'Power Test of a Paddle Wheel Wind-Mill'

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Books of Reference

Spons Engineering Dictionary
Haswels Manual of Engineering

The Machine used in this test was one recently built, at the Kansas State Agricultural College Mechanical Department, by the students under the direction of Prof. O. P. Hood in charge. It was built throughout of rough material without castings, as it was desired to make a machine similar to those commonly built by the farmers of western Kansas who use them for irrigating.

The machine is a horizontal paddle wheel eight feet in diameter and fourteen feet long, it has eight sails, weighs six hundred and sixty three pounds and the material from which it was built would cost about eleven dollars.

The axle is a piece of yellow pine four inches square. To this axle and at a distance of one foot from either end radial strips seven eighth inches thick by two inches wide, by eight feet long, are arranged in pairs and are fastened at the middle one on either side of the axle. To either end and between each pair of radial strips, sails are fastened with bolts. The members of each pair of radial strips are thus drawn together at the ends which places them in a curved position, thus increasing their resistance to twisting and bending and forming a strong radial arm. The sails are of white pine sheathing, seven eighth of an inch thick by sixteen inches wide by fourteen feet long. Their strength and stiffness is increased by fastening strips seven eighth inches wide by three inches wide and fourteen feet long, lengthwise, at the middle of the sail, on their edge.

To give the machine additional strength against severe winds, at about one foot from either end of the sails, wires are passed, one over the upper edge of the sail and one under the sail and thus crossing in passing to the next sail, over which they pass in the inverse order, being firmly tightened and fastened to each sail and so on untill the circuit is complete.

In order to give the heavy machine as little resistance as possible one and one half inches in diameter are fastened to either end of the axle. This fastening is obtained by boring holes into the ends of the axle of sufficient size to admit the shaft, and by cutting a slot of about one half inch longitudinally through the holes, these shafts are firmly fastened, by bolts passed perpendicularily through the slots of the axle. The bearings are made of yellow pine blocks which are so placed that the shaft will turn and wear on the end grain of the wood. The bearings are supported by heavy frames, built at either end of the machine and fastened to the ground.

To enable the machine to do effective work in the form of power, it is boxed up all around to the height of the axis, this shelters the lower half of the sails from the wind and thus the greater force is exerted on one side of the upper sails. At each end the sheathing boards, which are used, are nailed to the posts or frame which supports the bearings, while either side of the machine is provided with a door which is swung on hinges at the bottom, and thus be opened or closed and serve as a regulator to the machine. At the top of each door is a device to deflect the wind in an upward direction against the rear sail. It is a board one foot wide or more nailed to the upper edge of each door and projecting downward at an angle of 60° with the door.

After the description of the machine is well understood, the first question of inquiry might be asked. What regulates the width of the sail? or the open space between the sail and the axle? or why not have the space closed up for the full radius of the sail. In reply we will first make a reasonable assertion. The fewer the sails the less should be the open space between it and the axle. For if but one sail was exposed to the wind force at a time, the greatest possible surface area would be desired, hence the sail should equal the radius in width. But as we increase the number of sails the wind can effect only an area equal to the radius, since while one sail is raising it would cut off the wind effect on the sail higher up and so on. But if the sails were all equal to the radius in breadth, there would be an undesired effect obtained, for as the wind strikes a sail which is just rising it is directed downward and is forced against the lower sail which would tend to counteract the effect on the first sail. But if the sails are equal in breadth to about one third the radius, as is thought to be the proper breadth of the sails of this machine, the wind on striking a rising sail passe slightly down and then across to the other side through the openings, against the saie which is falling. Thus a double effect of the wind may be obtained. For variation in size, the power of these machines vary directly as the length and also as the increase of the radius.

In order to make the desired test of the machine, an iron pulley twenty two inches in diameter and six and one quarter inches broad was fastened to one of the shafts. To this wheel a friction break was applied, which was constructed from the patern of an instrument known as the "Prony Break". It consists simply of two heavy strips of timber seven inches square, which were sawed to fit the wheel. Through these pieces long bolts were placed one on either side of the wheel so as to form a clamp or frame which fits the wheel. The bolts were provided with thumb taps so as to enable an easy adjustment of pressure. The lower jaw of this clamp or break is extended six feet from the center of the wheel, at the end of which was placed a short vertical pin which rested on the end of a rod which stood vertically on the platform of a pair of scales.

The use of this "Prony Break" may be explained as follows. The thumb taps may be so adjusted as to cause friction on the moving wheel and register a load on the scales which is exerted through the six foot arm. During one revolution of the wheel the work is equal to the machine lifting a weight equal to the weight registered on the scales, through a distance equal to the circumference of the wheel, of a six foot radius.

To get the accurate weight on the scales due to friction of the wheel, the weight of the break must first be deduced. This is obtained by balancing the break on the quiet pulley and then taking its weight. Always in measuring the actual weight this constant weight must be deducted, and thus the actual force is obtained.

This test is made at some disadvantage and thus absolute accuracy in results is impossible. As to the location of the machine, it sets 46° 30' 20" to the S.E. by S and the axis is nine and one half feet above the surface of the ground. It is also placed near the shops which is a large building at the N.E. of the sight. Also the data taken for wind velocity is recorded by an anamometer at an elevation of about fifty feet from the ground and at a distance of about sixty five yards to the S.E. of the machine. The direction of the wind is taken by drawing a line, across a fixed sheet of paper, parallel to the axis of the machine and through this line, by means of a vulon placed in the direction of the wind the line of wind direction is obtained, in a measurable form. From this angle the probable total power of the machine may be determined.

In making the Power Test, the machine is placed in proper order to run. A desired load is applied to the wheel in the form of friction, and after preparing the stop watch and electric counter, or making ready to count, the machine is ready to run. Counts were made for periods of sufficient length to obtain as good an average as possible for one minute, such a period used was one of five minutes. After obtaining the average revolutions for one minute, the actual horse-power is first calculated for a single revolution a minute, by finding the number of foot pounds, which is calculated by taking the load in pounds times the circumference described by the arm to which the load is attached, and dividing the product by thirty three thousand which produces the actual horse power for a single revolution a minute, which serves as a constant quantity for a given load. The total horse power is then obtained by multiplying this constant by the number of revolutions per minute. This is a a result from the wind in its true direction, or impinging on the sails at an angle, since normal winds are rare. By considering the angle of the wind, we may obtain the effective length of the machine, which allows of much better comparison of the variation of the power, than merely reading the angle. By considering this angle & the total horse-power for the wind is obtained as if striking the sails normally. Thus the angle is measured as so many degrees from a normal wind, which involves the cosign of the angle as the effected length of the machine, then the total power is equal to the given power divided by the natural cosin.

The velocity which is taken directly from the record of the anamometer is computed from the record for each five minute interval and reduced to miles per hour, from which the various calculations are made. The energy in a cross-section of one square foot of wind is obtained from the formula $\frac{SDV^3}{33000}$ which equals the number of foot pounds per minute. This energy for a single square foot of cross section of wind multiplied by the total number of square feet exposed is equal to the total force in the wind. This surface exposed is considered as one sail with a radius entirely closed. From the total horse-power of the machine or the resultant effect of the wind in turning the machine, reduced to the same denomination as the total energy of the wind of the same cross section a comparison is made between the applied force and the effective force. Thus by dividing the power got out of the machine by the total power in the wind we obtain a fraction or percent called the efficiency of the machine.

By making an indefinite number of these tests with various wind velocities and with various loads, interesting data is obtained from which the most efficient point of the machine may be found. Thus at the best load with the most advantageous wind the greatest efficient point is obtained. which is the aim of this experiment.

The following is the data taken from one hundred and fifty tests. the greatest power obtained is .82 horse-power which was produced by a 38.4 mile wind and with a load of 20#
From the test it is evident that the best loading point is in the neighborhood of 7# at a wind velocity of about 18 miles per hour. The average efficiency of the machine is from one eighth to one tenth horse power

Data for April 27 - 1896

Time P.M.	Total no. of Revol.	Rev. per min.	Lbs. Pressure	H.P. per Rev. a Min	Total H.P.	Angle of ...	Effective Length	H.P. for full Length	Velocity of wind per Hr.	% Efficiency
2-24 to 29	65	13	4	.00499	.06487	53° 15′	8.37	.108421	20	3.6
30 to 35	109	21 4/5	"	"	.108782	"	"	.181812	"	6.04
35 " 40	111	22 1/5	"	"	.110778	"	"	.185148	"	6.15
40 " 45	94	18 4/5	"	"	.093812	"	"	.156792	"	5.2
45 " 50	105	21	"	"	.10479	"	"	.175140	"	6.82
50 " 55	82	16 2/5	"	"	.0181836	"	"	.153489	"	5.1
55 " 60	73	14 3/5	"	"	.072854	"	"	.121764	"	4.04
3- 0 " 5	56	11 1/5	"	"	.055888	"	"	.093241	19	3.61
26 " 31	90	18	"	"	.08982	44° 30′	9.98	.125930	"	4.84
31 " 36	67	13 2/5	"	"	.066866	"	"	.093748	"	3.63
36 " 41	104	20 4/5	"	"	.103792	"	"	.145520	"	5.64
41 " 46	102	20 2/5	"	"	.101796	"	"	.142721	"	5.53
46 " 51	103	20 3/5	"	"	.102794	"	"	.144120	"	5.59
4- 0 " 5	81	16 1/5	"	"	.080838	"	"	.113337	17	6.15
5 " 10	87	17 2/5	"	"	.086826	"	"	.121732	"	6.6
10 " 15	65	13	"	"	.06487	"	"	.081094	"	4.4
15 " 20	63	12 3/5	"	"	.062774	"	"	.088011	"	4.77
20 " 25	55	11	"	"	.05489	"	"	.076957	"	4.17
25 " 30	32	6 2/5	"	"	.031936	"	"	.044775	"	2.43
49 " 54	116	23 1/5	"	"	.115768	"	"	.162310	"	8.81
54 " 59	80	16	"	"	.07984	"	"	.110536	"	6.
59 " 5-4	107	21 2/5	"	"	.106786	"	"	.149716	"	7.99
5- 4 " 9	65	13	"	"	.06487	"	"	.090949	"	4.85
9. " 14	78	15 3/5	"	"	.077844	"	"	.109138	"	5.82

Data for April 30 – 1896

Time P.M.	Total Revol.	Revol. per min	Lbs. Pressure	HP per Rev. a min	Total HP	Ang. of W.	Effective Length	HP for full length	Velocity of wind	% Effic.
2 – 10 to 15	61	12 1/5	4	00499	.060880	39° 30'	10.8	.078883	28.	1.02
15 " 20	69	13 4/5	"	"	.068862	"	"	.089249	28.8	.99
20 " 25	79	15 4/5	"	"	.078845	"	"	.102182	29.	1.13
25 " 30	92	18 2/5	"	"	.091816	"	"	.118991	27.	1.6
30 " 35	82	16 2/5	"	"	.081836	"	"	.106037	29.2	1.13
35 " 40	125	25	"	"	.12475	"	"	.161671	31.	1.49
40 " 45	105	21	"	"	.10479	"	"	.135805	29.	1.51
45 " 50	90	18	"	"	.08982	"	"	.116404	27.5	1.51
50 " 55	126	25 1/5	"	"	.125748	"	"	.162966	31.5	1.38
55 " 60	63	12 3/5	"	"	.062874	"	"	.081483	28.	1.05
3 – 0 " 5	37	7 2/5	"	"	.036926	"	"	.047855	16.	3.11
5 " 10	54	10 4/5	"	"	.053892	"	"	.069842	17.8	3.29
10 " 15	55	11	"	"	.05489	"	"	.071136	18.	3.24
15 " 20	88	17 3/5	"	"	.087824	"	"	.113818	18.2	5.02
20 " 25	39	7 4/5	"	"	.038922	"	"	.050419	16.5	2.99
25 " 30	103	20 3/5	"	"	.102794	"	"	.133215	23.	2.91
30 " 35	113	22 3/5	"	"	.112774	"	"	.146152	24.	2.87
35 " 40	122	24 2/5	"	"	.121758	"	"	.157926	25.	2.61
40 " 45	115	23	"	"	.11477	"	"	.148739	24.1	2.82
45 " 50	60	12	"	"	.05988	67° 45'	5.3	158140	18.5	6.65
50 " 55	35	7	"	"	.03493	"	"	.092248	16.5	2.26
55 " 60	67	13 2/5	"	"	.066866	"	"	.176590	19.	6.76
4 – 0 " 5	19	3 4/5	"	"	.018962	"	"	.050077	18.	.22
5 " 10	50	10	"	"	.0499	"	"	.131784	21.	3.26

Data for May 5 - 1896

Time P.M.	Total no. of Revol.	Revol per min.	lbs Press.	HP per Rev. a min.	Total HP	Ang. of wind	Effective Length	HP for full Length	Velocity of wind per hr.	% Efficiency
3 - 55 to 60	101	20 1/5	7	.0079968	.161535	30°	11.32	.186523	15.	14.69
4 - 0 " 5	88	17 3/5	"	"	.140743	"	"	.162515	14.	14.55
5 " 10	62	12 2/5	"	"	.099160	"	"	.102952	12	15.86
10 " 15	82	16 2/5	"	"	.131147	"	"	.151434	13.	18.46
15 " 20	121	24 1/5	"	"	.193522	"	"	.200364	17.8	9.45
20 " 25	98	19 3/5	"	"	.156737	"	"	.180983	16.5	10.73
25 " 30	86	17 1/5	"	"	.137544	"	"	.158821	15.	12.51
30 " 35	144	28 4/5	"	"	.230307	"	"	.265934	20	8.84
~~30~~ 35 " 40	134	26 4/5	"	"	.214314	"	"	.247466	18.5	10.42
40 " 45	117	23 2/5	"	"	.187125	"	"	216072	16.	14.04
45 " 50	83	16 3/5	"	"	.132746	"	"	.153281	14.	13.73
50 " 55	99	19 4/5	"	"	.158336	"	"	.122829	18.	8.3
55 " 60	88	19 3/5	"	"	.156737	"	"	.180983	18.2	7.98
5 - 0 " 5	135	27	"	"	.215913	"	"	.249313	19.	9.68
5 " 10	70	14	"	"	.111955	39° 30'	10.8	.145090	14.	12.99
10 " 15	75	15	"	"	.119952	"	"	.155454	16.5	10.43
15 " 20	134	26 4/5	"	"	.214314	"	"	.279033	18.5	11.75
20 " 25	75	15	"	"	.119952	"	"	.155454	15.	12.39
25 " 30	70	14	"	"	.111955	"	"	.145090	14.	12.99
30 " 35	80	16	"	"	.127948	"	"	.165819	18.	7.55
35 " 40	64	12 4/5	"	"	.102359	"	"	.132654	15.	10.45
40 " 45	74	14 4/5	"	"	.118352	"	"	.153366	17.	8.32
45 " 50	42	8 2/5	"	"	.067173	"	"	.087054	12	13.41
50 " 55	75	15	"	"	.119952	"	"	.142494	14	12.67

Time	Total Revol	Rev. per min	Lbs. Press.	HP per Rev. a min	Total HP	Angle of blo.	Effective Length	HP for full Length	Velocity of wind	% Effic.
P.M. 55 to 60	55	11	7	.0079968	.087964	39°30'	10.8	.113999	13.	13.93
6 – 0 " 5	83	16 3/5	"	"	.132746	"	"	.173331	14.	13.01
5 " 10	27	5 2/5	"	"	.043182	"	"	.055964	13.	6.81
10 " 15	25	5	"	"	.039984	"	"	.051818	12.	7.95
15 " 20	37	7 2/5	"	"	.059176	"	"	.076690	12.	11.81
20 " 25	16	3 1/5	"	"	.025589	"	"	.033176	10.	8.85

Data for May 6 – 1896

Time	Total Revol	Rev. per min	Lbs. Press.	HP per Rev. a min	Total HP	Angle of blo.	Effective Length	HP for full Length	Velocity of wind	% Effic.
A.M. 11 – 42 to 47	123	24 3/5	"	"	.196721	30°	11.32	.227152	17.8	10.71
47 " 52	171	34 1/5	"	"	.273490	"	"	.315797	22.4	7.49
52 " 57	162	32 2/5	"	"	.259095	"	"	.299175	18.2	13.2
57 " 2	141	28 1/5	"	"	.205509	"	"	.260394	18	11.84
P.M. 12 – 2 " 7	152	30 2/5	"	"	.243102	"	"	.280709	24	5.4
7 " 12	133	26 3/5	"	"	.212714	"	"	.245505	21	7.05
12 " 17	119	23 4/5	"	"	.180323	"	"	.208219	20.6	6.37
17 " 22	129	25 4/5	"	"	.206317	"	"	.238233	23.7	4.07
22 " 27	128	25 3/5	"	"	.204618	"	"	.236271	23.5	4.86
27 " 32	144	28 4/5	"	"	.230307	"	"	.265934	24.	5.11
32 " 37	103	20 3/5	"	"	.164734	"	"	.190217	17.	10.32
37 " 42	111	22 1/5	"	"	.177528	"	"	.204991	18.5	8.63
42 " 47	136	27 1/5	"	"	.217512	"	"	.251161	22.	6.35
47 " 52	110	22	"	"	.175912	"	"	.203124	18.4	8.67

Data for May 6 – 1896

Time P.M.	Total Revol	Revol per Min	lbs Press.	HP per Rev. a min	Total HP	Angle of flo.	Effective Length	HP for full length	Velocity of w. part	% Effic.
12 – 54 to 59	60	12	10	.011424	.137088	30	11.32	.158294	16.5	10.62
59 to 4	43	8 3/5	"	"	.098246	"	"	.113444	13.	13.86
1 – 4 " 9	81	16 1/5	"	"	.18568	"	"	.226628	21	6.51
9 " 14	102	20 2/5	"	"	.233049	"	"	.269100	23.	5.89
14 " 19	110	22	"	"	.246928			.285126	23.8	5.6
19 " 24	85	17	"	"	.194208			.224366	21.5	6.
2 – 15 " 20	119	23 4/5	"	"	.271891			.313951	24.	6.04
20 " 25	133	26 3/5	"	"	.303878			.350886	25.	5.94
25 " 30	116	23 1/5	"	"	.265036			.306035	23.2	6.54
30 " 35	92	18 2/5	"	"	.21020			.235095	21.	6.75
35 " 40	67	13 2/5	"	"	.15310			.176783	20.	10.6
40 " 45	117	23 2/5	"	"	.267321			.307638	23.8	6.06
48 " 53	70	14	"	"	.159936			.184677	17.	10.02
53 " 58	73	14 3/5	"	"	.166790			.192591	18.	8.77
58 " 3	50	10	"	"	.11424			.134198	16.5	9.
3 – 3 " 8	98	19 3/5			.22391			.271261	25.5	4.18
8 " 13	112	22 2/5			.255897			.310012	27.	4.19
13 " 18	91	18 1/5			.205916			.249462	25.5	3.84
18 " 23	81	16 1/5			.185068			.226628	25.	3.85
23 " 28	74	14 4/5			.16975			.204830	25.	3.48
28 " 33	85	17			.194208			.234066	24	12.7

Data for May 8 - 1896.

Time	Total no. of Revol.	Revol. per min	lbs Press.	H per Rev a min	Total H	Angle ft.	Effective Length	H for full Length	Velocity of wind per hr.	% Effic.
A.M. 11 - 38 to 43	115	23	15	.018045	.415035	30°	11.32	.479224	25.32	11.07
45 " 50	141	28 1/5	"	"	.508871			.587590	30.	5.7
50 " 55	95	19	"	"	.342855			.396240	27.	5.35
55 " 60	75	15	"	"	.270675			.312546	23.	6.84
P.M. 12 0 " 5	86	17 1/5	"	"	.310374			.358387	24.	6.88
5 " 10	82	16 2/5	"	"	.295938			.341833	21.	9.82
10 " 15	96	19 1/5	"	"	.346464			.40006	25	14.68
15 " 20	93	18 3/5	"	"	.335637			.387558	22	9.68
20 " 25	80	16	"	"	.288720			.333267	19	12.93
25 " 30	82	16 2/5	"	"	.295938			.341833	21.	9.82
30 " 35	83	16 3/5	"	"	.299547	39° 30'	10.8	.388205	21.6	8.19
35 " 40	56	11 1/5	"	"	.202104			.261921	20.	10.
40 " 45	89	17 4/5	"	"	.321201			.416268	23	9.11
45 " 50	44	8 4/5	"	"	.158796			.205782	18	9.37
50 " 55	17	15	"	"	.306765			.397819	19.1	17.68
55 " 60	48	9 3/5	"	"	.173232			.224504	17.	12.18
1 - 0 " 5	82	16 2/5	"	"	.295938	53° 15'	8.37	.499628	24.	17.7
5 " 10	64	12 4/5	"	"	.230976			.386040	18.2	17.
10 " 15	27	5 2/5	"	"	.097443			.16469	17.9	7.63
15 " 20	24	4 4/5	"	"	.086616			.144598	19.	5.28
20 " 25	24	4 4/5	"	"	.086616			144598	19	5.28
25 " 30	25	5	"	"	.090225			150780	19.2	5.68
30 " 45	58	3 13/15	"	"	.069751			.116745	14.	11.35

Data for April 28 – 1896.

Time PM	Total no. of Revol.	Revol. per min.	Lbs Press	HP per Revo. a min.	Total HP	Angle of Sa.	Effective Length	HP for full Length	Velocity of wind per hr.	% Effic.
2- 0 to 5	40	8	20	.022848	.182784	44°30'	9.98	.256269	30.	2.52
5 " 10	42	8 2/5	"	"	.191923	"	"	.269082	32.	2.18
10 " 15	58	11 3/5			.265036	"	"	.371589	34.2	2.47
15 " 20	107	21 2/5			.488947	"	"	.685519	36.	4.02
20 " 25	166	33 1/5			.758553	"	"	1.063516	38.	5.15
25 " 30	180	36			.822528	"	"	1.153211	38.4	5.41
30 " 35	96	19 1/5			.438687	39°30'	10.8	.568519	31.	5.24
35 " 40	137	27 2/5			.626035	"	"	.871325	39.	3.64
40 " 45	127	25 2/5			.580339	"	"	.752104	37.	3.95
45 " 50	130	26			.594048	"	"	.769871	33.	5.71
50 " 55	89	17 4/5			.406694	"	"	.526706	35.	3.26
55 " 60	104	20 4/5			.475238	"	"	.615896	36.	3.71