The Commercial Efficiency of Small Electric Motors.

Barnard Capen, Jr.

May 19, 1891.

The Commercial Efficiency of Small Electric Motors.

The applications of the Electric Motor have come to be almost infinite in number and variety. It can be substituted in place of any other kind of motor, and combines the advantages of, portability, small weight per rated horse-power, that it may be used at a considerable distance from the main source of power. The high speed of the motor, makes it possible to couple directly to quick moving machinery, saving the loss from intermediate connections.

Also the power can be supplied in any amount. Another great advantage is that a skilled attendout is not required, the motor re-quiring very little care -

Within a few years the small machines have become of much commercial importance and to-day a large number of Motor Companies are supplying a demand for machines of less than one horse power

These small motors, are very convenient for driving fans, small drills, lathes, sewing machines, organ pumps, and for many other purposes where a small amount of power is required -

The small motor has the advantage, alike with the larger machines, of adaptability to any circuit with the single exception of the Alternating - as the machines can be wound for incandescent or arc circuits of any voltage — This is just now of some importance, owing to the extensive introduction of the overhead electric system. And it may become a function of Street Railway Corporations to supply, to some extent, electric power for running motors near its lines —

It may be said that the efficiency of electric motors of perhaps two horse-power and upwards is 85 or 90 % — but this is by no means true for small motors —

As with other motors, the efficiency of the electric motor increases with the size and this too quite rapidly up to a certain point — perhaps one horse-power — It is difficult to say to just what this is due; — but a number of causes tend to reduce the efficiency—

In the first place, the friction of the bearings is not at all in proportion to the size of machine, and is therefore a much larger factor of loss in the small motor—

Second—and perhaps almost as important, the small machines are not made (as a rule) with as much care and the material is probably inferior. A representative of one of the large companies, told me that the armatures in their small machines are wound by machinery, while in the larger ones all the winding is done by hand— Evidently this must contribute to lower their efficiency—

Also the "air gap", i.e. the space between the armature and the pole-pieces, can not be made as narrows in proportion in the small motors.

This question of size to efficiency has been discussed by Hopkinson, Fröhlich, Ayrton, Mascart & Joubert and others.

According to Mr. Kapp & Prof. Ayrton, the capacity of the machine varies as $n^{3\frac{1}{2}}$, whilst the work wasted varies as n^2. Hence that the economic coefficient will increase with the size of machine. In the above n = no. of times all the dimensions are increased.

Also that the smaller relative space required for clearance, in the larger machines, makes it possible to increase the current n^2 – hence a higher E. M. F. which would raise the capacity to $n^{3.7}$

These facts to-gether with

the advantages of the small machines makes the question of their efficiency well worth investigation.

The following tests were made entirely to determine the commercial efficiencies of small motors.

The developement of the Electric Motor is ably discussed in two previous theses:

"Electro Motors" by Messrs. Pickernell and Pratt of '85 and "The Electrical Transmission of Power." by Messrs. Bartlett and Clifford of '86.

The number of machines tested was five, and represent the types produced by four companies.

To determine the commercial efficiency of an electric motor, it is necessary to know the Electrical energy put into the machine, and that portion of the energy developed which may be utilized at the circumference of the pulley — and these two quantities the Input and the Output must be reduced to the same unit —

The Electrical Input expressed in H.P. = $\frac{CE}{746}$

where —

C = Current in amperes —

E = Electro motive force in Volts at terminals of machine —

746 = number of Watts in 1 H.P.

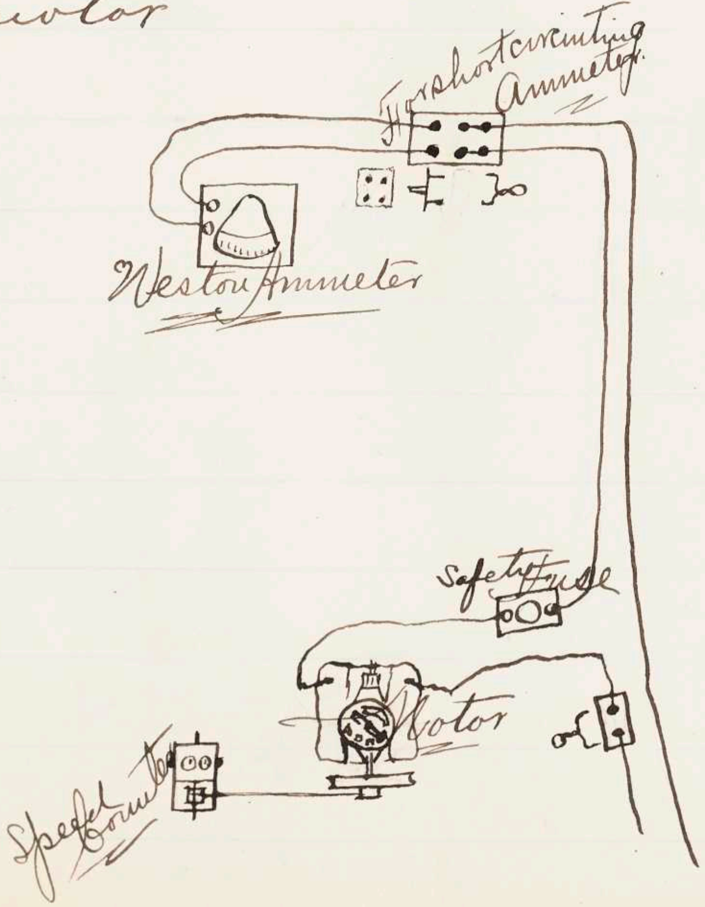
The mechanical work at the pulley in H.P. = $\frac{2\pi r n W}{33,000}$ — where:

r = radius of brake pulley in feet —

n – no. of revolutions per minute –
W – effective pull in lbs – at the circumference of the pulley –
33,000. = no. of foot-lbs – in 1 H.P.

In all the tests which I have recorded, the current was measured by a Weston Ammeter* reading to .05 of an ampere –

The instrument was placed at a distance of about 10 feet from the motor



Early in the tests, a Voltmeter (Weston) was placed on the mains or rather at the motor terminals and the Voltage found to be 109 - This voltage was assumed constant throughout the tests, the regulation being such as to keep the potential within a volt at the switch board in the dynamo room -

The mechanical output was measured by a form of friction brake (Similar to one of the methods used by Messrs Pickernell and Pratt)

A spring balance was hung by an iron wire from the ceiling, and a cord attached to its lower end passed once around the pulley and fastened to a scale pan - The balance was one by Chatillon graduated in ½ ounces, & reading up to 48 oz - A brass piece was carefully turned, so that when fastened to the lower end of the balance the needle pointed very nearly to 0 -

Tested the balance with the weights used in the tests and found the error slight -

The speed was measured by a small piece counter, the pulley of which was connected by a string belt with a step on the brake pulley of almost exactly the same diameter - within .01" in every case -

I made a series of tests to check the record of the speed counter, using for the purpose a hand recorder -

To eliminate possible slip between the diamond point of the hand recorder & shaft - had the hole in the shaft grooved - In this way tested two of the pulleys, and the other, used in the tests upon the $\frac{1}{6}$th & one of the $\frac{1}{8}$th machines, was almost exactly the same diameter as one tested - The mean percentage deviation in one series was .2%. - in the other .15%-

The brake pulleys three in number were of brass and carefully turned The diameters were measured accurately at intervals during the tests -

The brake band used was cotton string and consisted for very light loads of one cord - for the higher loads 20 cords -

The method of testing was as follows;

Having adjusted the brushes carefully, ran the machine for 20 minutes or half an hour to allow it to heat;- then stopped it just long enough to adjust the brake with the desired load - Next, readjusted the brushes, if necessary, and, as soon as the load became constant, started the test by throwing the speed counter into operation -

During the test the balance and ammeter were read as often as possible - At the end of 5 minutes the speed counter was stopped and the reading taken -

A second test was made following the first within a few minutes provided the balance reading remained sufficiently constant -

Assuming the voltage as 109, the mean of the ammeter readings gave the current in amperes -

The average of the balance readings gave the weight in ounces to be subtracted from, the weight in the scale pan + the weight of the scale pan string and oil - This difference expressed in lbs. gives the effective load = W.

This with the number of revolutions per minute, and the correct radius of the brake pulley, give sufficient data for calculation of the efficiency.

In general, the tests upon each motor were two each, at five to seven intervals from full load to no load, or running free.

I experienced considerable difficulty in making the tests at the higher loads, from the fact that the friction changes from time to time, and seemingly with no regularity. This of course changes the load, with the consequent variation in the current.

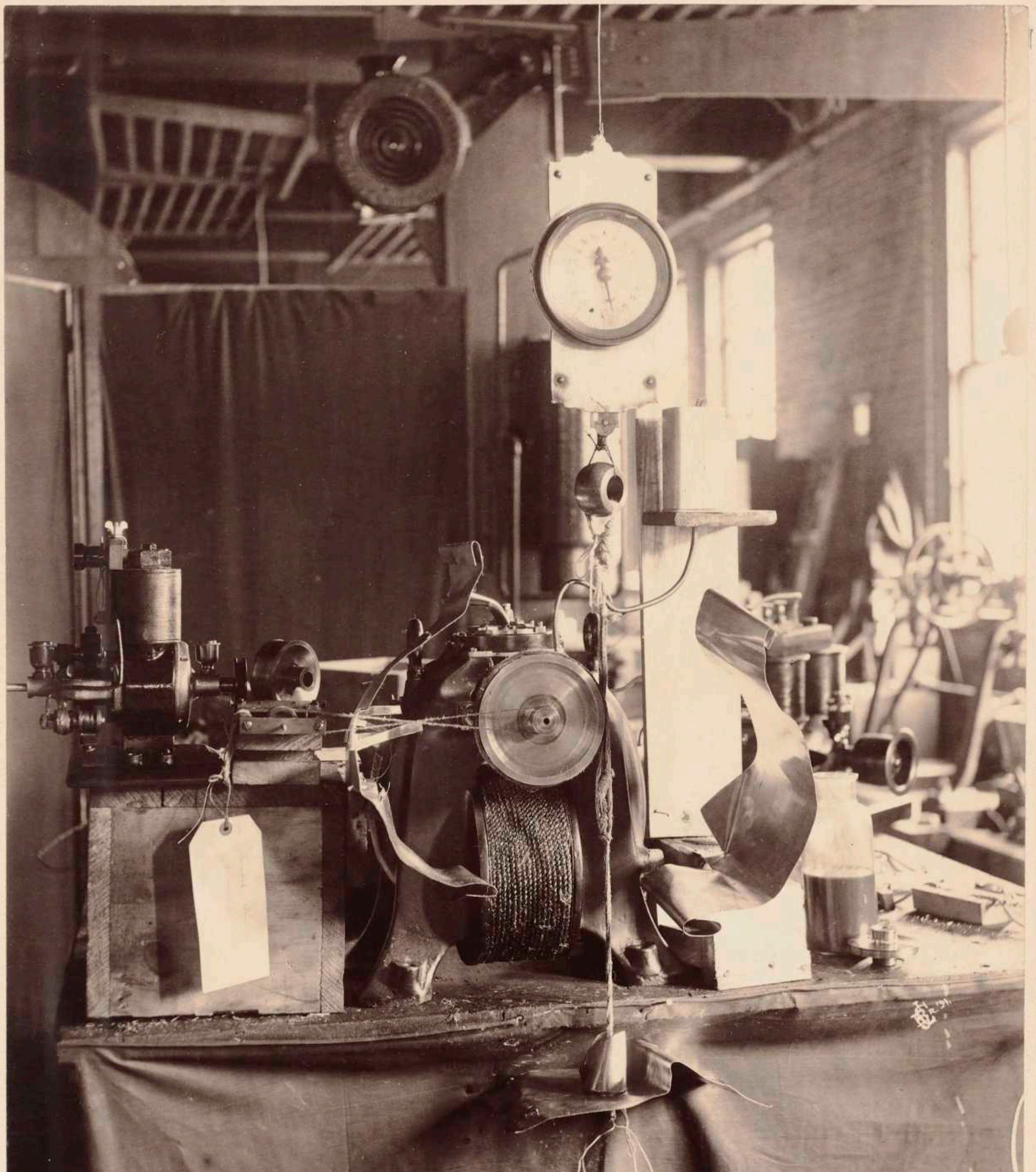
In all the tests, I found that the load falls off as the pulley becomes heated, and this quite rapidly at first.

This effect was, of course, most noticable with the high loads, and would seem to indicate, that the coefficient of friction decreases with rise of temperature of the rubbing surfaces.

Throughout the tests, it was necessary to keep the brake band saturated with oil. The lubricating oil used for this purpose, was conducted, from a small reservoir, by a bent brass tube to the upper part of the pulley.

The arrangement of the apparatus for the testing, with one of the motors in position, is shown in the photograph upon the next page.

Following are the results of the tests upon each machine; with a brief description of the construction of each.



The Crocker Wheeler Motor -

The Crocker Wheeler tested, is a simple Shunt motor running on constant potential 110 Volts, - and rated at $\frac{1}{6}$ H.P. - Speed of 2050 -

The armature is a form of Pacinotti ring, the winding being below the surface of the core, so that the magnets may approach very closely to the core, without fear of injury to the coils - "The armature is mounted upon a brass face-plate, which is first turned perfectly true and after completion the armature is very carefully balanced, so that when run at full speed the motion is hardly perceptible."

"The field magnets are composed entirely of the best wrought iron, each magnet being forged in a single piece, and set deeply into the base, thereby securing great solidity and ample magnetic contact. The space for wire on these magnets is perfectly cylindrical, in the form of an ordinary spool, thereby insuring smooth and perfect winding of the wire, and is short in length permitting the shaft of the machine to be low enough to free it from vibration."

"The bearings are all of the self-oiling type ..." "The base of the pillow-block is hollow, and contains a supply of oil which is carried over the shaft by two rings which travel upon the latter, and are caused to revolve by its motion. They dip in the oil and carry it continuously to the upper side of the shaft. The bushings or brasses in which the shaft runs, rest in turn in universal or ball joints in seats of babbit metal in the pillow blocks, so that the bearings are sure to assume perfect alignment when the shaft is introduced."

The brushes are fixed upon a rocker arm the connection being such that each brush may be moved through a limited space. A coiled spring makes it possible to regulate the bearing pressure of the brush.

The Crocker Wheeler Co. claim the advantage of slow speed in their machines. This is due to the comparatively large diameter of the armature.

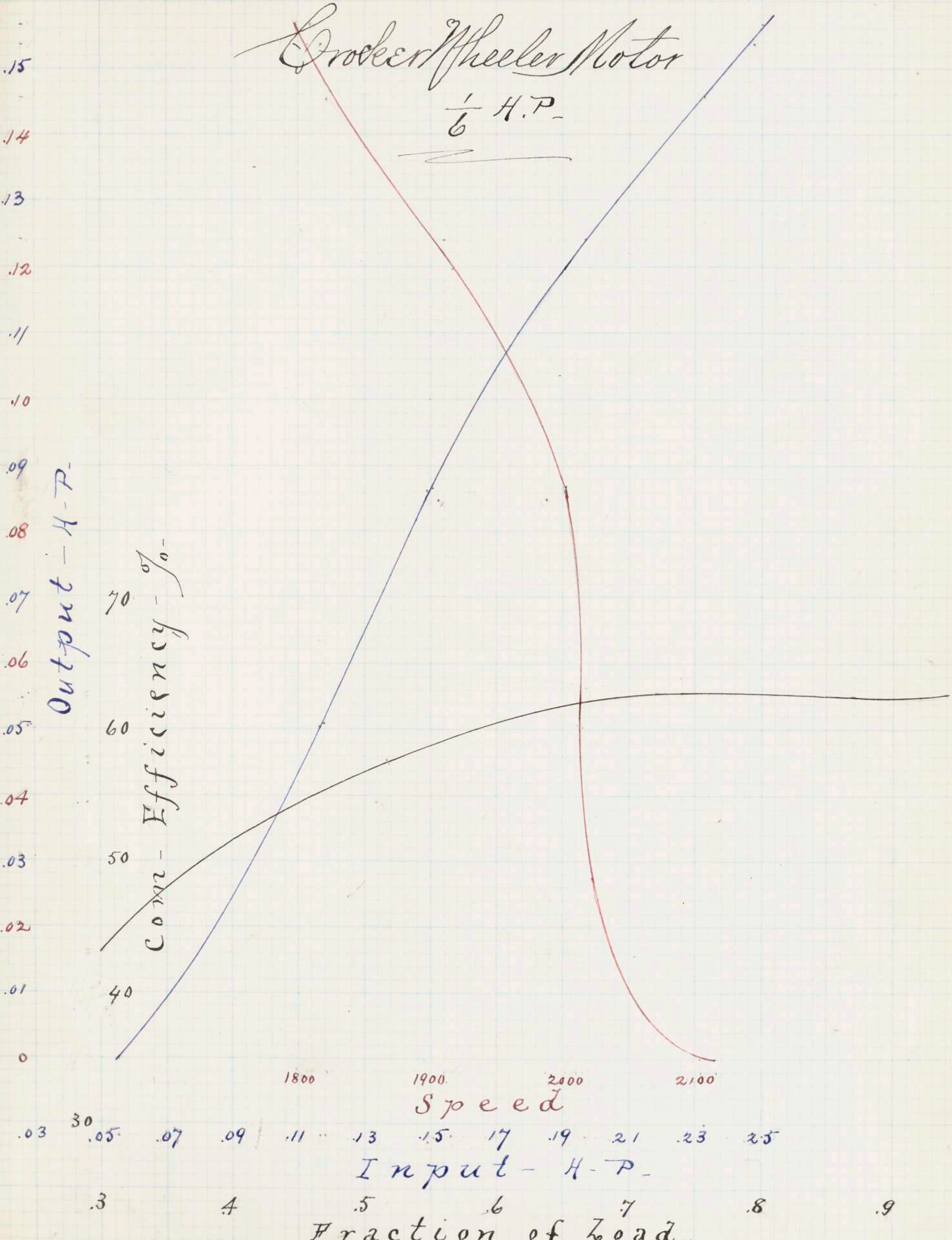
"The best double insulated wire is used throughout for the windings, the cores being first wrapped with oiled paper and heavy canvas saturated with shellac, and the motors are severely tested for insulation - - -"

In the starting device for this motor, a metal sector, having an insulated knob, is made to pass successively under four contacts. The field is made as soon as the switch touches the second contact, and the armature circuit is made at the third, through a small resistance coil. This coil is shortcircuited as the switch passes under the fourth contact.

There is a large amount of side-play for the revolving parts, a feature which, in the larger machines, is used in regulation, by changing the position of the armature relatively to the poles. This would also tend to produce a more uniform wearing of the commutator.

The Crocker Wheeler Motor

Time	Volts	C Amperes	Speed per min	Input H.P.	Output H.P.	Fraction of Load	Com'l Efficiency	
March 30	109	0.374	2104	.05465				
	109	0.379	2116	.05538				
	109	0.799	2015	0.1167	.05045	0.303	43.2%	C W
	109	0.807	2010	0.1179	.05061	0.304	42.9	C W
March 31	109	1.069	1988	0.1562	.08494	0.5095	54.4	C
	109	1.019	2002	0.1489	.08615	0.5168	57.9	C
	109	1.032	2002	0.1508	.08657	0.5193	57.4	C
	109	1.351	1910	0.1974	0.1240	0.7439	62.8	
	109	1.306	1917	0.1908	0.1199	0.7193	62.8	
April 1	109	1.593	1821	0.2328	0.1455	0.8728	62.5	
3d "	109	1.687	1807	0.2465	0.1538	0.9226	62.4	
	109	1.711	1799	0.2500	0.1564	0.9383	62.6	
4th "	109	0.388	2121	0.05669				
	109	0.389	2123	0.05684				


Crocker Wheeler Motor
1/6 H.P.
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
Output - H-P.
70
60
50
40
30
Com - Efficiency - %.
1800
1900
2000
2100
Speed
.03
.05
.07
.09
.11
.13
.15
.17
.19
.21
.23
.25
Input - H-P.
.3
.4
.5
.6
.7
.8
.9
Fraction of Load.

From the table, it will be seen, that there is a variation in the efficiency at different loads of about 20%.

That from .3 load, the efficiency rises from about 43%, to a maximum of 62.8% at a little under $\frac{3}{4}$ load; - and that from this point up to .94 load, it remains practically constant, falling very slightly.

This is very well shown on the plot.

The blue curve, drawn with Input and Output as co-ordinates, is first concave upward, then becomes concave downward, and finally becomes a straight line.

The falling off in the Speed as the load comes on, shown by the red curve, is rather peculiar. There is a considerable drop, as the load is put on, then it remains practically constant up to ½ load, - then falls off quite rapidly but at a nearly uniform rate.

The variation in speed from no load to 0.94 load is about 14.5 %.

A peculiarity about the Crocker Wheeler motor tested is, that at the higher loads there is bad sparking at the lower brush.

At this brush, the sparking persisted in spite of everything. Changing the brushes, and filing them, failed to remedy it.

On account of the difficulty in reducing this spark to fairly reasonable proportions, I concluded not to carry the tests above .94 load.

Aside from this sparking the motor runs very smoothly. The high efficiency of the machine, compared with the others, is due in part, it seems to me, to the self-oiling bearings.

The C & C Motors.

The two C. & C. machines tested, are of the same type, are shunt wound, designed for constant potential circuit of 110 Volts.

The armature is a form of Gramme ring. It revolves between salient poles, and is brought quite near to the base. The field coils, are placed just above the armature and are circular in section.

The $\frac{1}{4}$ H.P. machine has two pairs of brushes upon a rocker-arm. Each of the brushes may be adjusted; and any desired tension may be obtained, by turning the thumb-screws in the ends of the brush holders.

The brushes rest between thick metal strips, which keep the thin copper strips, of which they are made up, from spreading, and yet allows them soft pressure on the commutator-"

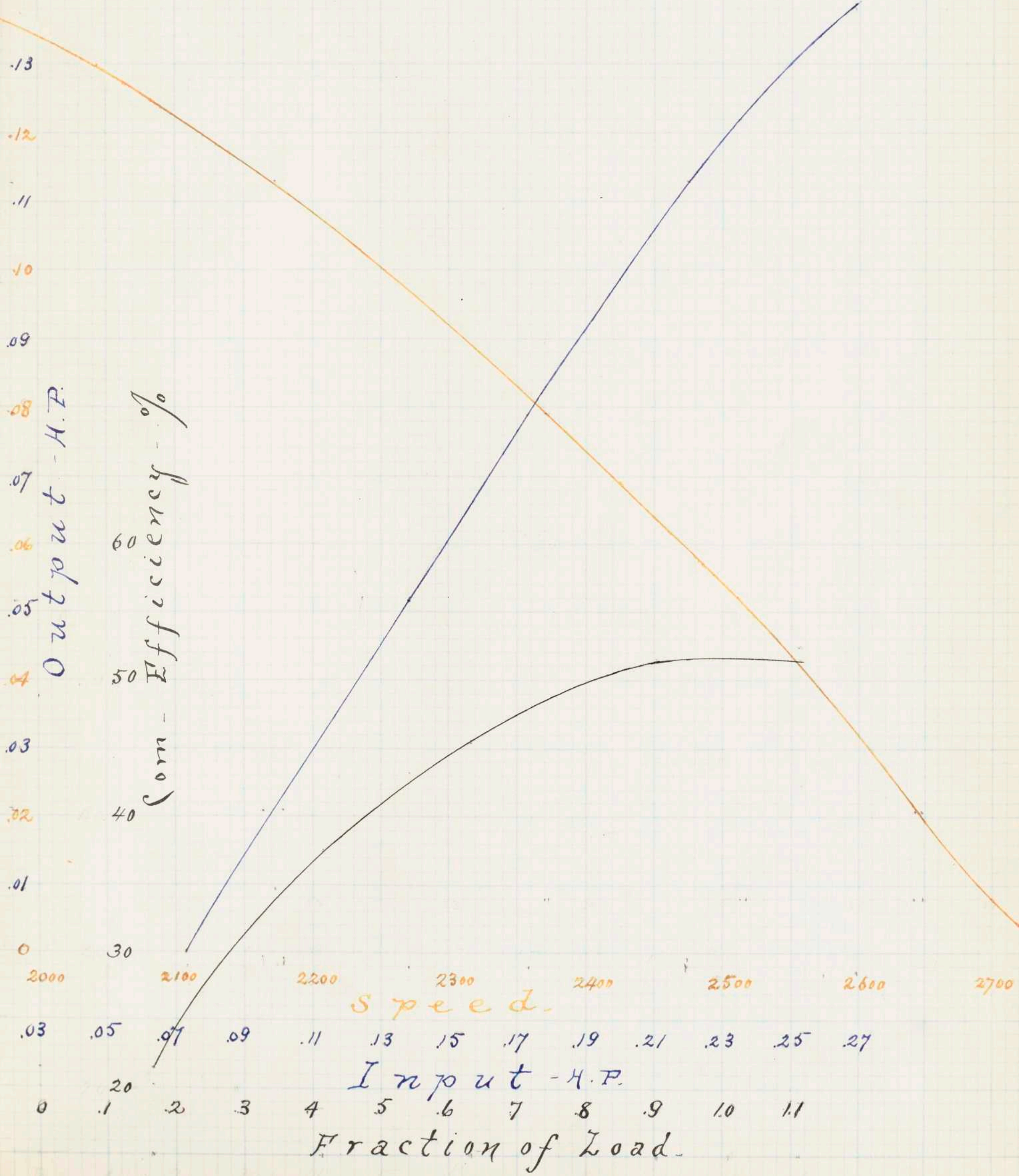
A resistance box is provided with this machine, sectioned so that the resistance in the armature circuit may be cut out or thrown in grad-ually-

The smaller machine has no rocker arm, but the brush holder con-nections are arranged to permit a considerable range of adjustment of the brushes - The commutator has 15 segments placed at a slight angle-

The C. & C. Motor — $\frac{1}{8}$ H.P.

Trial	Volts	Amperes	Speed	Input H.P.	Output H.P.	Fraction of Load	Efficiency
April 8	109	0.5041	2748	0.07366			
	109	0.5043	2748	0.07354			
25	109	0.6638	2649	0.09699	.02070	.01656	21.34 %
	109	0.7030	2641	0.1027	.02074	0.1659	20.21 "
9	109	0.9438	2516	0.1379	.05164	0.4131	37.45 "
	109	0.9460	2512	0.1382	.05161	0.4129	37.34 "
8	109	1.189	2372	0.1737	.07909	0.6327	45.53 "
	109	1.188	2370	0.1736	.07919	0.6335	45.62 "
	109	1.504	2173	0.2198	0.1126	0.9008	51.23 "
	109	1.509	2172	0.2205	0.1131	0.9048	51.29 "
	109	1.842	1958	0.2691	0.1380	1.104	51.28 "
	109	1.845	1946	0.2696	0.1386	1.109	51.41 "

C & C - Motor - $\frac{1}{8}$ H.P.



The results from the $\frac{1}{8}$ H.P. C&C motor, show a variation in the efficiency of about 30% - (from about 21% at .16 load to about 51% at .9 load) - The efficiency is but slightly different at .1 over-load -

The rise in the efficiency is shown, on the plot, by the curve in black -

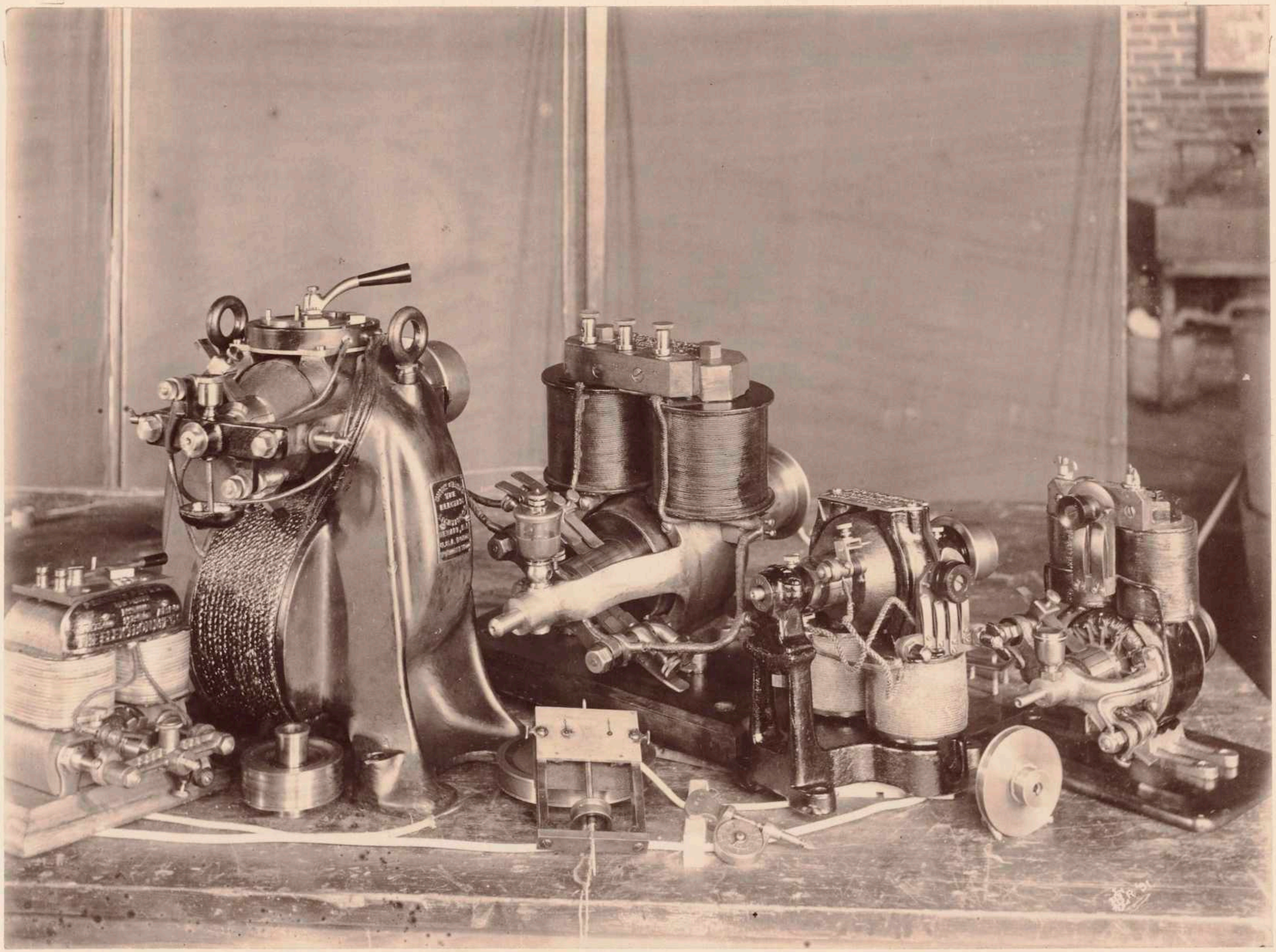
The curve in blue showing the relation between Input and Output is slightly concave downward -

The change in speed in this motor with change in load is from 2748 revolutions per minute at no load ~~to~~ 1946 at 1.109 load - 802 revolutions or about 29% variation -

The yellow curve is drawn with speeds (revolutions per minute) as abscissae, and Output in H.P. as ordinates.

As will be seen from the curve, the decrease in the speed is greater than the increase in the output, - the curve being, for the most part, concave downward.

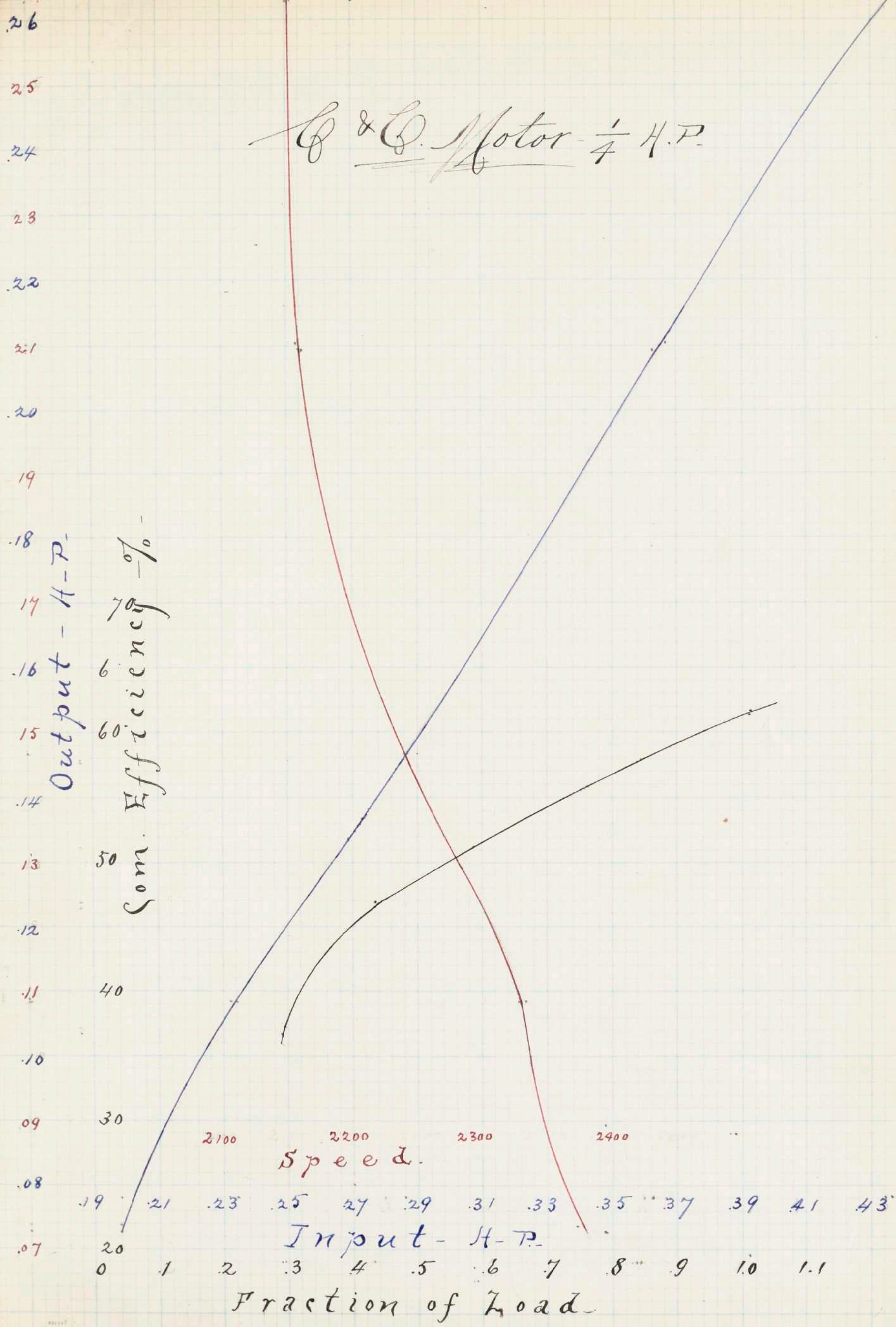
The $\frac{1}{8}$ H.P. C & C. Motor runs smoothly, with but slight sparking and very little heating.



United States ~ $\frac{1}{2}$ H.P.
Perret ~ $\frac{1}{8}$ H.P.
C & C ~ $\frac{1}{4}$ H.P.
Crocker Wheeler ~ $\frac{1}{6}$ H.P.
C & C ~ $\frac{1}{8}$ H.P.

The C. & C. Motor ¼ H.P.

Time	Volts	Amperes	Speed	Input H.P.	Output H.P.	Fraction of Load	Efficiency
April 17	109	1.356	2394	0.1981	0.07276	0.291	36.73%
	109	1.358	2372	0.1984	0.07384	0.295	37.22
	109	1.601	2329	0.2339	0.1084	0.4336	46.34
	109	1.586	2334	0.2317	0.1085	0.434	46.83
16	109	1.958	2241	0.2861	0.1466	0.586	51.24
	109	2.482	2161	0.3627	0.2095	0.838	57.76
	109	2.509	2157	0.3666	0.2115	0.846	57.69
20	109	2.971	2153	0.4341	0.2637	1.055	60.75
	109	2.986	2150	0.4363	0.2635	1.054	60.39
24	109	0.8266	2469	0.1208			
	109	0.8171	2494	0.1194			


C & C Motor ¼ H.P.
Output - H-P.
.26
.25
.24
.23
.22
.21
.20
.19
.18
.17
.16
.15
.14
.13
.12
.11
.10
.09
.08
.07
Com. Efficiency - %
70
6
60
50
40
30
20
Speed.
2100
2200
2300
2400
Input - H-P.
.19
.21
.23
.25
.27
.29
.31
.33
.35
.37
.39
.41
.43
Fraction of Load.
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1

In the ¼ H.P. C&C. Motor, the efficiency ranges from 36.73%. at about .3 load to 60.75%. at 0.055 overload - a change of 24%.

As shown on the black curve, the rise in efficiency is quite rapid from .3 to about .4 load, and is then very nearly proportional to the increase in load.

The ratio of input and output, is not far from being constant: but although the curvature is slight, it is peculiar, being concave upward in the middle and concave downward at the ends.

The speed changes from 2494 at no load, to 2150 at 1.054 load, - 344 revolutions - nearly 14%. The greatest change, apparent on the red curve, occurs between .4 & .8 load.

The heating is more noticable in the $\frac{1}{4}$ H.P. - C & C than in the $\frac{1}{8}$ H.P.

The Perret Motor.

This machine is shunt wound, to run at 110 Volts like the other motors, but its construction is different from either of the others.

The most noticeable feature, is in the field magnets. These are laminated, and are built up of "thin plates of softest charcoal iron, which are stamped directly to their finished form, and clamped to-gether by bolts, in such a manner as to secure great mechanical strength." The sections are perhaps 1/16" thick, placed at right angles to the armature shaft. This laminated core is rectangular in section.

The armature is of the drum pattern, the binding being of fine

german silver wire, insulated from the coils by thin strips of mica.
It is brought low down as in the C & C motors.

"The armature core is also laminated; and the plates have teeth which form longitudinal channels on its periphery, in which the coils are wound."

"The plates, in both field and armature, are in the same plane, and are of the softest charcoal iron, with its grain running in the direction of the line of magnetic force, and there is the least possible break in the continuity of the circuit ----."

"The armature shafts are of high grade steel." and the bearings are very long in proportion to their diameter. Hence the wear is very small."

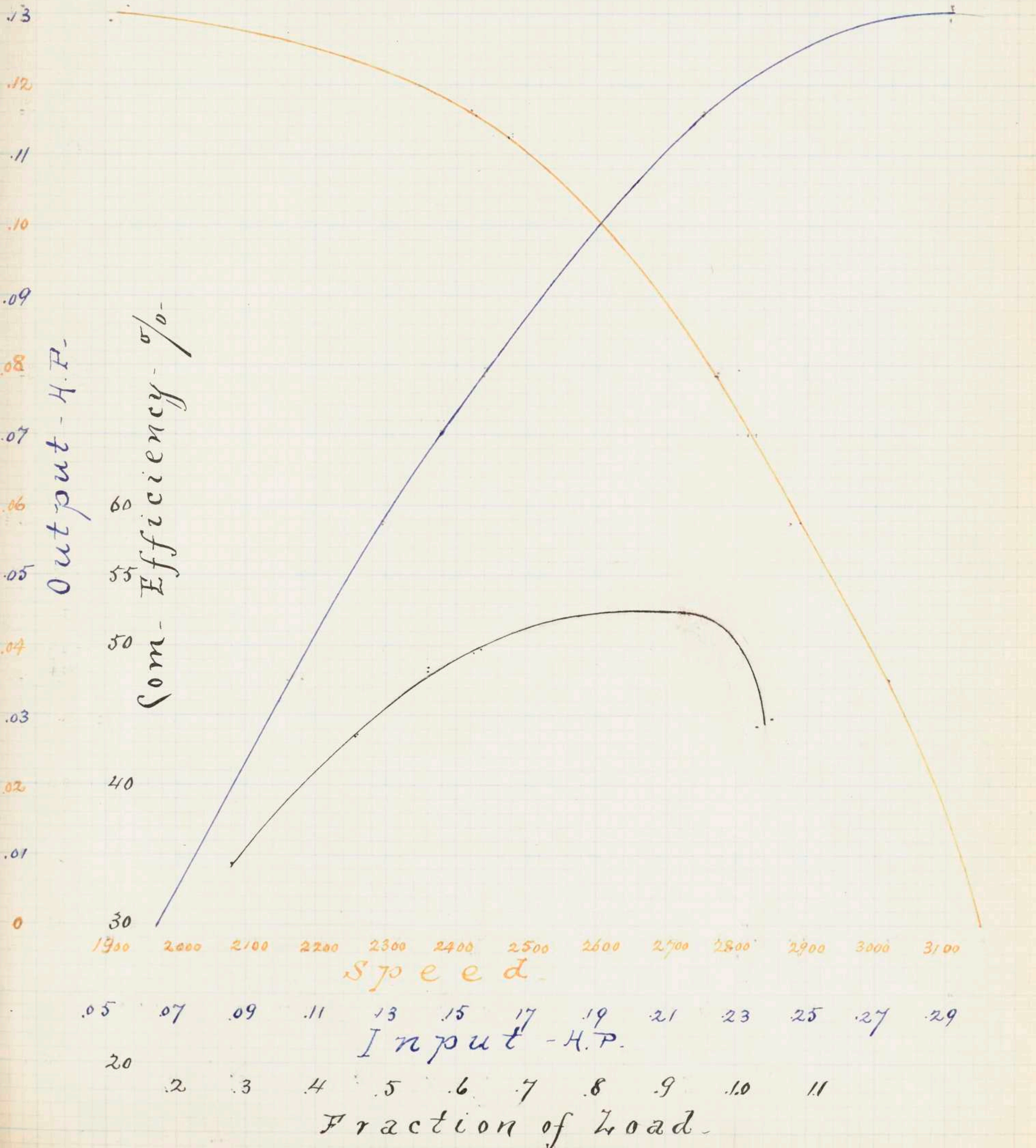
The armature and com-

mutator, are of very much smaller diameter than in either of the other machines.
The latter consists of 11 segments- The motor is rated at $\frac{1}{8}$ H.P. and stamped,- 1 Ampere, 110 Volts-

The Perret Motor. $\frac{1}{8}$ H.P.

Time	Volts	Amperes	Speed	Input H.P.	Output H.P.	Fraction of Load	Efficiency
April 30	109	0.6997	3018	0.1022	0.03510	0.2808	34.34%
29	109	0.8805	2877	0.1287	0.05729	0.4580	44.51
	109	0.8825	2888	0.1289	0.05755	0.4604	44.65
	109	0.9977	2816	0.1458	0.07002	0.56	48.02
	109	0.9928	2827	0.1451	0.07009	0.56	48.30
	109	1.082	2779	0.1581	0.07824	0.626	49.49
	109	1.087	2802	0.1588	0.07908	0.633	49.80
	109	1.512	2427	0.2209	0.1158	0.9264	52.42
	109	1.527	2421	0.2231	0.1162	0.9300	52.08
28	109	1.994	1907	0.2913	0.1289	1.031	44.25
	109	2.001	1931	0.2924	0.1311	1.049	44.84
30	109	0.4431	3147	0.06474			
30	109	0.4430	3153	0.06473			

Perret Motor - $\frac{1}{8}$ H.P.



In the Perret motor, the efficiency rises from 34.34 %- at .28 load, to 52.42 %- at .93 load, - an increase of 18.08 %-

The two tests at .03 - .05 overload, show a drop in the efficiency, from that at .9 load, of nearly 8 %-

These results plotted are shown by the black curve-

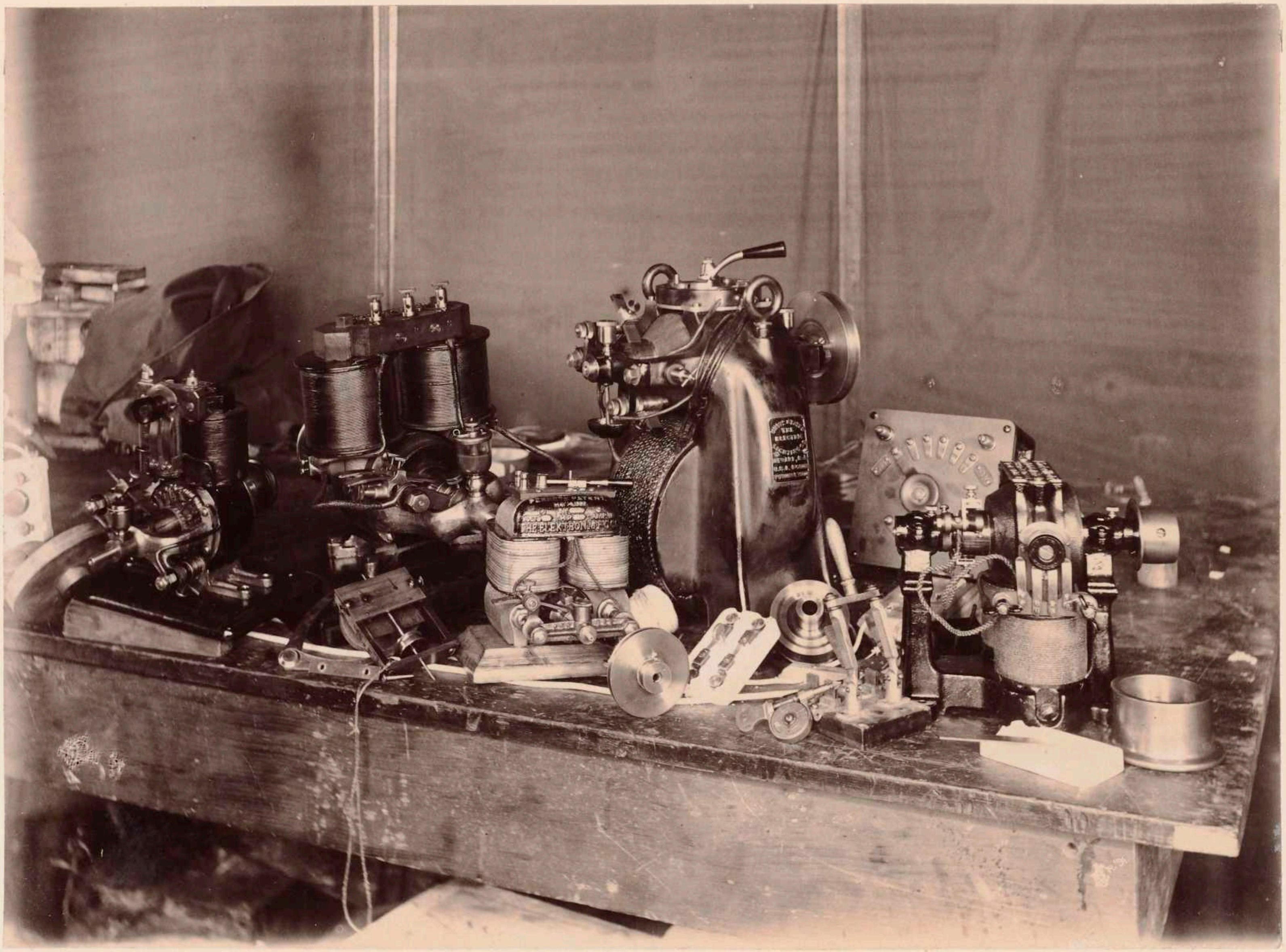
The speed falls off from about 3150, when running free, to about 1900, at slightly overload - a decrease of 1250 revolutions per minute, or about 39.7 %- The relation of speed and output, is shown by the curve in yellow.

The immediate cause of the drop in efficiency is seen by inspection of the yellow curve. The speed falls off 500 revolutions from .9 load, and as the load is but .1 greater, the ratio of output to input is smaller.

The Perret motor runs smoothly, with little sparking: but at the high loads, everything became very hot. At the overload test, the armature and the sections of the field magnet cores, were too hot to touch.

I am not prepared to say however, that the machine could not run for some time, at that at that temperature. Even 100° C is considered a safe temperature for the armature of a motor.

The drop in the efficiency, already spoken of, is probably the result of this heating.



C & C ~ $\frac{1}{4}$ H.P. United States ~ $\frac{1}{2}$ H.P.

C & C ~ $\frac{1}{8}$ H.P. Perret ~ $\frac{1}{8}$ H.P. Crocker Wheeler ~ $\frac{1}{6}$ H.P.

The United States Motor.

This motor was the largest one tested, and is rated at $\frac{1}{2}$ H.P.
It is shunt wound - Speed 1700 revs. per minute @ 110 Volts.

The features of its construction are as follows;

Its shape is such, that all vital parts are well protected from injury. "The field is made in the shape of a horse shoe, cut in the center, and fastened to-gether by bolts.

There is but one field coil wound upon a movable spool.

This construction, makes but one joint in the machine, and renders removal and replacement of the field coil extremely simple."

"The armature is built up of

discs of decarbonized steel, which has been found to be the best material for the purpose. These discs are firmly secured to a steel shaft. The coils and bands are entirely below the surface of the armature." This allows the coils to approach very near to the poles, and also protects the wires from injury.

"The winding of the armature, and the proportion existing between it and the field, are such as to give a fixed point of commutation, thus overcoming the necessity of changing the position of the brushes on the commutator, however the load may vary, and entirely avoiding a spark.

The commutator is made very heavy, of pure copper strips insulated by mica."

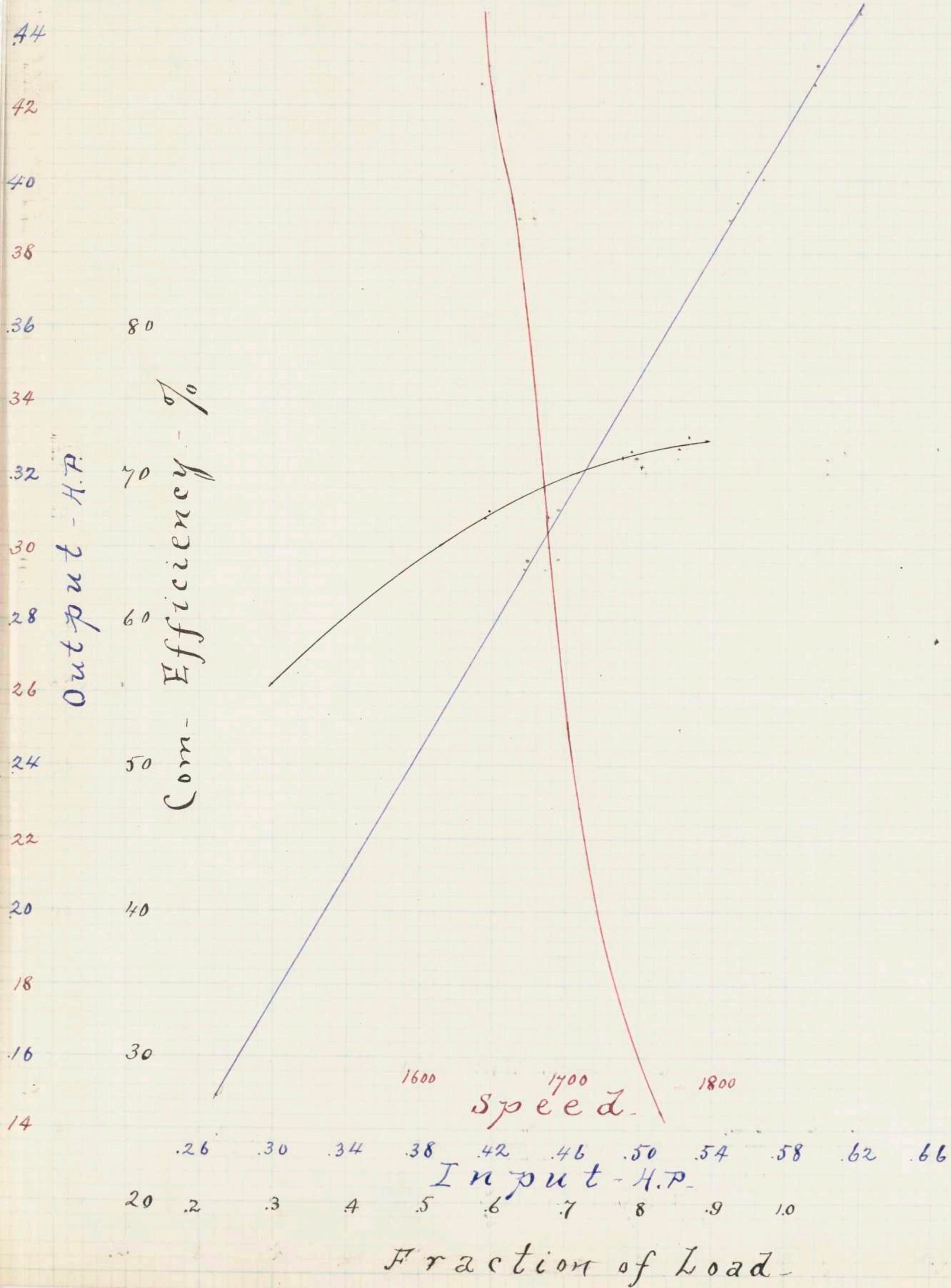
The brush holder, is rigidly attached to the frame, and the position of the brushes cannot be changed very much. The bearings are made of "special hard bronze".

The particular feature of the motor, is in the starting and stopping device, and the fact of its being located on the motor itself. The switch is placed on the top of the motor, the sections of the ring being connected to resistance coils, which are wound with the field coils.

The United States Motor – ½ H.P.

Time	Volts	Amperes	Speed	Input H.P.	Output H.P.	Fraction of Load	Efficiency
May 7	109	0.793	1866	0.1157			
	109	1.838	1765	0.2686	0.1491	0.2982	55.51%
	109	1.841	1766	0.2690	0.1493	0.2986	55.35
	109	2.999	1686	0.4382	0.2937	0.5874	67.02
	109	3.011	1694	0.4399	0.2967	0.5934	67.45
6	109	3.747	1667	0.5475	0.3887	0.7774	71.00
	109	3.778	1662	0.5520	0.3936	0.7872	71.30
	109	3.889	1652	0.5682	0.4002	0.8004	70.43
8	109	4.068	1640	0.5944	0.4261	0.8522	71.69
	109	4.075	1646	0.5954	0.4312	0.8624	72.42
5	109	4.220	1646	0.6166	0.4451	0.8902	72.19

United States Motor - $\frac{1}{2}$ H.P.



From the table of results from the United States motor, it will be seen, that the efficiency ranges from 55.51 %.- at about .3 load, to 72.4 %. at .86 load - A difference of nearly 17 %.-

I did not succeed in getting a test above .89 load, because the friction did not increase sufficiently, even with 20 cords in the brake band - The tests upon this motor, were made with the largest brake pulley of diameter of about $4\frac{7}{8}$".

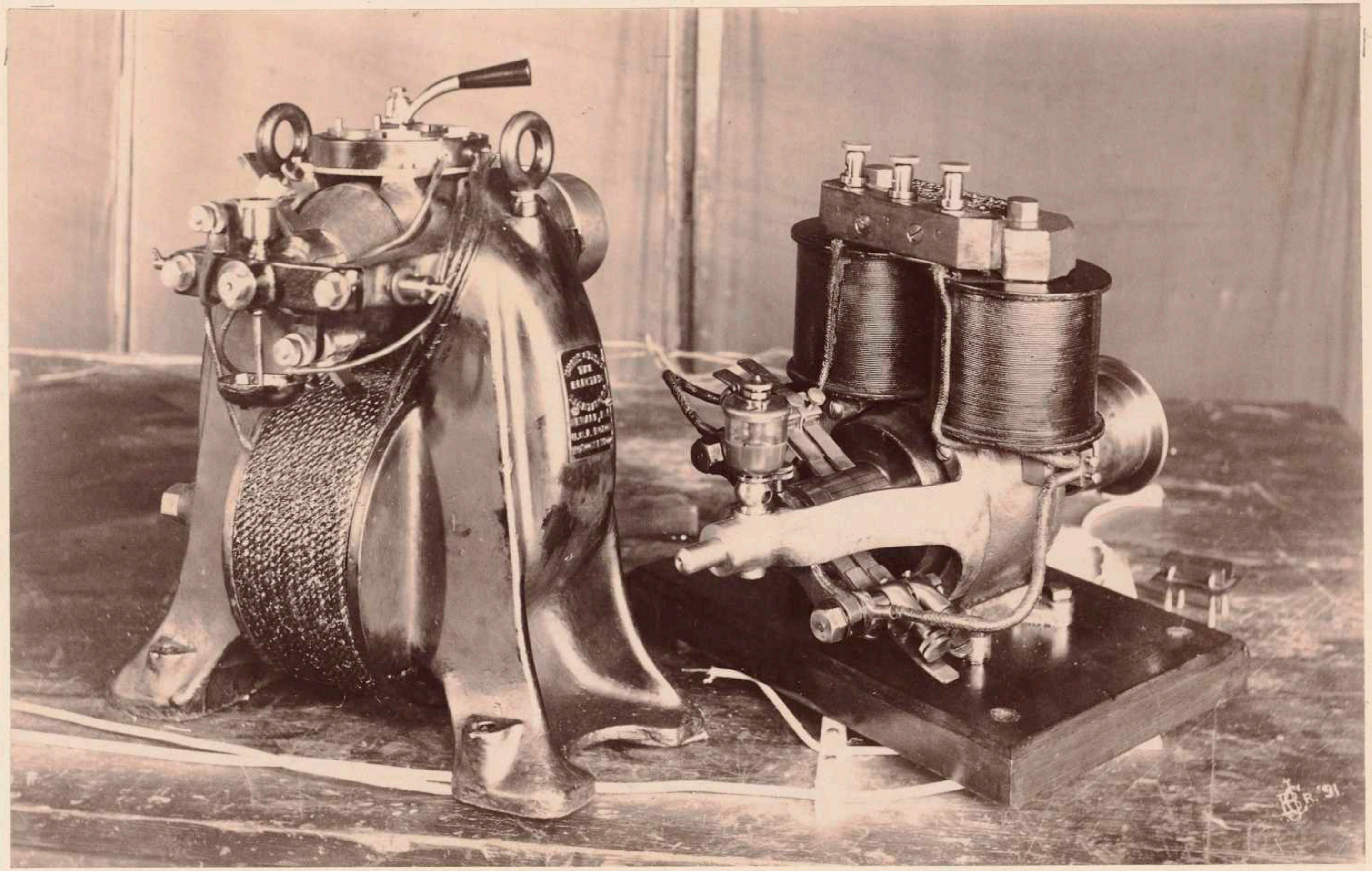
I think the higher loads could be obtained, without difficulty, if a 6" or $6\frac{1}{2}$" pulley were used.

The efficiency curve, as heretofore, is shown in black -

The variation of speed with change of load, is shown by the red curve - The speed changes from

1866 at no load, to 1646 at .89 load, -220 revolutions per minute or 11.79 %-

From the blue line, it is evident that the ratio of Input to Output is a constant-



United States Motor. C & C Motor – 1/4 H. P.

From the forgoing series of Commercial Efficiency tests, the following table shows the more important of the results, viz; the maximum efficiency obtained from each motor, the difference in efficiency from .3 to .9 load, and the percentage variation in speed from no load to about .9 load.

Motor	Maximum Efficiency	Difference in Efficiency	Speed Variation
C. & C. – $\frac{1}{8}$ H.P.	51.4 %.	.3 – .9 Load 20	0 – .9 Load 20.96 %.
Perret – $\frac{1}{8}$ "	52.4 "	.28 – .93 Load – 18	0 – .9 Load 21.4 "
C. & C. – $\frac{1}{4}$ "	60.8 "	.3 – .9 Load 22	0 – .9 Load 13.6 "
Crocker Wheeler – $\frac{1}{6}$ "	62.8 "	.3 – .9 Load 20	0 – .9 Load 14.0 "
United States – $\frac{1}{2}$ "	72.4 "	about .3 – .86 Load – 17	0 – .89 Load 11.8 "

The results in the second column, show clearly the rise in the commercial efficiency as the size increases – A direct comparison of the two C & C motors, machines of the same type, gives a gain of nearly 10 %- for the larger one-

The tests show a steady rise, of from 17 to 22 %- in efficiency, as the load comes on, the maximum being reached between 3/4 & 9/10 load.

The greatest rise in efficiency, occurs in the C. & C. 1/4 H.P., the least in the United States motor- Also from the table, it will be seen, that the speed variation is greatest in the Pemb motor, the United States machine approaching most nearly to a "constant" speed motor.

The variation in speed, as would be expected, is inversely as the capacity-

In addition to the Commercial Efficiency tests, the power expended in the field magnets was determined, and also the horse power developed per pound weight.

For the former test, the machines were connected in parallel and allowed to run for about two hours and a half, to ensure thorough heating. They were then disconnected, and the field currents measured as quickly as possible.

In the latter test, the weight of each motor, complete, was measured carefully to ounces on a small platform scale (Fairbanks) weighing to about 300 lbs.

The rated H.P. of the motor, divided by its weight in lbs., gives the horse-power developed per pound weight, or the Weight Efficiency.

The results from these tests are given in the table. The maximum efficiency is also inserted here, to aid in comparison.

Motor.	Size	Weight.	H.P. developed per lb. wt.	Current in Field Amp.	H.P. used in Fields	Max Efficiency.
Perret	$\frac{1}{8}$	17.81 lbs	0.007019	0.273	0.03989	52.4%
C. & C.	$\frac{1}{8}$	18.24 "	0.006853	0.300	0.04383	51.4 "
Crocker Wheeler	$\frac{1}{6}$	26.03 "	0.006404	0.205	0.02995	62.8 "
C. & C.	$\frac{1}{4}$	60.07 "	0.004162	0.218	0.03185	60.8 "
United States	$\frac{1}{2}$	138.1 "	0.003621	0.320	0.04676	72.4 "

From these results, it will be noticed that the weight efficiency of the several motors, varies inversely as the capacity. The Perret motor, gives the highest result — nearly twice the power per pound weight, as the United States machine. Also, the current for the fields is least in the Crocker-

Wheeler and greatest in the United States motor. The small current necessary in the fields of the Crocker Wheeler, is significant when its high efficiency is considered.

Considering now, the precision in the final results. In this discussion, three tests are omitted,-viz:-the two lower tests on the C&C $\frac{1}{8}^{th}$ H.P. motor, and the lowest test on the Perret machine. This is on account of the small diameter (1") of the brake pulley used.

The precision sought is, <u>one</u> percent-[1%]. Now;—

$$\eta = \frac{2\pi r n W \times 746}{C E \times 33,000.}$$

where;

η = commercial efficiency.

r = radius of brake pulley in feet.

n = no. of revolutions per minute.

W = effective load in lbs. at circumference of brake pulley.

C = current in amperes.

E = electomotive force [E.M.F] in volts.

By the Method of Equal Effect;

$$\frac{\Delta\eta}{\eta\sqrt{5}} = \frac{\delta r}{r} = \frac{\delta n}{n} = \frac{\delta W}{W} = -\frac{\delta C}{C} = -\frac{\delta E}{E} = \frac{.01}{\sqrt{5}} = 0.00446$$

Of these quantities, the voltage is assumed correct within one volt. By the method of Equal Effects,- the allowable δ, is 0.49 volt. Since $\delta E = E \times .00446 = 109 \times .00446 = 0.49$.

The error in n is negligible, because the calculation gives its δ, - 7.34 revolutions per minute or 36.7 i.e. 37 revolutions for 5 minutes, in the case of the smallest n in the series, viz; 1646; - and this δ is easily within the limits of error of reading and the error in the counter itself [correct to .2%].

The error introduced by r is within the limits of precision, if the radius of the smallest pulley be measured to 0.00651 of an inch or the diameter to 0.01302": for $\frac{\delta r}{r} = .00446 \therefore \delta r = .00446 \times 1.4604 = 0.00651$

The pulleys were measured accurately, at frequent intervals, the diameters being found to $\frac{1}{100}$th inch in nearly all cases, and to $\frac{1}{64}$" inch in the remainder.

Since $\frac{\delta r}{r} = \frac{x}{\sqrt{5}} = \frac{x}{2.24}$, $x' = \frac{\delta r}{r} \times 2.24 = \frac{\frac{1}{100} \times \frac{1}{2} \times 2.24}{1.4604}$

$\therefore x' = 0.0077$ also $x'' = \frac{\frac{1}{64} \times \frac{1}{2} \times 2.24}{1.4604}$

$\therefore x'' = 0.0120$.

That is, in the cases where the diameters were measured to $\frac{1}{64}$" in. the precision was decreased by 0.2 %; while in all others, the effect upon the final result, being but .7 %, the error was negligible.

The ammeter scale, was divided into $\frac{1}{2}$ tenths of amperes, so that by estimating tenths, the reading could be obtained to .005 Ampere. Considering this the greatest precision attainable, the error introduced is within the limits, if the current is 1.121 Amps. i.e. $\frac{\delta c}{c} = .00446$ $\therefore c = \frac{.005}{.00446} = 1.121$. In the tests in which $c < 1.121$, the precision will not be decreased more than 0.4 %. For the smallest current considered, is 0.799 Amp.

Hence by the method of Equal Effects, –

$$\frac{\delta C}{C} = \frac{\delta \eta}{\eta\sqrt{5}} \quad \text{i.e.} \quad \frac{0.005}{0.799} = \frac{x}{2.24} \quad x = \frac{0.005 \times 2.24}{0.799}$$

$x = .01402$ or 1.4 %.

Considering the last factor

W. The balance is divided into half ounces. Now, taking 0.1 of an ounce as the δ in the scale reading, this error is allowable if **W**, i.e. w – w, is 1.4 lbs. (w = wt. in scale pan plus wt. of pan etc. and w = balance reading, mean)

$$\underline{W} = w - w \quad \therefore \quad \delta \underline{W} = -\delta w.$$

$$\frac{\delta \underline{W}}{\underline{W}} = .00446 \quad \therefore \underline{W} = \frac{\delta \underline{W}}{.00446} = \frac{0.1}{0.00446} = 22.42 \text{ oz.}$$

or $\underline{W}$ = 1.40 lbs.

To find the effect produced by the smallest **W** in the tests viz. 0.8594 lb.

Since by Equal Effects, – $\frac{\delta \underline{W}}{\underline{W}} = \frac{\delta \eta}{\eta\sqrt{5}}$,

$$\frac{\delta \underline{W}}{\underline{W}} = \frac{x}{2.24} \quad \frac{0.1}{13.75} = \frac{x}{2.24}$$

$$\therefore x = \frac{.224}{13.75} = 0.0163 \text{ or } 1.63\%.$$

That is, the precision in the final result is diminished 0.63 %. by this VI.

In conclusion it may be said, that, aside from the voltage, the greatest effects are due to the current and effective load: the maximum being, in the case of the current, 0.4 %. and in that of the effective load (W) — about 0.6 %. The tests affected, are checked in the margin of each table. In all others (excepting of course the 3 tests beforementioned & marked thus - o), the errors due to these factors are negligible.

The factor producing the greatest diminution in the precision is the voltage. This was assumed, because of the insufficient number of reliable instruments in the department. An accurate volt meter, should have been placed at the motor terminals, and the voltage taken as often as were the balance and ammeter readings.

Now since $\frac{\delta E}{E} = \frac{\Delta \eta}{\eta\sqrt{5}} = \frac{x}{2.24} \therefore \frac{1}{109} = \frac{x}{2.24}$

$$\therefore x = \frac{2.24}{109} = 0.0206 \text{ or } \frac{\Delta\eta}{\eta} = 2.06\,\%.$$

That is, the final results i.e. the Commercial Efficiencies cannot be relied upon to a precision greater than 2.06 %.

Although the voltage is the least precise of the several quantities, the calculation of the others has been given for the sake of completeness.

Oct. 16, '91.

Bernard Capen, Jr.

So. Boston, Mass.