Thesis

Efficiency Test of a 33" McCormick L. H. Holyoke Turbine made at the Holyoke Testing Flume

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Contents

Efficiency Test of a 33" "McCormick" Holyoke Turbine.

Introduction.

Previous to 1870 the power furnished was divided about equally between steam and water, and although according to the last census the steam has increased more rapidly than water power, nevertheless the amount of water power used is increasing steadily and will probably continue to do so, until the enormous amount of water power available throughout the U. S. is exhausted.

Throughout New England the water power is utilized to a great extent, but in the South and

West the people are just beginning to appreciate the tremendous energies offered them by nature.

The Merrimac River supplies 10,000 horse power at Manchester N.H. and about the same amount at Lowell. Holyoke is furnished with about 18,000 horse power, with a fall of nearly 60 ft, while the numerous rivers of Maine are being utilized more and more every year now that power is transmitted by electricity.

Probably the greatest step in this line at present, is the large plant under construction at Niagara, which is designed to develope 120,000 H.P.

We often hear steam enthusiasts speak of water power, as impracticable because, as they say, "It is irregular in its action throughout the year". But this defect can be, and is, to a great extent obviated by the well organized system of storage reservoirs employed throughout New England and the Pacific Slope.

The system employed by the Gardiner Water Power Co. of Maine is a good example of the manner in which the flow of a stream can be kept nearly constant throughout the year.

Under the superintendence of Mr. Hiram F. Mills of Lowell, the outlet of a large pond, at the head of the stream, was checked by means of a stone dam, with sluice gates, so that the supply from that quarter could be regulated according to the needs of the stream. Tables were then constructed which indicate the amount of gate opening at upper mill dam consistent with the gauge readings at storage reservoir and that at upper mill pond. These tables were calculated from the following estimates made by Hiram F. Mills, of the total capacity of that stream. When the gauge at the storage reservoir reads–

(7 ft or more) the cap. of stream is 300 cu. ft. per. sec.
6–7 " " " " " 290 " " " "
5–6 " " " " " 285 " " " "
4–5 " " " " " 280 " " " "

Now suppose the daily record sent down from the reservoir dam is 7 ft, this we see from our tables insures us a flow of 300 cu. ft. per sec. and if the gauge in the mill pond reads 136.4, we can interpolate from tables and find the height to which the gate must be set for the day to insure a constant quantity of water to mills below. The following shows a tabulated form of daily records kept by the engineer in charge

Daily Record.

Date		Res. Gauge	Pond Gauge	Height of Gates	Water Deliv'ed	Height of Flashbds	Water deliver Flashbds	Total Water Deliv'ed
Jun 16	7AM.	7.0	136.4	1.86	300	136	40	340
17	7AM.	7.1	136.5	1.85	300	136	40	340
Etc				Etc			Etc.	

Note:- These records happened to be taken just after a severe rain storm which compelled a loss of 40 cu. ft. per. sec. as 136 ft. was the legal limit to height of flash boards.

By method explained above the supply to mills on this stream seldom if ever falls below 290 cu. ft. per. sec.

Without going into an historical sketch of water wheels it is sufficient to state, that the wheels commonly used in the U. S. today, are almost universally of the class known as turbines, wheels in which the water enters the guide ports from the head race or turbine case, and flows along the curved guide-blades and is by them directed into a wheel, with its proper velocity and direction. A very large portion are of the type which may be designated as the "inward and downward flow."

All the large streams are controlled by corporations which have full charge of the water power, this they rent to the mill owners by the mill-power, which is a quantity of slightly variable amount, it being at Holyoke 38 cu. ft. per. sec. under a head of twenty ft. The large amount of competition in the wheel construction has been a great incentive to systematic wheel testing which is carried on at present on a large scale at the Holyoke testing flume. Moreover if the wheel used by the mill has been previously tested for the quantity of water used at the various openings of gate, it can be used by the company as a water meter, since the engineer has only to read the gauge on the gate of each wheel at regular intervals and with this to ascertain from diagrams of discharges of that wheel, (explained later) the amount of water the wheel is taking and to determine what is due the company for the operation of that wheel at that time; in fact, this is the method employed by the Holyoke Water Power Co. to measure the amount of water used by the mill owners, since all the wheels there have been previously tested in the Holyoke testing flume.

Lowell is unable to do this to a great extent, as many of the wheels of the Lowell mills have never been tested.

The Flume and Apparatus.

Many tests had been made on wheels previous to the construction of Holyoke testing flume, but with varying results so that it became necessary to have a standard testing flume.

In 1882 Mr. Clemens Herschel, aided by James B. Francis, reconstructed the old testing flume at Holyoke, and furnished it with all the modern apparatus for the exact measuring of power developed by the wheel and the amount of water passing the weir. This flume is capable of testing wheels of any of the usual diameters under a head of 17 ft. The measuring weir having a capacity of 200 cu. ft. per. sec.

The methods of conducting a test and the apparatus employed are essentially the same as those used by Mr. James B. Francis in his Lowell hydraulic experiments.

The water is ~~generally~~ conducted from the main canal into a flume (its flow being regulated by gates) and from thence it enters a large water tight wheel pit at the bottom of which the wheel to be tested is placed. At the raising of the gates the water passes through the guides into the wheel and down into the tail race below, at the end of which the quantity of water used is measured over a weir by means of a hook gauge. The power generated by the passing of the water through the wheel is measured by means of a dynamometer, which is mounted upon the head of its shaft.

The accompanying circular and plan give an accurate description of the testing flume itself, so I shall only compare the main points of this flume with those of that used by Mr. James B. Francis in his Lowell experiments.

It will be noticed from the plan of the flume that the wheel pit D is placed at a distance of about 38 ft. from the weir C, and that two gratings are used to quiet the surface of the water in the tail race E. Moreover the gauge

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TESTING FLUME

OF THE

HOLYOKE WATER POWER CO.,

AT

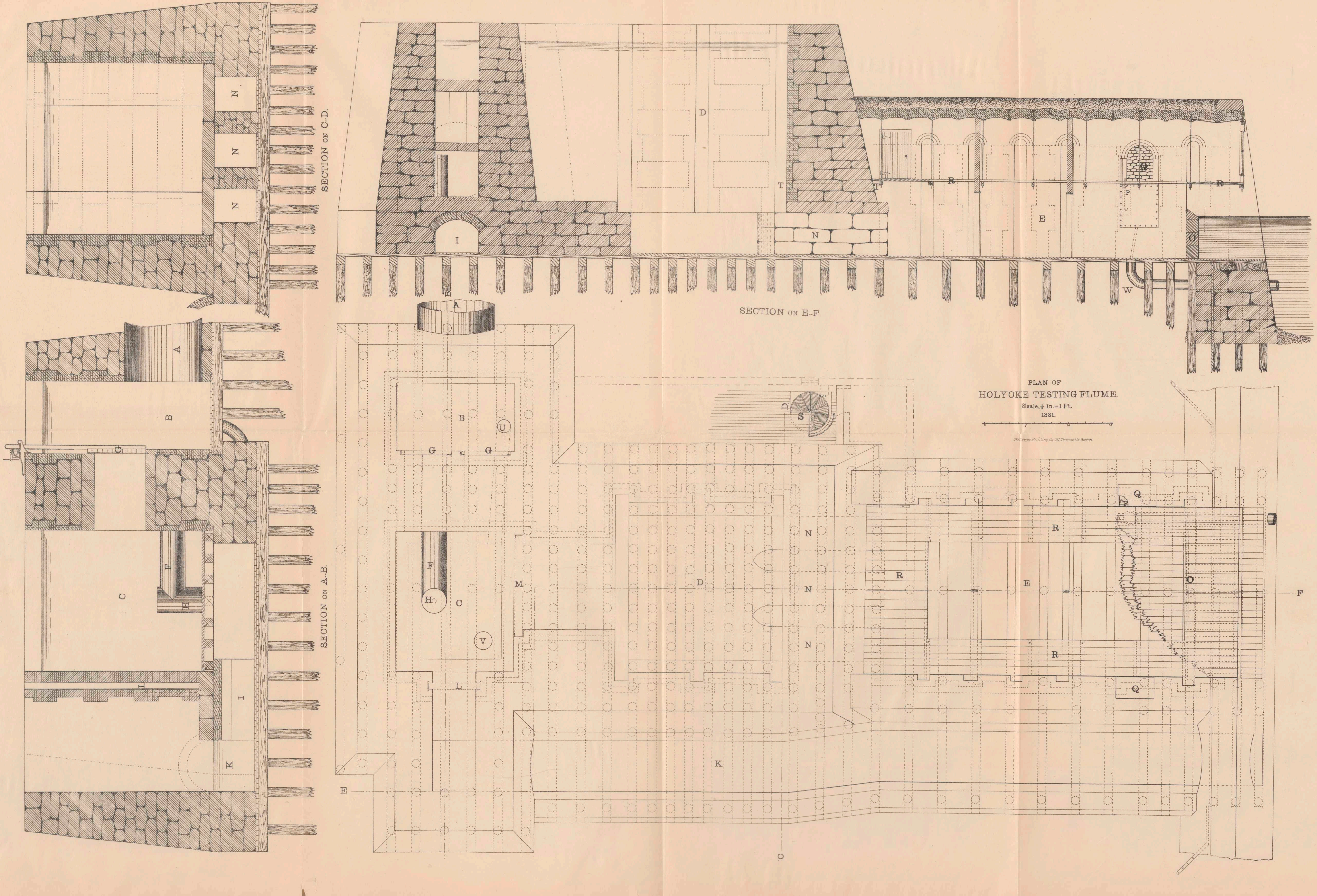
HOLYOKE, MASS., U. S. A.

SECOND EDITION.

the discharge is one-half that at full opening, and at 5 or 6 different velocities of revolution at each gate-opening, making some 30 odd experiments in all on each wheel. The final result is, that for all practical purposes the water-wheel has been converted into a water meter, and its discharge may be known under any of the conditions under which it is found in the mill. Besides this, its efficiency, or the value of the wheel as a water-motor, is also known.

Being fitted to make these tests at any time, summer and winter, and with many tests to make, the expense of a single test when made by the Holyoke Water Power Co., need be but moderate. In former years such tests could be made only in the mills where the wheel happened to be set, and at great expense for preparation, all of which preparation was available for that one wheel only. In this way the cost of a wheel test might readily amount to $2,500, where the Holyoke Water Power Co., would now undertake to do it for $100 or $150. And this has gradually led to the making of a great many wheel tests each year for outside parties, sending wheels from all parts of the U. S. Tests for the public are made subject to the requirements of the circular, given in the Appendix. As will be seen from the description of the testing-flume, it is suitable, moreover, to the making of hydraulic experiments, other than the efficiency test of wheels, and will no doubt be used for such, from time to time.

The under-ground portion of the testing-flume consists in the main of the trunk or penstock, A, bringing the water; a sort of vestibule, B; an ante-chamber, C; the wheel-pit, D; and tail-race, E. The trunk A is, of boiler iron, about 9 feet in diameter, laid low down in the ground, so as to pass longitudinally under the centre of a street, and thus take up no land suitable for building purposes. The object of the vestibule B is simply to afford opportunity for the application of the two head-gates, G G. Besides these, there is a head-gate at the point of entry of the trunk A into the canal whence it takes the water. A small trunk, F, about 3 feet in diameter, takes water from this vestibule, independently of the gates G, and leads it to a turbine wheel, H, set in an iron casing, in the chamber or pit, C, so that this wheel can run, even when C is empty. This wheel discharges through the floor at the bottom of C, thence through the arch I and the supplementary tail-race K, into the second level canal. It is used to operate the repair shops; also to lift and lower the gates G. The chamber C is bounded on one side by a tier of stop-plank L, and on another side, by a tier of stop-plank M. The object of the stop-planks L is to afford a waste-way out of the chamber C. This is of especial use in regulating the height of the water when testing under low heads; also to skim off the oil floating on the water, which has dropped down from the dynamometer. The water thus wasted


SECTION ON C-D
SECTION ON E-F
SECTION ON A-B
PLAN OF
HOLYOKE TESTING FLUME.
Scale, ¼ In. = 1 Ft.
1881.

over the planks L, falls directly into the tail-race K and passes into the second level. The stop-planks M come into use when testing scroll, or cased wheels. In that event, D is empty of water and the wheel case in question is attached to the planks M, over a proper opening cut through the same. Large case-wheels could be set in the centre of D, and the water be led to them by a short trunk or penstock, leading from an opening cut in the planks M. Flume wheels are set in the centre of the floor of D, and D is filled with water. They discharge through the floor of D, (not shown on the drawing) and out of the three culverts N N N into the tail-race E. At the down-stream end of this tail-race is the measuring weir, O, the crest being formed of a piece of planed wrought iron. It can be used with or without end contractions. The depth of water on the weir, is measured in a quarter-cylinder P, set in a recess, Q, fashioned into the sides of the tail-race. These recesses are water-tight, and the observer is thus enabled to stand with the water-level about breast-high, or at convenient height for accurate observation. The methods of measuring water over this weir, are those described in Lowell Hydraulic Experiments, by James B. Francis. In this work are detailed at great length all the experiments made to establish a formula, which should express the relations between the quantity of water discharged per second, the length of a weir, and the depth of water upon that weir. The experiments consisted of letting large volumes of water run over weirs of various sizes and forms, a given length of time, and of catching the water thus allowed to flow over, in a measuring tank. In this country these experiments are well known, and the formula which was derived from them has met with general acceptance. To those who are not familiar with the book and who wish to learn the authority for this method of measuring water, its study is strongly recommended. A platform R surrounds the tail-race, and is suspended from the iron beams that roof it in. Above the tail-race is a street. The wheels to be tested arrive on this street, are lifted from the wagon by a travelling windlass that runs out on a frame-work over the street, are run into the building and lowered into the wheel-pit D. Winding stairs lead into a passage way that leads in turn to the platform R. In the well hole of these stairs is set up the glass tube which measures the head of water upon the wheel. It is connected with the pit D or the chamber C, by means of pipes running through a cast-iron pipe T, built into the masonry dam which forms the down-stream end of the wheel-pit D. The power is weighed by a Prony brake, consisting of a cast-iron pulley, surrounded by a hollow brass band, through which a stream of water is allowed to circulate, and a bent lever and weights, to hold the band and pulley in place. Five sizes of pulley and band are used, to weigh different sizes of wheels. The limits of power weighed have been from 1 1-4 to 230 H. P. Heads have varied from 4 to 19 feet. To enable the observer at the brake wheel, the one at the head gauge, and the one at the measuring weir to take simultaneous observations at intervals of one minute, an electric clock is set up in the testing flume, which rings three bells simultaneously at intervals of one minute, or of half a minute if desired.

The whole structure is built in a durable and efficient manner. The pits and tail-race are all lined with brick laid in cement. The stone masonry was intended by careful work and grouting to be water-tight without the brick lining, and the brick lining was then carefully laid up with joints full of mortar as an extra precaution. As a consequence, the front of the wall forming the down-stream side of the pit D, is barely damp with 20 feet head of water upon it, The floor of the pit D is built so tight, that an exact measurement of the leakage of the wheel-gate could be made, if desired. An approximate estimate is readily made by filling the pit before the tail-race is allowed to fill up, and apportioning the total measured leakage, between the leakage of the wheel gate, and that of the flume.

U V W show three waste-pipes, from the vestibule, ante-chamber, and tail-race respectively. Another not shown serves to draw the water out of and through the floor of the pit D. To close or open these waste-pipes they are fitted with the cases of small water-wheels, which thus form convenient valves for the purpose indicated. The waste-pipe V, serves also to help regulate the height of water in the ante-chamber C and pit D, during tests under low heads.

The pipe W leads into a sewer on the other side of the second level canal and thence into the river. It enables the tail-race to be emptied of water down to within some ten inches of the bottom planking.

Up to date the Holyoke Water Power Co., has tested 185 wheels, of which about 125 were tested for the public, and the rest solely in its own interests. This represents some three years' work in the present flume, and in another, less perfect and of a temporary nature only, which preceded it.

Holyoke, Mass., U. S. A., July 18, 1883.

APPENDIX.

HOLYOKE, MASS., July 18, 1883.

TO MANUFACTURERS, WATER-WHEEL BUILDERS, AND LESSORS OF WATER POWER:

GENTLEMEN,—

We have completed our new Testing Flume, and furnished it with apparatus to test wheels of any of the usual diameters, (the pit is 20 feet square) and of any power up to 230 H. P.

The measuring weir has a capacity of 200 cubic feet per second.

Wheels can be tested under any head from 4 to 17, and in some cases, nearly 19 feet. Parties sending wheels should comply with the following directions:

The wheel should be sent ready to set.

For wheels of 25 H. P. or less, have distance from platform on which wheel rests, to top of shaft, 4 feet, 3 inches; have 4 inches of top of shaft 2 inches in diameter; with key seat 1-2 inch wide and 3-16 deep.

For wheels 25 to 75 H. P., platform to top of shaft, 5 feet, 6 in.; 5 inches of top of shaft 3 inches in diameter; key-seat, 9-16 x 3-16 inches.

For wheels 75 H. P., or over, platform to top of shaft, 7 feet; 6 inches of top of shaft 4 inches in diameter; key-seat, 1 in. x 3-8.

The price of test and of a full and carefully computed report, is 10 per cent., of list price of wheel, but no wheel for less than $30. The sender to pay freight and cartage. Scroll wheels, or wheels set in iron cases, may cost from $10.00 to $15.00, possibly more, in addition.

HOLYOKE WATER POWER CO.,

HOLYOKE, MASS.

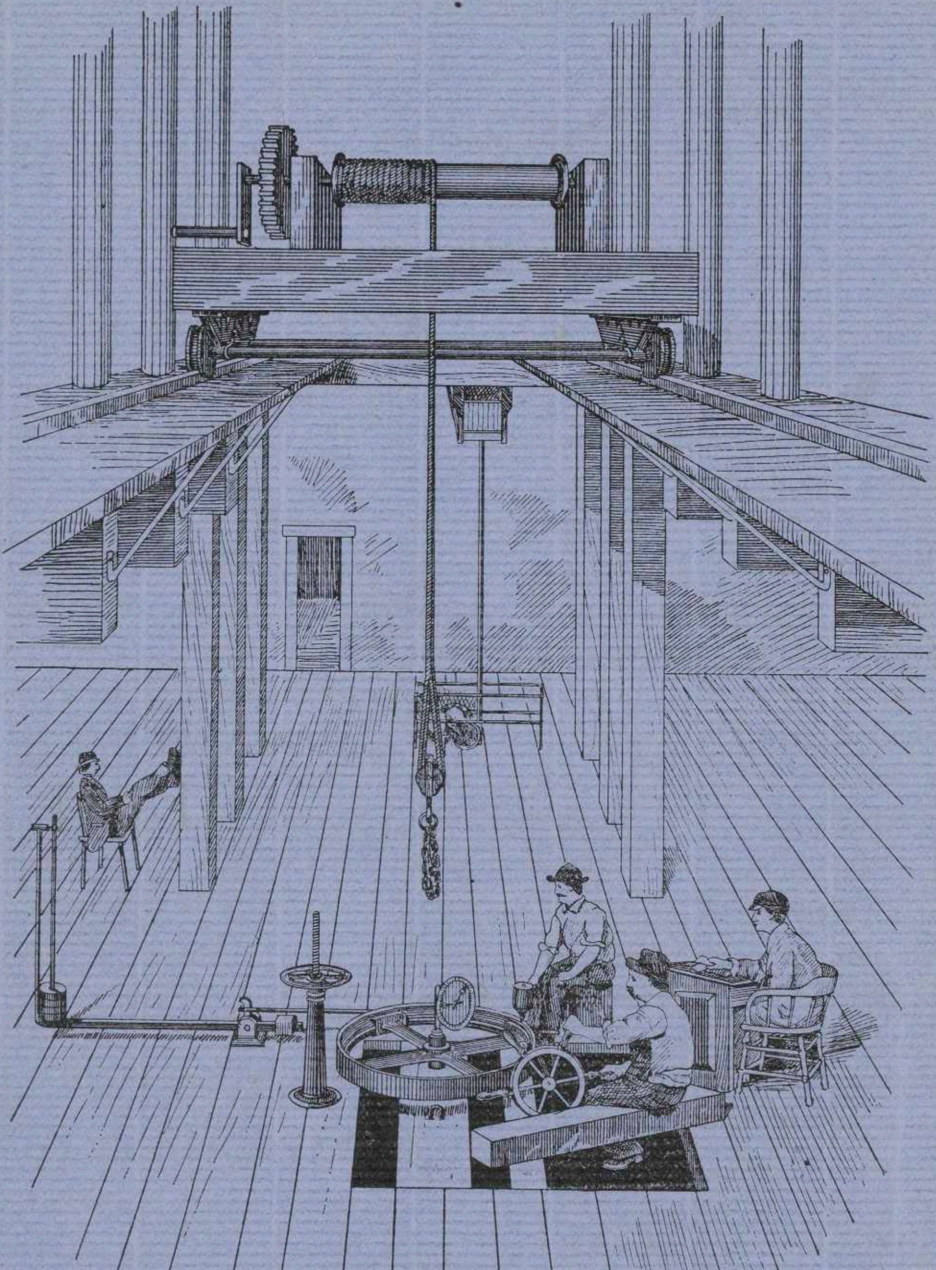
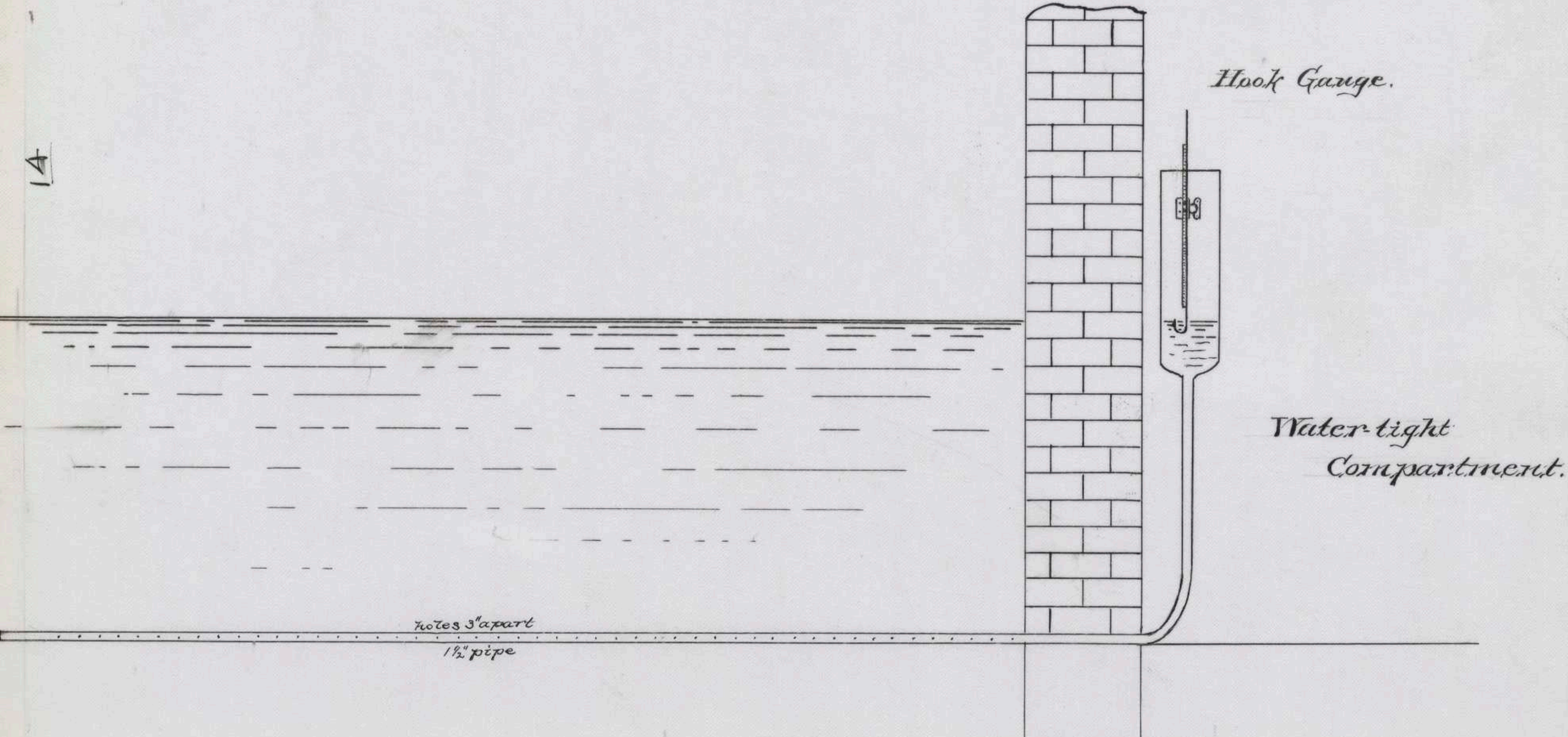
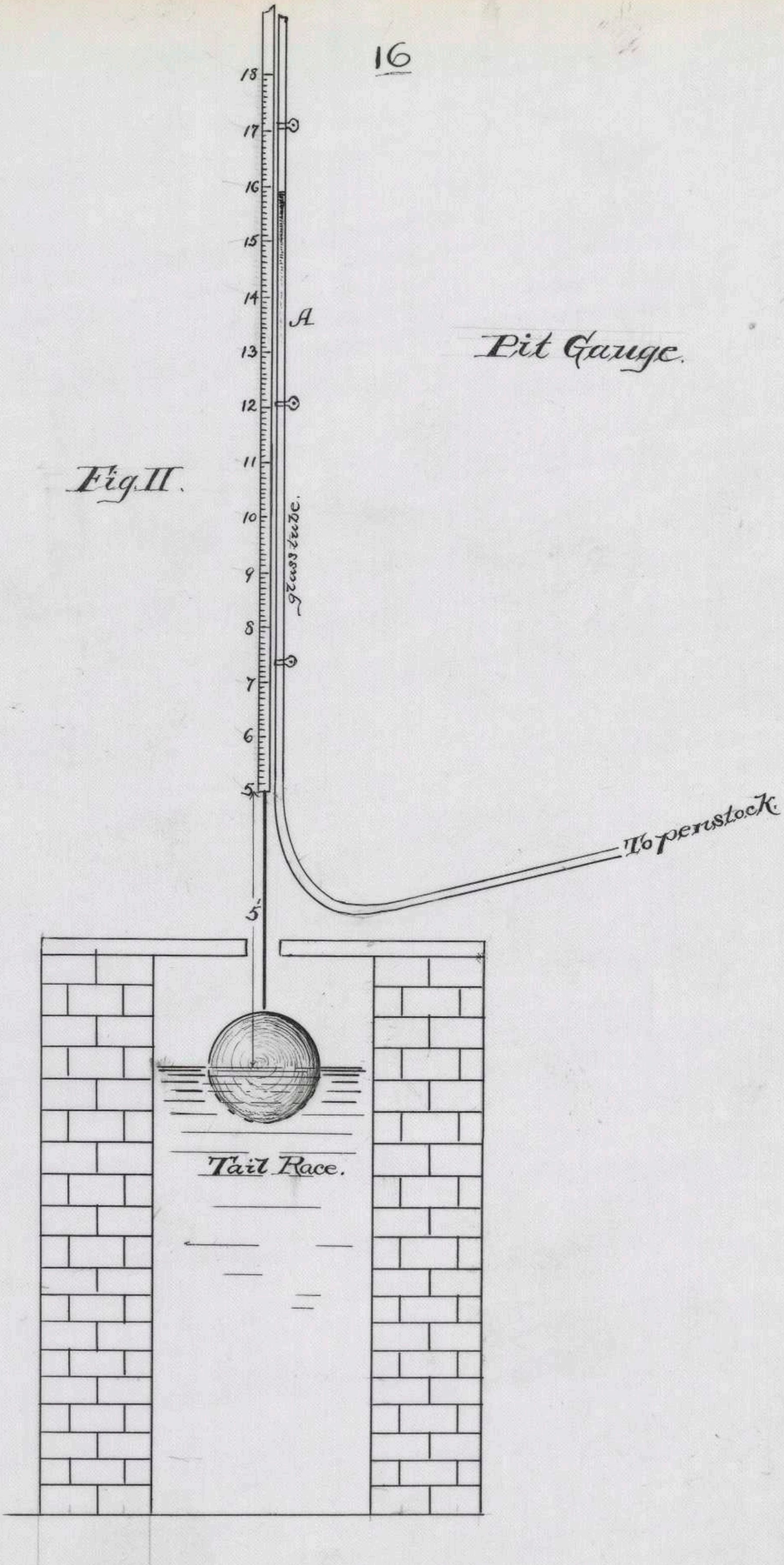


Fig I.



one grating was used, and in the place of the perforated tube, the hook gauge was surrounded with fine wire screens. Of course this would not give as accurate results as the tube since there is always a certain amount of backing up of the water on a screen

The hook gauge is of inestimable value in hydraulic experiments; - "If the point of the hook is a very little above the surface, the water in the immediate vicinity of the hook is by capillary attraction elevated with it, causing a distortion in the reflection of the light from the surface of the water." With this instrument by special arrangement for light, differences of .0001 ft. can be easily



Pit Gauge.

Fig. II.

appreciated.

The head acting on the wheel is measured by means of an apparatus called a "pit gauge", shown in Fig II, which is stationed in the stair way at S. on plan. From this it will be seen that the float with rod attached, serves as an automatic "hook gauge." The float being so constructed, that the distance from top of water in tail race to bottom of graduated stick is just 5 ft. A flexible rubber tube leads from the penstock to the lower end of the vertical glass tube A, which is fastened to the wall, and serves as a gauge, giving the height of the water-level in the penstock. As the graduated rod on the float has full play, the exact head on the gate, (or difference of level of tail race and penstock) can be obtained.

Method of Testing

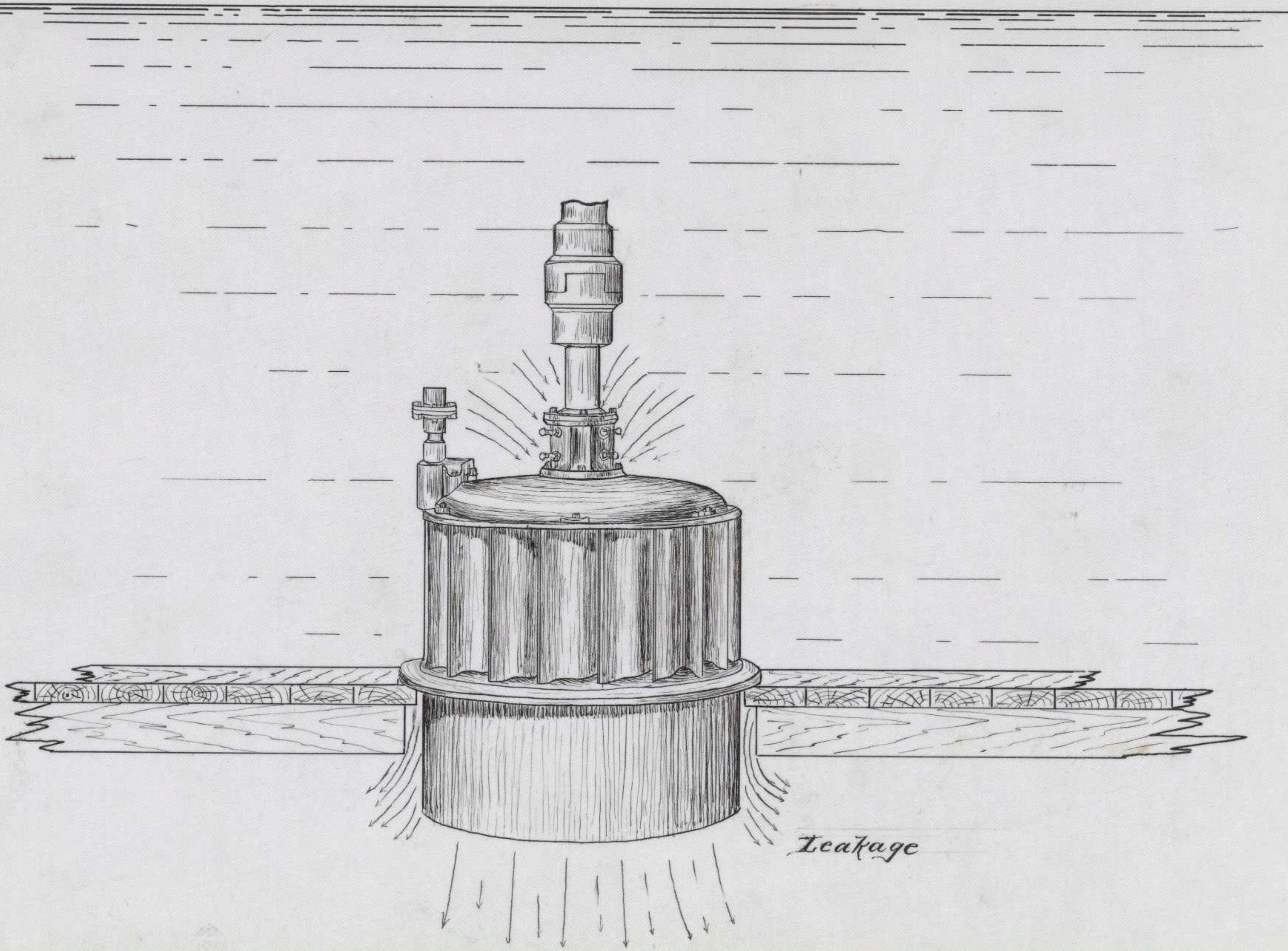
The test is conducted by four men. The engineer in charge, assisted by a man at the brake governs the dinamometer by adjusting the weights and at the same time he takes observation of the speed at one minute intervals given by the stroke of an electric bell.
The last page of the blue circular gives a good illustration of a dynamometer in place, showing the dial on end of shaft, which gives number of revolutions.
The only difference between the "Cut" and practice is, that since two men do this work instead of four-(as "Cut") there

is no chance for either one of them to have his feet up on a post.

The readings of the hook-gauge ~~and~~ at weir, and the float gauge at stairway are taken by the other two assistants; the stroke of the bell occurring at the same instant at every post of observation, so that all the readings are taken simultaneously.

Before opening the gate of the wheel to begin testing, the water is allowed to fill the wheel pit D, and the total amount of leakage of the flume and wheel gate is obtained by readings of hook gauge at weir. The engineer then goes in under the platform upon which the wheel rests, and estimates

Fig III.



what portion of the total leakage is the leakage of the platform; since the leak of flume has to be considered in computation, whereas the leak through the gate is a defect in the construction of wheel, and should not be deducted from the total quantity passing the wheel when gate is open. Fig. III shows where the leakage is apt to take place. This wheel in Cut ~~being~~ is closed by movable guides.

Let Q = total discharge over weir when the gate is open –

Q' = water passing through blades of wheel when gate is open.

L' = leakage of platform

L = leakage of wheel (defect)

$$Q = Q' + L' + L''$$

$$Q' + L'' = Q - L'$$

Or in words the leakage of the flume has to be deducted from the total Q in order to obtain the amount passing through the wheel.

After the amount of leakage of the flume is determined the dynamometer is clamped fast and a small load is applied to the scale pan. The wheel gate is then raised about one fourth of its full capacity, and the brake readjusted, until it exactly balances the load on scale pan. With this combination five or six readings of the dial of dynamometer are taken, of a minute each, and the average of the three best ones goes into the final record. The weight is then increased about four lbs, and a second set of readings is taken. The experiment is generally continued without change of weight until the observer at the weir signals to the engineer at dynamometer, by means of an electric bell, that the readings of the hook gauge at weir are uniform. This is especially necessary when the gate opening is increased, as an extra volume of water makes the surface unsteady and therefore an extra number of readings has to be taken. This process is continued with an increase of from four to five lbs. wt. each time, and at the various gate openings. The weights used in the adjustments of the dynamometer are always examined and certified by the official "Scaler of weights and measures".

The minute records taken at the flume, are examined, and an average of the most reliable ones are transferred from note books to the engineers records, at the office of the chief engineers, and the data worked up and results placed on permanant record.

The Wheel

The test witnessed by me at the flume in January 1891 was on a 33" Mc. Cormick R. H. Holyoke turbine. The flow of the water through this wheel was a combination of "inward downward and outward," so that, as the maker said, the water was "completely tired out," when it left the wheel.

Fig. I with table I page 27 shows the detail measurements of one of the bucket orifice. This sketch Fig. I is not intended to represent the shape of the orifice but to show the manner of taking measurements. The distance ab is laid off in equidistant stations and the shortest distance measured by calipers

Table II.

20 Guides.		
No.	Width.	
	b Bot	a Top
17	0.198	0.202
18	.201	.203
19	.199	.200
20	.200	.201
1	.200	.202
2	.195	.202
3	.200	.200
4	.198	.200
5	.197	.197
6	.198	.200

Lift of gate 1.203 ft. = c

Table I.

16 Buckets.	
Sta.	Width.
a	0.060
0.2	.068
0.4	.078
0.6	.082
0.8	.095
1.0	.111
1.2	.140
1.4	.172
1.6	.209
1.8	.230
2.0	.242
2.2	.203
2.4	.115
b	.091

Fig. I

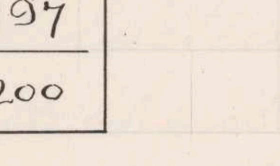
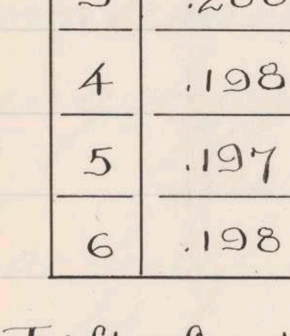


Fig. II



Length (ab) = 2.44 ft.

" (cd) = 2.06 ft.

" (de) = 0.10 ft.

from each of those stations to the back of the adjacent bucket. Table II (with Fig II) gives the measurements of a few of the guide openings, so that one may obtain the area of smallest cross section of guide opening. (explained later)

The gate employed on this wheel was of the "lift" type and was raised to the desired opening by means of a hand wheel.

The test lasted a day and a half and the direct results obtained were placed in columns 1, 2, 3, 4, 7, 8, 14, of Plate IV (next page).
(See back of sheet for extra data.)

HOLYOKE TESTING FLUME.

33" L.H. McCormick's Holyoke Turbine Wheel

Tested Jan 29-30 1891

1. Number of Experiment.	2. Proportional Gate Opening.	3. Head on Wheel.	4. Depth on Weir.	5. Quantity of Water passing the Weir. c. f. p. s.	6. Quantity of Water passing the Wheel. c. f. p. s.	7. Weight on Dynamometer Lever. lbs.	8. Revolutions of Wheel per Minute.	9. H. P. developed by Wheel under actual head.	10. Efficiency of Wheel. %	11. Quantity of Water discharged by Wheel, reduced to head of 18 feet.	12. Ratio of Discharge of Wheel, to full gate discharge at max. eff.	13. Ratio of V. P. W. to V. D. H.	14. Duration of Experiment.
40	1.000	11.27	1.516	73.13	72.98	107	112.75	73.39	78.6	92.23	1.012	0.603	4
39	"	11.30	1.514	72.98	72.83	104	116.75	73.87	79.1	91.92	1.009	0.624	3
38	"	11.32	1.511	72.76	72.61	101	121.00	74.35	79.7	91.56	1.005	0.646	4
37	"	11.36	1.509	72.61	72.46	97	126.00	74.35	79.6	91.21	1.001	0.671	5
36	"	11.40	1.501	72.02	71.87	92	132.20	73.99	79.6	90.31	0.991	0.703	5
35	"	11.45	1.492	71.39	71.24	85	140.00	72.39	78.2	89.32	0.981	0.743	3
34	0.783	11.48	1.408	65.51	65.36	98	115.00	68.56	80.5	81.84	0.898	0.609	4
33	"	11.51	1.406	65.40	65.25	95	120.00	69.35	81.4	81.60	0.896	0.635	5
32	"	11.55	1.401	65.06	64.91	92	124.00	69.40	81.6	81.03	0.890	0.655	4
31	"	11.55	1.395	64.62	64.47	87	130.00	68.80	81.4	80.48	0.884	0.687	4
30	"	11.61	1.389	64.10	63.95	82	136.00	67.84	80.5	79.63	0.874	0.716	4
29	"	11.66	1.377	63.43	63.27	75	144.25	65.82	78.6	78.61	0.863	0.758	4
27	0.634	11.59	1.287	57.33	57.18	85	115.00	59.47	79.1	71.26	0.782	0.606	4
26	"	11.64	1.281	56.93	56.78	81	121.00	59.62	79.5	70.61	0.775	0.637	4
25	"	11.67	1.274	56.46	56.31	76	127.75	59.07	79.2	69.93	0.768	0.671	4
24	"	11.73	1.262	55.67	55.52	70	135.00	59.49	77.8	68.78	0.755	0.708	4
28	"	11.79	1.249	54.81	54.66	64	142.00	55.29	75.6	67.54	0.741	0.742	4
22	0.493	13.21	1.180	50.39	50.24	77	120.50	56.45	74.9	58.65	0.644	0.595	4
21	"	13.21	1.177	50.26	50.11	73	127.50	56.62	75.4	58.49	0.642	0.620	4
20	"	13.23	1.168	49.63	49.48	69	132.50	55.62	74.8	57.71	0.634	0.654	4
19	"	13.25	1.160	49.14	48.99	65	138.00	54.57	74.1	57.10	0.627	0.681	3
18	"	13.28	1.154	48.76	48.61	61	143.00	53.07	72.4	56.59	0.621	0.704	4
17	"	13.33	1.147	48.31	48.16	56	150.00	51.10	70.1	55.96	0.614	0.738	3
16	0.377	12.55	1.012	40.10	39.95	60	105.25	38.42	67.5	47.85	0.525	0.533	4
15	"	12.54	1.009	39.90	39.75	57	112.00	38.84	66.7	47.62	0.523	0.568	3
14	"	12.54	1.003	39.55	39.40	54	118.00	38.76	69.1	47.20	0.518	0.598	4
13	"	12.55	1.000	39.40	39.25	51	122.00	37.85	67.7	47.01	0.516	0.618	4
12	"	12.57	0.991	38.85	38.70	47	128.00	36.60	66.3	46.31	0.508	0.648	4
11	"	12.60	0.986	38.57	38.42	44	133.75	35.80	65.2	45.92	0.504	0.676	4
10	"	12.63	0.978	38.09	37.94	40	139.75	34.01	62.5	45.29	0.497	0.706	4
9	"	12.68	0.969	37.59	37.44	35	148.25	31.57	58.6	44.61	0.490	0.747	4
8	"	12.72	0.960	37.07	36.92	30	155.33	28.35	53.2	43.92	0.482	0.782	3

For continuation see inside

During the above experiments, the weight of the dynamometer, and of that portion of the shaft which was above the lowest coupling was lbs.

With the flume empty, a strain of lbs., applied at a distance of ft. from the center of the shaft, sufficed to start the wheel.

7	0.241	12.69	0.791	27.78	27.63	36	105.00	23.00	57.8	32.91	0.361	0.529	4
6	"	12.71	0.785	27.45	27.30	32	114.75	22.34	56.7	32.49	0.357	0.578	4
5	"	12.73	0.779	27.12	26.97	28	124.00	21.12	54.2	32.07	0.352	0.624	3
4	"	12.76	0.772	26.77	26.62	24	1.32.00	19.28	50.0	31.62	0.347	0.663	4
3	"	12.78	0.768	26.54	26.39	21	1.38.00	17.63	46.1	31.32	0.344	0.693	3
2	"	12.80	0.763	26.29	26.14	18	145.25	15.91	41.9	31.00	0.340	0.729	4
1	"	12.82	0.758	26.05	25.90	15	151.50	13.82	36.7	30.69	0.337	0.760	3

LEAKAGE.

NUMBER.	TIME TAKEN.	HEAD.	DEPTH ON WEIR.	QUANTITY PASSING WEIR. C. F. P. S.	Q REDUCED TO HEAD OF FEET.	ESTIMATE OF GATE LEAK.	LEAK OF FLUME.	REMARKS.
							0.15 c.f.p.s. for all expers.	

Length of Weir, 12.00 ft. 2 end contractions Channel of approach 20 ft wide 5.85 deep below weir crest.

Temperature of Water, 32° F

No 2 Lever ; ratio of arms, 10.024

No...... Dynamometer, diameter 6.375 ft.

Guide area, 4.804 sq. ft.

Bucket area, 5.270 sq. ft.

Unit Q. 91.10 c. f. p. s., under head of 18 ft.

Co-efficient of guide discharge, 0.5678 under head of 18 ft.

Co-efficient of bucket discharge, 0.5176 " " " "

Measurements of wheel, see...

NOTES OF TEST.

Revolutions...

Hook Gauge...

Head Gauge...

For computation, see comp. book No. pp
No. pp

The Computation

The method of computation of this test as employed at Holyoke is as follows:- The quantity of water passing over the weir for each experiment is taken from the red curve in Plate I which (is as explained in note) corrected for velocity of approach. It will be noticed from the two curves given on Plate I that the increase in Q due to velocity of approach is very slight at the beginning of the test, where the gate opening is small, and as a result the height on crest of weir is small also; but as the height on weir increases the correction for velocity of approach also

Plate I

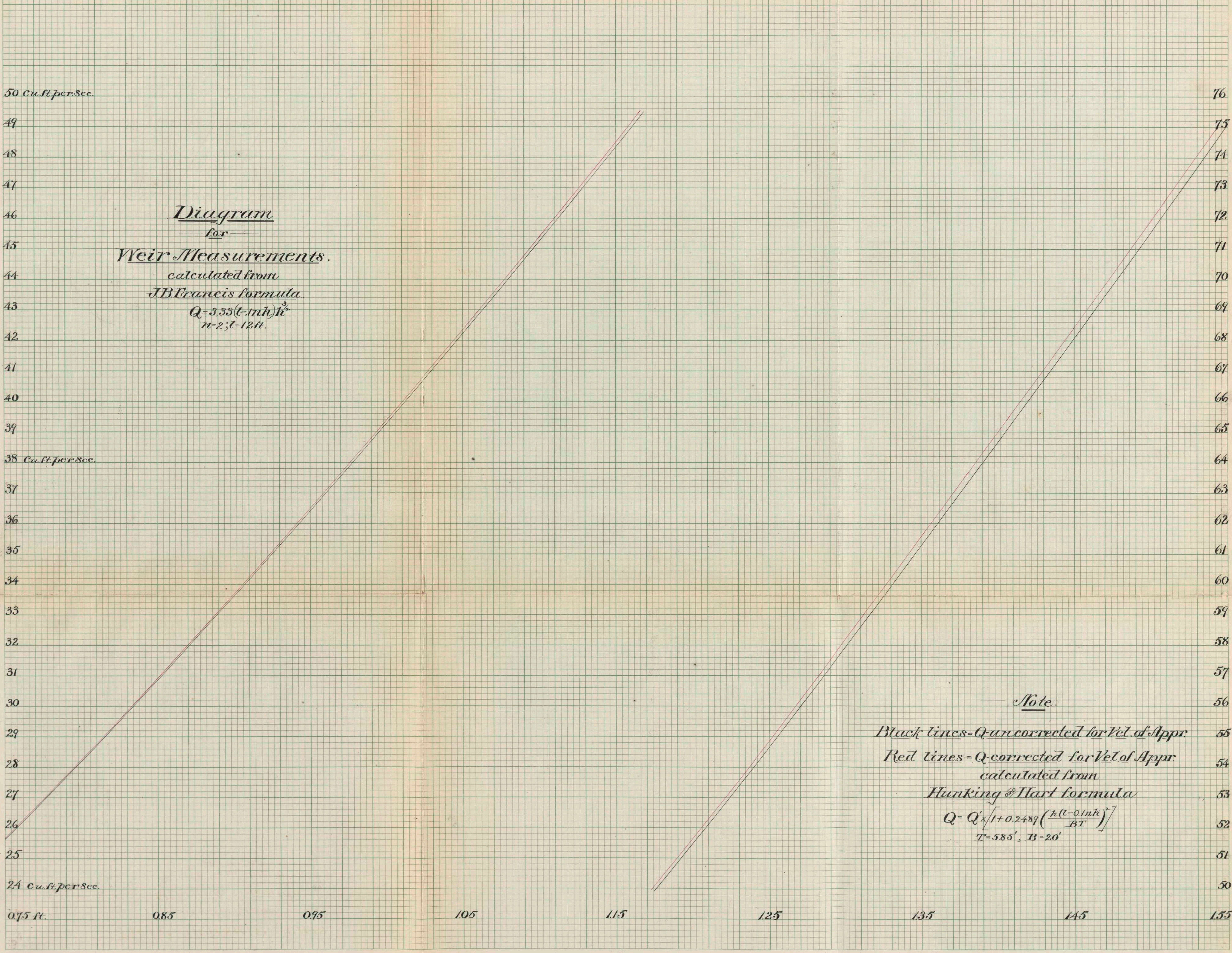


Diagram
for
Weir Measurements.
calculated from
J.B.Francis formula.
Q=3.33(l-.1nh)h^3/2
n=2; l=12 ft.
Note.
Black lines=Q-uncorrected for Vel. of Appr.
Red lines=Q-corrected for Vel. of Appr.
calculated from
Hunking and Hart formula
Q=Q'x[1+0.2489(h(l-0.1nh)/BT)^2]
T=5.85'; B=20'
50 Cu.ft.per Sec.
49
48
47
46
45
44
43
42
41
40
39
38 Cu.ft.per Sec.
37
36
35
34
33
32
31
30
29
28
27
26
25
24 Cu.ft.per Sec.
76
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60
59
58
57
56
55
54
53
52
51
50
0.75 ft.
0.85
0.95
1.05
1.15
1.25
1.35
1.45
1.55

increases.

As we have already seen the leakage of the flume must be subtracted from this value of Q obtained from diagram. In this case the leakage of the flume was $\frac{1}{3}$ of total leakage and equal to .15 cu. ft. per. sec.. Therefore .15 is subtracted from each value of Q and the result placed in column 2. (See Plate II) opposite the respective number of experiments.

The horse power of wheel is calculated from the formula

$$HP = \frac{W \times R \times L \times C}{33.000}$$

Where W = wt. on lever in lbs

R = number of rev. per. min.

L = ratio of level arms.

C = circum. of brake.

Plate II

1	2	3	4	5	6	7	8	9	10	11
No. of exp.	Q Head.	Log. $\sqrt{\frac{18}{H}}$. Log. Q. Log. H.	Rev. Wt.	Log. rev. Log. wt.	Log. H.P. wheel. Log. H.P. water. Log. effic.	H.P. %.	Q'. Log. Q'.	Ratio of dis. Log. R of dis.	Log. v.p.w. Log. v.d.h.	Vel. ratio. Log. vel. ratio
40	72.98 11.27	.101674 1.863204 1.051924	112.75 107	2.052117 2.029384	1.865658 1.970061 9.895597	73.39 .7863	92.23 1.964878	1.012 0.005360	1.210449 1.430136	.6030 9.780313
39	72.83 11.30	.101097 1.862310 1.053078	116.75 104	2.067258 2.017033	1.868448 1.970321 9.898127	73.87 .7909	91.92 1.963407	1.009 0.003889	1.225590 1.430713	.6236 9.794877
38	72.61 11.32	.100713 1.860996 1.053846	121.00 101	2.082785 2.004321	1.871263 1.969775 9.901488	74.35 .7971	91.56 1.961709	1.005 0.002191	1.241117 1.431097	.6457 9.810020
37	72.46 11.36	.099947 1.860098 1.055378	126.00 97	2.100371 1.986772	1.871300 1.970409 9.900891	74.35 .7960	91.21 1.960045	1.001 0.000527	1.258703 1.431863	.6712 9.826840
36	71.87 11.40	.099184 1.856548 1.056905	132.20 92	2.121231 1.963788	1.869176 1.968386 9.900790	73.99 .7958	90.31 1.955732	0.991 9.996214	1.279563 1.432627	.7030 9.846936
35	71.24 11.45	.098234 1.852724 1.058805	140.00 85	2.146128 1.929419	1.859704 1.966462 9.893242	72.39 .7821	89.32 1.950958	0.981 9.991440	1.304460 1.433577	.7428 9.870883
34	65.36 11.48	.097665 1.815312 1.059942	115.00 98	2.060698 1.991226	1.836081 1.930187 9.905894	68.56 .8052	81.84 1.912977	0.898 9.953459	1.219030 1.434145	.6094 9.784885
33	65.25 11.51	.097098 1.814581 1.061075	120.00 95	2.079181 1.977724	1.841062 1.930589 9.910473	69.35 .8137	81.60 1.911679	0.896 9.952161	1.237513 1.434712	.6350 9.802801
32	64.91 11.55	.096345 1.812312 1.062582	124.00 92	2.093422 1.963788	1.841367 1.929827 9.911540	69.40 .8157	81.03 1.908657	0.890 9.949139	1.251754 1.435465	.6551 9.816289
31	64.47 11.55	.096345 1.809358 1.062582	130.00 87	2.113943 1.939519	1.837619 1.926873 9.910746	68.80 .8142	80.48 1.905703	0.884 9.946185	1.272275 1.435465	.6868 9.836810
30	63.95 11.61	.095220 1.805841 1.064832	136.00 82	2.133539 1.913814	1.837510 1.925606 9.905904	67.84 .8052	79.63 1.901061	0.874 9.941543	1.291871 1.436590	.7165 9.855281
29	63.27 11.66	.094286 1.801198 1.066699	144.25 75	2.159116 1.875061	1.818334 1.922830 9.895504	65.82 .7862	78.61 1.895484	0.863 9.935966	1.317448 1.437524	.7585 9.879924
27	57.18 11.59	.095594 1.757244 1.064083	115.00 85	2.060698 1.929419	1.774274 1.876260 9.898014	59.47 .7907	71.26 1.852838	0.782 9.893320	1.219030 1.436216	.6065 9.782814
26	56.78 11.64	.094659 1.754195 1.065953	121.00 81	2.082785 1.908485	1.775427 1.875081 9.900346	59.62 .7950	70.61 1.848854	0.775 9.889336	1.241117 1.437151	.6367 9.803966
25	56.31 11.67	.094100 1.750586 1.067071	127.75 76	2.106362 1.880814	1.771333 1.872590 9.898743	59.07 .7920	69.93 1.844686	0.768 9.885168	1.264694 1.437710	.6714 9.826984
24	55.52 11.73	.092987 1.744449 1.069298	135.00 70	2.130334 1.845098	1.759589 1.868680 9.890909	59.49 .7779	68.78 1.837436	0.755 9.877918	1.288666 1.438823	.7077 9.849843
28	54.66 11.79	.091879 1.737670 1.071514	142.00 64	2.152288 1.806180	1.742625 1.864117 9.878508	55.29 .7560	67.54 1.829549	0.741 9.870031	1.310620 1.439931	.7425 9.870689
22	50.24 13.21	.067184 1.701050 1.120903	120.50 77	2.080987 1.886491	1.751635 1.876886 9.874749	56.45 .7495	58.65 1.768234	0.644 9.808716	1.239319 1.464626	.5952 9.774693
21	50.11 13.21	.067184 1.699924 1.120903	127.50 73	2.105510 1.863323	1.752990 1.875760 9.877230	56.62 .7538	58.49 1.767108	0.642 9.807590	1.263842 1.464626	.6298 9.799216
20	49.48 13.23	.066856 1.694430 1.121560	132.50 69	2.122216 1.838849	1.745222 1.870923 9.874299	55.62 .7487	57.71 1.761286	0.634 9.801768	1.280548 1.464954	.6540 9.815594
19	48.99 13.25	.066528 1.690107 1.122216	138.00 65	2.139879 1.812913	1.736941 1.867256 9.869685	54.57 .7407	57.10 1.756635	0.627 9.797117	1.298211 1.465282	.6807 9.832929
18	48.61 13.28	.066037 1.686726 1.123198	143.00 61	2.155336 1.785330	1.724823 1.864857 9.859966	53.07 .7244	56.59 1.752763	0.621 9.793245	1.313668 1.465773	.7045 9.847895
17	48.16 13.33	.065221 1.682686 1.124830	150.00 56	2.176091 1.748188	1.708436 1.862449 9.845987	51.10 .7014	55.96 1.747907	0.614 9.788389	1.334423 1.466589	.7376 9.867834
16	39.95 12.55	.078314 1.601517 1.098644	105.25 60	2.022222 1.778151	1.584531 1.755094 9.829437	38.42 .6752	47.85 1.679831	0.525 9.720313	1.180554 1.453496	.5334 9.727058
15	39.75 12.54	.078487 1.599337 1.098298	112.00 57	2.049218 1.755875	1.589250 1.752568 9.836682	38.84 .6666	47.62 1.677824	0.523 9.718306	1.207550 1.453323	.5678 9.754227
14	39.40 12.54	.078487 1.595496 1.098298	118.00 54	2.071882 1.732394	1.588433 1.748727 9.839706	38.76 .6914	47.20 1.673983	0.518 9.714465	1.230214 1.453323	.5983 9.776891
13	39.25 12.55	.078314 1.593840 1.098644	122.00 51	2.086360 1.707570	1.578084 1.747414 9.830670	37.85 .6771	47.01 1.672154	0.516 9.712636	1.244692 1.453496	.6183 9.791196
12	38.70 12.57	.077968 1.587711 1.099335	128.00 47	2.107210 1.672098	1.563465 1.741979 9.821486	36.60 .6630	46.31 1.665679	0.508 9.706161	1.265542 1.453842	.6482 9.811700
11	38.42 12.60	.077450 1.584557 1.100371	133.75 44	2.126294 1.643453	1.553904 1.739861 9.814043	35.80 .6517	45.92 1.662007	0.504 9.702489	1.284626 1.454360	.6765 9.830266
10	37.94 12.63	.076934 1.579097 1.101403	139.75 40	2.145352 1.602060	1.531569 1.735433 9.796136	34.01 .6254	45.29 1.656031	0.497 9.696513	1.303684 1.454876	.7060 9.848808
9	37.44 12.68	.076076 1.573336 1.103119	148.25 35	2.170995 1.544068	1.499220 1.731388 9.767832	31.57 .5859	44.61 1.649412	0.490 9.689894	1.329327 1.455734	.7475 9.873593
8	36.92 12.72	.075392 1.567262 1.104487	155.33 30	2.191255 1.477121	1.452533 1.726682 9.725851	28.35 .5319	43.92 1.642654	0.482 9.683136	1.349587 1.456418	.7819 9.893169
7	27.63 12.69	.075905 1.441381 1.103462	105.00 36	2.021189 1.556303	1.361649 1.599776 9.761873	23.00 .5779	32.91 1.517286	0.361 9.557768	1.179521 1.455905	.5292 9.723616
6	27.30 12.71	.075563 1.436163 1.104146	114.75 32	2.059753 1.505150	1.349060 1.595245 9.753815	22.34 .5673	32.49 1.511726	0.357 9.552208	1.218085 1.456247	.5779 9.761838
5	26.97 12.73	.075222 1.430881 1.104828	124.00 28	2.093422 1.447158	1.324737 1.590642 9.734095	21.12 .5421	32.07 1.506103	0.352 9.546585	1.251754 1.456588	.6240 9.795166
4	26.62 12.76	.074710 1.425208 1.105851	132.00 24	2.120574 1.380211	1.284942 1.585992 9.698950	19.28 .5000	31.62 1.499918	0.347 9.540400	1.278906 1.457100	.6634 9.821806
3	26.39 12.78	.074370 1.421439 1.106531	138.00 21	2.139879 1.322219	1.246255 1.582903 9.663352	17.63 .4606	31.32 1.495809	0.344 9.536291	1.298211 1.457440	.6930 9.840771
2	26.14 12.80	.074031 1.417306 1.107210	145.25 18	2.162117 1.255273	1.201547 1.579449 9.622098	15.91 .4189	31.00 1.491337	0.340 9.531819	1.320449 1.457779	.7289 9.862670
1	25.90 12.82	.073692 1.413300 1.107888	151.50 15	2.180413 1.176091	1.140661 1.576121 9.564540	13.82 .3669	30.69 1.486992	0.337 9.527474	1.338745 1.458118	.7597 9.880627

In this test the diameter of the dynamometer is 6.375 ft. and the ratio of arms is 10.024.

Now W. and R. are variables, but the rest of the formula is a constant quantity and equal to

$$\frac{6.375 \times 3.1416 \times 10.024}{33.000}$$

The log of this quantity

(7.784157)

is written on a piece of paper and carried down column 5 adding it in. The sum of these three logs is placed at top of column 6.

To obtain the horse power of the water we have

$$HP = \frac{Q \times h \times 60 \times wt.}{33.000}$$

where Q = quantity passing wheel
h = head on wheel
wt = weight in lbs of 1 cu. ft. of H_2O at temperature of water at time of experiment.

1 cu. ft. of H_2O at 32° F. = 62.416 lbs.

Here again we have a constant quantity, as the water remained at about a constant temperature of 32° F,

$$\frac{60 \times 62.416}{33.000}$$

the log of which (9.054933) is written on piece of paper as before and added to log Q and log h in column 3, the sum being placed in column 6 (middle) (Plate II)

The efficiency of the wheel is of course the ratio of these two quantities, and we therefore subtract one log from the other in column 6. and we get the log of efficiency which is placed in the same column and the number corresponding in column 7.

As it is of great importance to the engineer to know the proportional part of the discharge at each gate setting of the wheel, the unit taken is the discharge for full gate, when giving best efficiency, and in order to obtain this, the discharge must be reduced to a uniform head.

Now the discharge under different heads varies as the square root of the heads.

Since $Q = A\sqrt{2gh}$ (A is constant)

$$Q : Q' = \sqrt{h} : \sqrt{h'}$$

$$\text{or } Q' = Q\sqrt{\frac{h'}{h}}$$

where h' is the standard head to which the discharges are to be reduced (say 18 ft)

Log $\sqrt{18}$ (0.627636) and from this we subtract $\frac{\log h}{2}$ for each experiment and place our results in column 3. This log is then added to log of Q and the sum placed in column 8 and the corresponding number is written in the same column.

Moreover on account of variation of head we cannot compare the revolutions of different experiments; but we can compare the ratios of velocity due to head to the velocity of a point in the periphery of the wheel. To obtain this ratio we know the velocity due to head = $\sqrt{2gh}$

We therefore take the log $\sqrt{2g}$

~~$\sqrt{2g}$~~ = (0.904174) and writing it on piece paper pass it down column 3 adding it to $\frac{\log h}{2}$ in each experiment. The sum is then placed in column 10 under log "$V\partial h$".

To get the velocity in ft. per. sec. of a point on the periphery of wheel we have $V = R\frac{c}{60}$

where R = rev. of wheel per. min.

C = cir. " "

Bucket in this wheel have vertical edges. and the diameter at edges is 33"

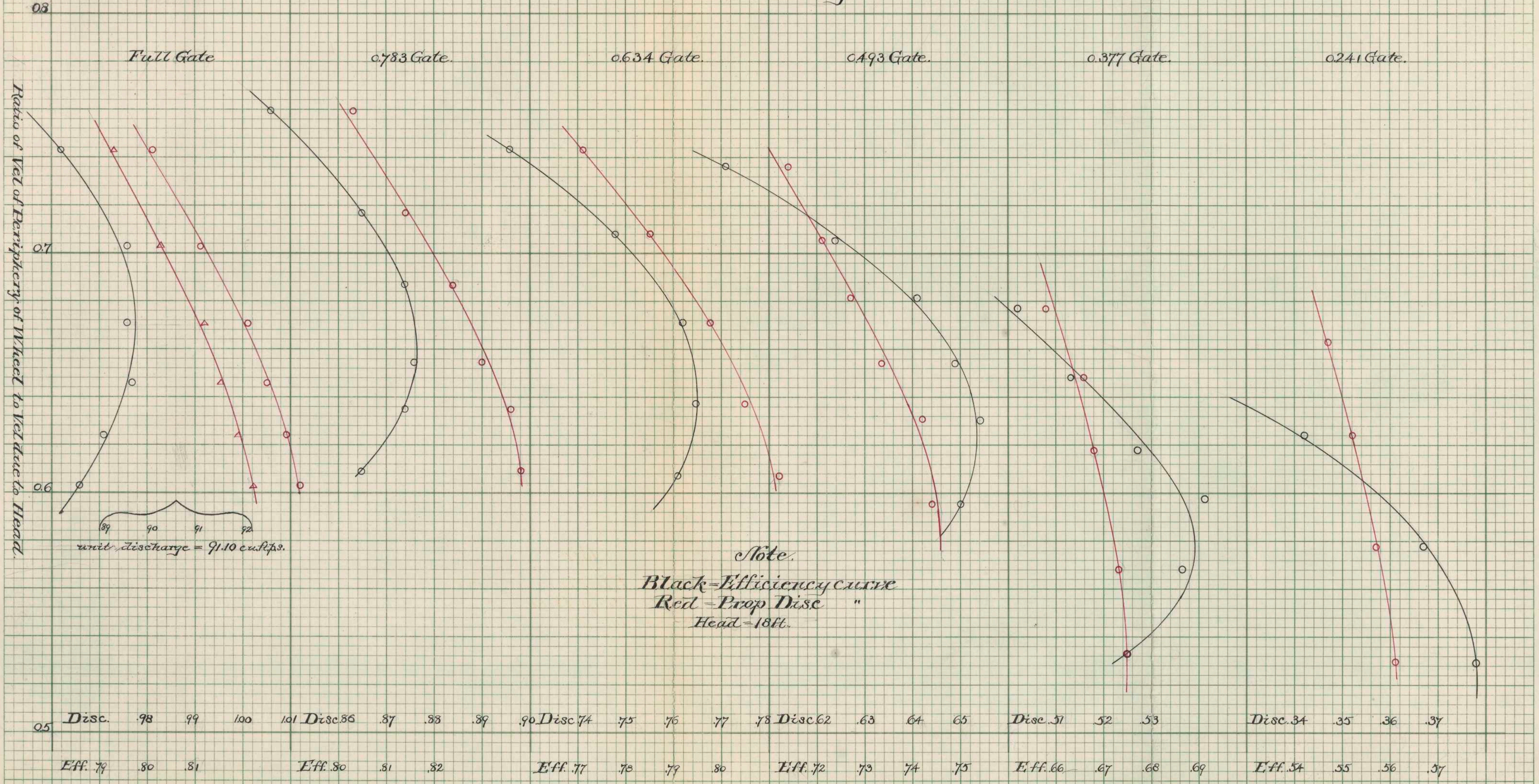
$$\log \frac{33 \times 3.1416}{12 \times 60} = 9.158332$$

This log is placed on slip of paper and added to log of rev. (col 5) of each experiment and results (log $V p w$) placed in

column 10.
The ratio obtained by taking the difference of two logs in column 10 is written in col 11 and the corresponding number written in same column.

Now to find the ratio between discharges at full gate and at any one of the other six gate settings, a unit must be selected from full gate discharges and this should be at speed which gives maximum efficiency. This maximum may be at one of the points tried, or it may be between them.
If the law of variation of efficiency and of velocity of wheel can be determined it becomes easy to ascertain where the true maximum may be

Curves showing Maximum Efficiencies at each Gate Setting



found and to obtain the exact value of the efficiency of the wheel at that speed of maximum efficiency. This is easily accomplished by drawing curves of "proportional discharges" and efficiencies. (See Plate III) The curves are constructed for each series of tests, on which the ordinates represent the ratio of velocity of periphery of wheel to velocity due to head, while the abscissas of the black curves measure efficiencies, and the red curves denote the ratio of the actual discharges at the given speed to the "unit discharge", or quantity of water passing the wheel at the full gate discharge, when giving the best efficiency of the wheel at that gate, which was found in this case to be 91.10 cu. ft. per. sec. The log of this = 1.959518 and is subtracted from each of the Q's column 8 and results placed in col. 9 and corresponding numbers in same column.

The results of table II are copied on to final sheet table IV. The curves on Plate III are constructed for each setting of wheel so that the maximum efficiency attainable at each gate, and the best speed of wheel under given head and at the given gate opening is determined

Now from inspection

of the results it will be seen that the best average efficiency gives a velocity ratio of about .67 therefore for the greatest amount of work attainable. the wheel should be geared to run at that speed.

Then $R = 67 \frac{"v2h"}{c}$

Where R = rev. of wheel per. min.

"v2h" = vel. due to head of 18 ft.

$C = \frac{\text{circumference}}{60}$

$R = \frac{67 \times 12 \times 60 \times \sqrt{2g \times 18}}{33 \times 3.1416} = 158$ rev. per. min.

From the tables already referred to on page 27, the coefficient of discharge of both the buckets and guides, can be easily determined as follows:—

From table II the average smallest cross section of guide opening is found to be .2402 Therefore the total guide area is

$$20 \times .2402 = 4.804$$ Now from experiment 40 Plate II we have a discharge of 92.23 at full gate and under a head of 18 ft. The log of this quantity being 1.964878 Therefore we have

$$Q = CA\sqrt{2gh} = 92.23$$

where C = coef. of discharge of guides

A = total area of smallest sec. of guide opening

$$\therefore C \times 4.804 \times 8.02 \times \sqrt{18} = 92.23$$

$$C = \frac{92.23}{4.804 \times 8.02 \times \sqrt{18}}$$

$C = .5678$ = coef of discharge of guides (under head of 18 ft.)

In like manner from table I Page 27 the area of bucket opening is .3294 from which we get a total area of

$$.3294 \times 16 = 5.270$$

Here we have

$$Q = C'A'\sqrt{2gh} = 92.23$$

where A = total area of bucket opening

C' = coef. of dis. of buckets

$$\therefore C' \times 5.270 \times 8.02 \times \sqrt{18} = 92.23$$

$$C' = \frac{92.23}{5.270 \times 8.02 \times \sqrt{18}}$$

$\therefore C' = 5176$ = coef. of dis. for buckets

Conclusions from Results

The table at bottom of this page shows results as taken from Plate IV They do not quite come up to the standard of efficiency of this make of wheel, but nevertheless are very good.

The two tables found on next page give results of tests made on two of McCormick's standard wheels.

Test on a 33" McCormick Holyoke Turbine.

Made Jan 29-30 1891

Gate	Prop Dis.	Head	Revs.	H.P.	Effic.
1.000	1.005	11.32	121.0	74.35	0.797
0.783	0.890	11.55	124.0	69.40	0.816
0.634	0.775	11.64	121.0	59.62	0.795
0.493	0.642	13.21	127.5	56.62	0.754
0.377	0.518	12.54	118.0	38.76	0.691
0.241	0.361	12.69	105.0	23.00	0.578

Test of a 51" L.H. McCormick's Turbine.

Made June 28th 1890

Gate	Prop Disc	Head	Revs	HP	Effic.
1.000	1.001	11.62	84.50	185.17	84.56
0.818	0.895	12.99	87.62	197.34	85.32
0.685	0.797	13.09	83.00	171.77	82.39
0.554	0.677	13.17	88.00	139.27	77.99
0.414	0.542	13.93	84.25	110.26	70.84

Test of a 33" R.H. McCormick's Turbine

Made June 13th 1890

Gate	Prop Disc	Head	Revs	H.P.	Effic.
1.000	0.999	14.57	140.00	101.36	82.30
0.808	0.901	14.87	144.50	95.83	83.65
0.640	0.791	14.98	138.50	82.58	81.21
0.510	0.665	15.06	145.33	65.43	75.96
0.368	0.521	15.35	134.50	47.46	68.32
0.227	0.354	15.29	126.33	26.13	55.62

People are apt to get misled by statements made by companies in regard to tests made on their own wheels, as giving extraordinary efficiencies but when tested at a standard flume, by impartial engineers, the efficiencies are seldom if ever found to go much over 85 per. ct.

The following will show how even under the very best circumstances errors will creep in and wonderful results be obtained:- When the new testing flume at Holyoke was first started in 1883 a test was made by Mr. Herschel the engineer then in charge, on a 36" R.H. Hercules, with the unparalleled result of 86.94

maximum efficiency.
"The second trial giving an equally good result, it was feared by the constructors that there might be some fault of construction in the flume or of method in calculation." So Professor Thurston was sent for, as consulting engineer, and "was requested to investigate these points and determine if possible, whether it would be safe to accept the values of efficiency reported. A full description of the third test made "under his eye" can be found in article by Prof. Thurston in the Transactions of Mechanical Engineers Vol VIII Page 399-408 in which he agrees with the results of

the test and states that after a careful examination of the method of observation and calculation employed there, that efficiencies can be obtained "within a limit of error of certainly less than one per. ct. and probably to within one half of one per. ct,

It will also be noticed in the discussion of the article referred to that Mr. Samuel Webber in speaking of the above test said, that his own results, "with this type of wheel varied between 81 and 84 per. cent," which is quite a different thing from 87 per cent. In fact it was afterwards discovered that the knife edge of the dynamometer was defective giving as a consequence too high efficiency. This was quickly remedied and after that wheels made from the same patterns, as the above wheel, and even with greater care did not produce anywhere near the same results.

There is no doubt but that today Prof. Thurston's statement in regard to the flume would hold true - namely that "for all practicable purposes, the results of the trials of the turbine water wheels at the Holyoke flume may be taken as exact and absolutely trustworthy."

It will be seen from a study of the tables on page 46 and the curves of Plate III, that the efficiency kept up to 70% even with the gate at .377 and prop. dis. above .518.

This is very good, although ~~by good rights~~ the efficiency ~~ought, if possible, to be independent of the amount of water used, or if not it~~ should be the greatest when the water supplied is low. This is very difficult to obtain.

It should be noted however that it is not the mere variation of the quantity of water which causes the efficiency to vary, but it is the losses of head which are consequent thereon.

For instance in practice when water is low, gates must be lowered to diminish the area of orifice, and this produces sudden changes of cross-section which diminish the effective head h.

These losses cannot be avoided by any practical means yet in use.

In the case of the wheel tested, a lift gate was used so that when it was only quarter open, a loss of head ensued, due to sudden enlargement of the stream in the buckets, this loss is partially obviated by means of partitions, parallel with the direction of flow, which subdivide the buckets so as to form practically several narrow wheels connected together and keyed to one shaft.

It will also be noticed in all the tests above referred to - (Pages 46-47) that the maximum efficiency is obtained at about 3/4 gate, and not at full gate opening as one would suppose; this fact is noticeable in all our best wheels today. This is probably due to the fact that "at full gate when all of the divisions (above referred to) are full, the water leaving the uppermost devision is owing to the tapering form of the inside of the wheel and the obstruction of the boss, more abruptly deflected and impeded in its off flow than the water from the lower divisions."

In addition to this reason the area of draft tube, which is generally used in connection with this wheel, may be small in proportion to the relative area of the outflow so that the water is somewhat checked in its course at full gate, while at part gate this does not occur.

The End.

Abstract
of
Thesis

Efficiency Test
of a
33" McCormick L. H. Holyoke Turbine
made at the
Holyoke Testing Flume.

A. E. Hatch.

May 15th 1891.

Without going into a detailed account in regard to the construction of the testing flume at Holyoke, it will be sufficient to state that the method of conducting a test and the apparatus employed are essentially the same as those used by Mr James B. Francis in his Lowell hydraulic experiments: - The water is conducted from the main canal into a flume and thence it enters a large water tight wheel pit, at the bottom of which the wheel to be tested is placed. At the raising of the wheel gate the water passes through the wheel and down into the tail race below, at the end of which the quantity of water used is measured over a weir by means of a hook gauge. The power generated by the passing of the water through the wheel is measured by means of a dynamometer which is mounted upon the head of the shaft. The effective head acting on the wheel is obtained by a "pit gauge", which is connected with both the pen-stock and the tail race.

The computation of the test is made as follows:- The quantity of water passing over the weir is taken from a diagram constructed according to Francis formula with Hunking & Hart's correction for velocity of approach. From the value thus obtained the leakage of the flume must be subtracted, in order to deter-

mine the quantity of water actually passing through the wheel. The efficiency of the wheel or the ratio of H. P. of wheel to H. P. of water, is computed for each variation of head and gate opening.
In order to obtain the proportional part of the full discharge at each gate setting of the wheel we must reduce all the discharges to a uniform head and then take as a unit the discharge for full gate when giving best efficiency.

Now the discharge under different heads varies as the square root of the heads.
Moreover on account of the variation of head, we cannot

directly compare the revolutions of different experiments, but we can compare the ratio of velocity due to head, to the velocity of a point on the periphery of the wheel. Therefore with this ratio as ordinates and the efficiency as abecissas a curve is plotted for each gate opening and from these the maximum efficiency for each gate setting is obtained.

The test witnessed at the flume in Jan. was on a 33" McCormick L. H. Holyoke turbine which had a combination of "inward, downward, and outward, flow."

The results obtained gave about 74 H. P. at full gate and

158 revolutions per min. as the corresponding best speed, or speed up to which the wheel should be geared.

In regard to the coef. of discharge it was found that the area of the smallest cross section of guide opening was 4.804 sq. ft. and the bucket area 5.270 sq. ft. making the coef. of guide discharge 0.5678 under a head of 18 ft. and the coef. of bucket discharges .5176, under the same head.

The maximum efficiency obtained was 81.6% and occurred at 0.783 gate. This is not quite up to the standard of this make of wheel, which has been known to

run as high as 85.3 %.
The fact that the maximum occurs generally at about 3/4 gate with the McCormick and also with the Hercules wheel may be owing either to some defect in the construction of the upper part of the wheel, or else to the draft tube used being too small for the amount of water discharged at full gate.
It further appears from the results of the test that the efficiency was maintained at 70 % even at 0.377 gate and proportional discharge about 0.518. This is a favorable showing for a reaction turbine although the efficiency ought if possible to be greatest when the water

supplied is low. This is very difficult to obtain. It should be noted however that it is not directly the variation of the quantity of water which causes the efficiency to vary but it is the losses of head which are consequent thereon. For instance in practice when the water is low the gates must be lowered to diminish the area of orifice and this produces sudden changes of cross section which diminish the effective head. This loss is somewhat obviated in the wheel considered by means of partitions parallel with the directions of flow, which subdivide the buckets so as to form practically several narrow wheels connected together and keyed to one shaft.