. Now, remembering that the lever arms, L', are to, a, in the proportion of two to one, and representing the weight on the scale pan by, W, the velocity of the wheel by, V, the circumference of the circle due to the arm, L, as a radius, by c, =(66 feet) We have the following $\frac{2WVc}{33000} = \frac{WV}{250}$ = Horse power. To find the horse power of a wheel, it was only necessary to multiply the product of the weight and revolutions by 4 and point back three decimal places.

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simple and should apparently yield reliable results, it is found by manufacturers and practical mill owners, to be altogether unreliable, as an indicator of the amount of work the wheel will perform. In a great many instances, it has been found that different wheels when under test and giving about the same per cent of efficiency, differed greatly when in practical use; some of them loosing about one half their supposed power. After all, this testing seems to be of but little value; it scarcely shows more than the inadequacy of such tests, to reveal the true merits of the wheel. In 1860 there was a competitive test of water wheels at the Fairmount Water Works in Philadelphia, and a great many wheels gave nearly 90 per cent of power, and it was afterwards found in their practical opperations, that the wheels which had given the most flattering

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results, were of comparatively little value; while others which stood low in the experimental scale, proved to be far superior. The very wheel which gave the greatest satisfaction in the Fairmount test, was found to be so inefficient, when put to practical use, that it was finally abandoned by the maker, and in its stead, he adopted one of the class that gave the lowest percentage at that time, and is now engaged in its manufacture with much better results. The Fairmount tests were conducted with the greatest skill, and was superintended by the best engineering talent in the country.

To avoid any error in measuring the water by the use of the weir, (which is liable to erroneous results) an absolutely certain was adopted, the water being caught in a large tank and measured with perfect accuracy. These deceptive results are certainly discouraging, but may be accounted for, by the variation of the load the wheels are required

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to move. This of course directly affects the wheel." The motion, especially in woolen, cotton and saw mills, is ever changing, exceedingly unsteady, and these changes by no means in a uniform degree, and of course discharging for each interval of time different quantities of water than where the conditions are uniform and favorable in the test flume. On the following page will be found in tabulated form, a few of the results of the tests, made at the centenial exhibition; showing per cent of efficiency under fractional gates.

The Victor and Leffel wheels are not found in this table; though they are probably the most popular wheels at present. The Victor is manufactured by Stilwell & Bierce of Dayton, Ohio - and the Leffel wheel by James Leffel of Springfield Ohio. The Victor 10 inch wheel, under a 10 foot head, gives 5.58 horse power, and uses 348 cubic feet of water, while the Leffel 10 inch wheel under a 10 foot head, gives

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Name of Exhibitor	Diameter of wheel.	Fraction of Gate.	Revolutions per minute.	Horse power of wheel.	Head on Wheel.	Flow due leakage per minute.	Horse power of water.	Per cent of efficiency.
F. H. Risdon	30"	1	266	82.99	30.36	34.66	94.87	87.56
"	"	3/4	248	57.53	30.84	"	69.73	82.66
"	"	1/2	258	42.31	31.00	"	56.22	75.26
Noye & Sons	26"	1	269	36.58	31.10	34.66	58.57	62.45
"	"	3/4	289	30.05	31.24	"	49.01	61.31
"	"	1/2	265.5	20.52	31.28	"	39.12	53.45
Barber & Harris	20"	1	330.5	37.01	31.18	53.40	48.55	76.25
"	"	3/4	299	23.92	31.45	"	33.60	71.19
"	"	1/2	271.5	17.37	31.62	"	24.23	71.68
Goldie & McCulloch	27"	1	281.5	78.82	30.05	34.66	96.01	82.09
"	"	3/4	280	56.00	30.14	"	77.79	71.99
"	"	1/2	325	39.00	30.65	"	68.70	58.22
Putnam Mach. Co.	30"	1	257	74.01	30.05	14.35	93.09	79.50
"	"	3/4	261	58.46	30.25	"	73.23	79.83
"	"	1/2	241	43.47	30.60	"	64.86	67.02
Thos. Fait	25"	1	288.5	46.16	31.00	14.35	56.27	82.03
"	"	3/4	292	30.37	31.32	"	41.76	72.72
"	"	1/2	258	22.70	31.44	"	33.91	66.94
"	"	1/4	235	7.52	31.59	"	17.47	43.05
"	"	1/8	266	6.38	31.61	"	16.92	37.71
Rodney Hunt, Mach. Co.	24"	1	276	79.48	29.25	14.35	101.79	78.08
"	"	3/4	289	67.04	29.60	"	93.69	71.55
"	"	1/2	312	49.42	30.25	"	72.56	68.79
"	"	1/3	238	32.37	30.44	"	64.26	50.35

30 1 266 82.99 30.36 34.66 94.78 87.56

Name of Exhibitor	Diameter of Wheel	Fraction of Gate	Revolution per Minute	Horse power of Wheel	Head on Wheel	Flow duct leakage per Minute	Horse power of Water	Percent of Efficiency
F.H. Risdon	30”	1	266	82.99	30.36	34.55	94.87	87.06
“	“	¾	248	57.53	30.84	“	69.73	82.66
“	“	½	258	42.31	31.00	“	56.22	75.26
Noye & Sons	26”	1	269	36.58	31.10	34.66	58.57	62.45
“	“	¾	289	30.05	31.24	“	49.01	61.31
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2.00 horse power and uses 122 cubic feet of water. It will be seen from this that the "Victor" gives nearly three times as much power as the "Leffel", but at the same time it will be seen that it requires more water, in about the same proportion.

In order to make a judicious selection between these two wheels, it would be necessary to take into consideration the amount of water available, as the Leffel wheel would be better capable of utilizing a limited quantity than the Victor. In order to utilize very high falls, it is necessary to have some thing stronger than the ordinary wooden penstock, and to this end an iron case has been introduced, which is capable of withstanding any pressure that might come upon it. The wheel being placed in this casing, any heigth of fall may be utilized.

At Ithaca, New York, there is a 11½ inch wheel operating under a head of 95 feet. The water is

2.00 horse power and uses 12.2 cubic feet of water. It will be seen from this that the “Victor” gives nearly three times as much power as the “Leffel” but at the same time it will be seen that it requires more water, in about the same proportion.

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At Ithaca, New York, there is a 11 ½ inch wheel operating under a head of 95 feet. The water is

carried to the wheel through an iron pipe 500 feet long where it is attached to a Globe case, in which the wheel is placed.

This wheel gives about one hundred horse power.

In regard to setting the Turbine wheel, the first thing demanding attention, is the head race or conduit Care should be taken to have this of sufficient size, and this is especially necessary where the race is of considerable length, and a large quantity of water is to pass through it. The water should never flow faster than from 60 to 120 feet per minute. It has been noticed in long races, that after the wheel has been running a few hours, the water draws down from 1 to 3 feet. The effect of this is the same as if the dam had been lowered an equal amount, and the result is a loss of power, which might have been saved by making the race deeper and wider. The next point of importance is the wheel pit, and to obtain the

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best results from the wheel, it
must be of the proper depth, which
depends on the size of the wheel,
and varies from 2 to 7 feet. The
pit should be so made, as to
allow about 2 feet of water to
stand in it, when the wheel is
not running. In all cases, care
must be taken, to prevent the
water from backing up into the
wheel when in motion, as part
of the power would be expended
in forcing it away. In making
the pit, if there is a sandy or
mud-bottom, mud-sills must be
put down to prevent the foundation
from washing out, and these sills
should be covered with heavy
plank. A rock bottom does not
require mud-sills or plank, but
must be blasted out so as to give
the desired depth of standing tail
water. The tail race should
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The prosperity of the New England States, is, in a great measure due to water power. Not that water is more abundant there than in other parts of the United States but more of it has been profitably utilized. "The South is better provided with water power than any other section of the country. This is peculiarly so of the Atlantic slope. The four states of Virginia, North Carolina, South Carolina and Georgia, having water power equivalent to 14 000 000 horse power, four times that of all the steam engines in the world. The Yadkin river of N.C. alone has sufficient force to turn 12 000 000 spindles."

In the northern part of the Southern states, there is an elevated region of more than one hundred thousand square miles, in which there is a vast amount of water power, and being in the cotton region, with a fine, healthy climate, its only needs, are rail roads, capital and population, to make it the greatest manufacturing

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Fig. 1

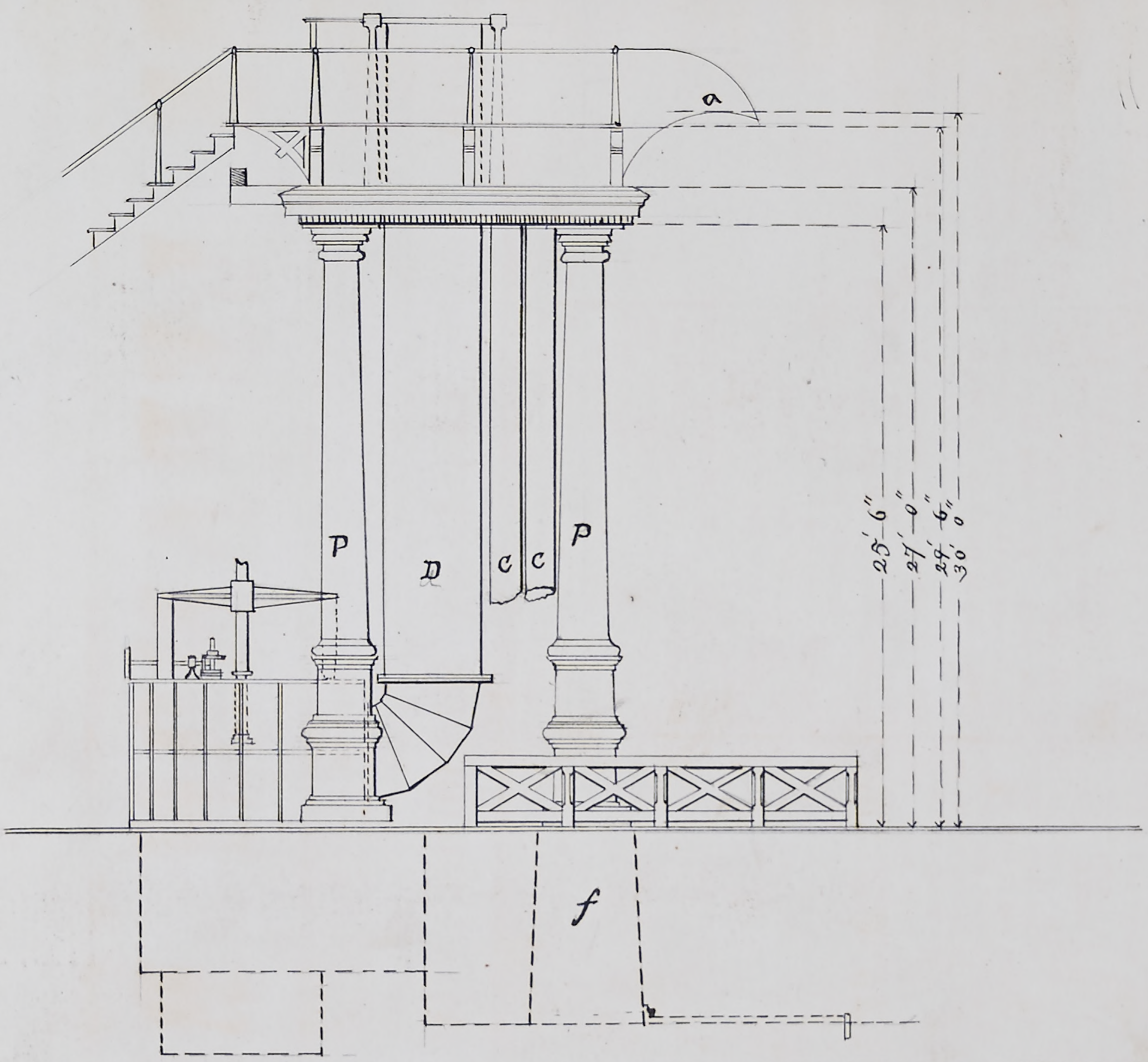


Fig. 4

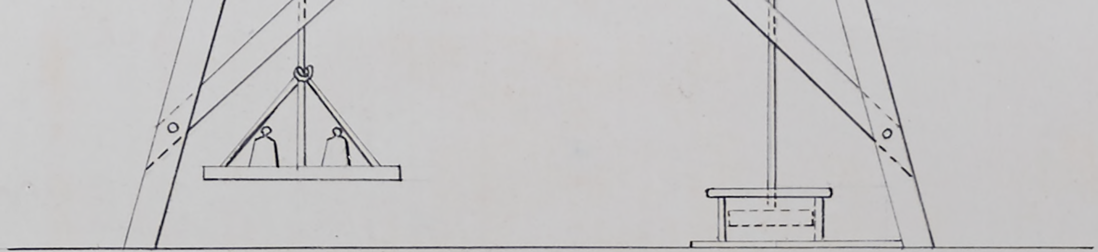


Fig. 2

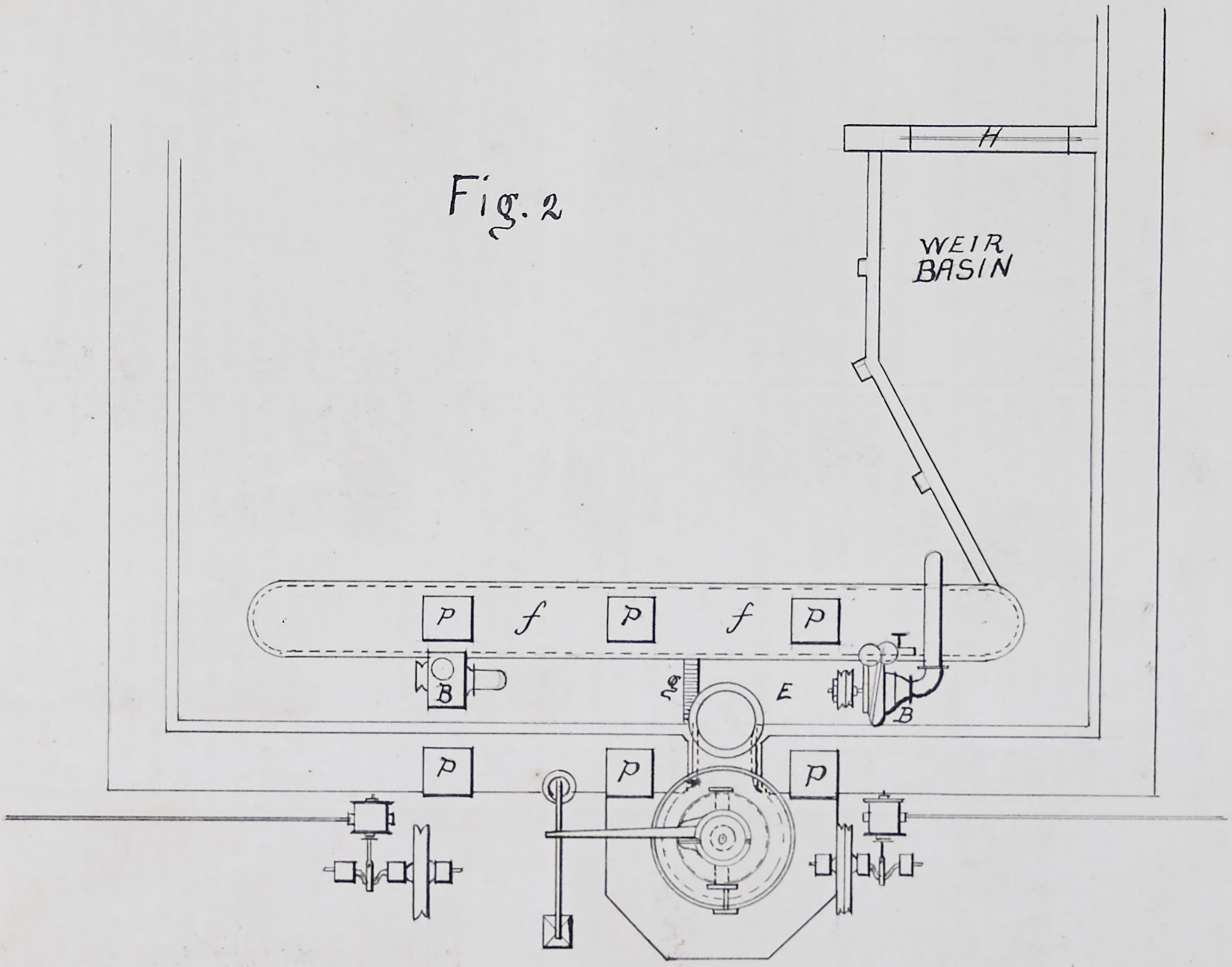
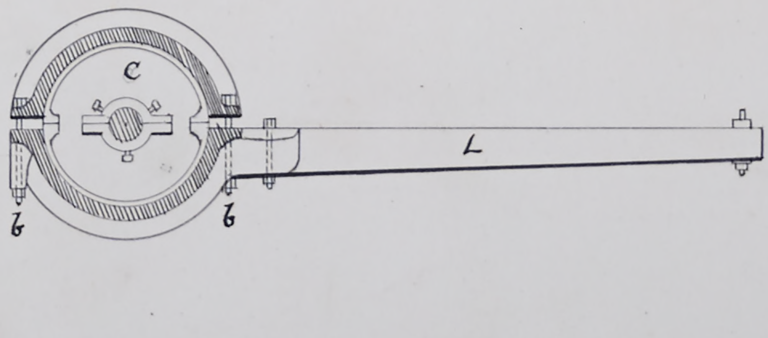
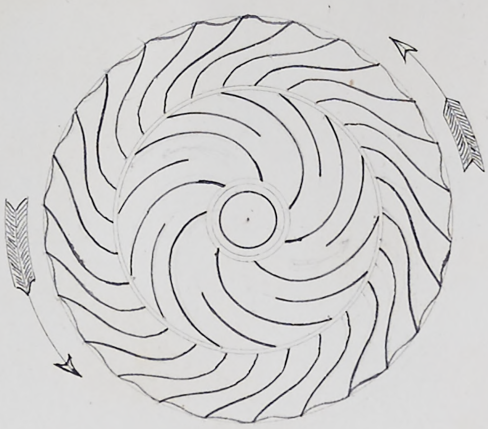
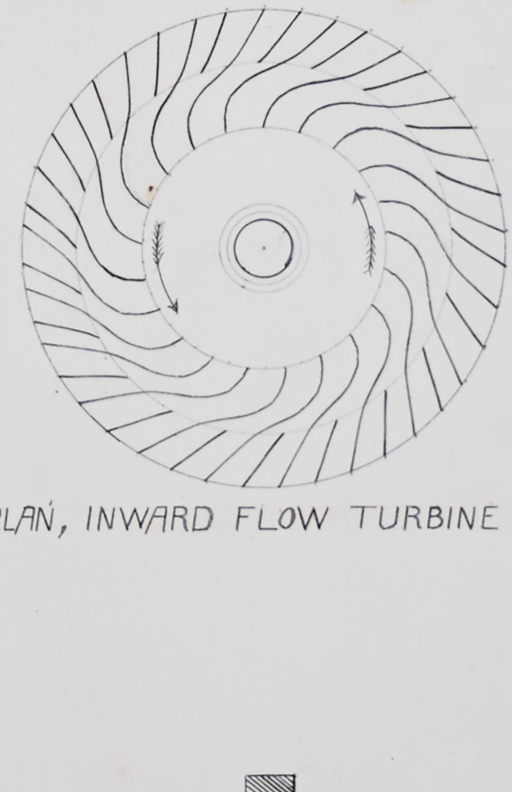


Fig. 3





PLAN, OUTWARD FLOW TURBINE



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