

T H E S I S

T H E I N T E R P O L E M O T O R

by

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The Interpole Motor.

Introduction

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not to be taken 378.73

The Interpole Motor.

Among the many improvements that have been embodied in the construction of direct current motors, none are of more importance than the interpole, the feature of which did not become general until the last few years. The general idea of providing a special field for the purpose of producing sparkless commutation, is an old one, but it is only recently that designers have gone to providing the extra pole pieces to effect the result. The advantage of the commutation pole construction lies in the fact that the commutation can be rendered practically perfect under all conditions of load and speed.

On account of the cost of adding the commutating poles and the decrease in ventilation caused by their presence, it is claimed that the interpole construction is, in general disadvantageous. It is claimed by some that cheaper and more efficient machines can be obtained by omitting the special poles, and depending solely upon the careful arrangement of the armature coils, the selection of the proper number of commutator segments, and the employment of the correct shape for the pole faces. These designers claim that the maximum speed of a given machine, when properly proportioned, is limited by mechanical consideration and not by sparking, so that the addition of interpoles, to prevent sparking is useless.

Lower speed can be obtained easily, without sparking by strengthening the field, but only at the sacrifice of output, and the output cannot be increased by adding commutating poles. The advocates of the interpole design claim that by the use of

interpoles, the whole machine can be so redesigned that considerable saving can be effected in material, the efficiency can be raised, and the working of the machine greatly improved.

The best design for commutating pole machines, requires an increase in the proportion of copper to iron as compared with the proportion in machines without interpoles. Hence, it is probable that they will be more expensive.

While the question of regulation is of leading importance in alternating current, generators, for continuous current dynamos, good commutation is the most important requirement. Machines may be required to run with sparkless commutation from zero load to fifty per cent overload, with fixed brush position, and sometimes they may be required to run without detrimental sparking even as high as 75 per cent overload for a short time, which is sometimes the case with motors in practice. In order to produce perfect commutation, the short-circuited coil under commutation must have the current in it reduced to zero, and an equal current set up in the opposite direction. If this condition is not fulfilled when the coil leaves the brush it offers a high resistance to the heavy on-coming current due to the induction of the coil; hence, since the current will take the easiest path, it jumps through the air to the brush, rather than passing thru the coil. Hence, there is sparking at the brushes. In the interpole or commutating pole designs the use of the interpole is to set a current up in the opposite direction in the short-circuited coil.

In cases where the commutation is poor due to inherent designs, as for instance to high reactance voltage, it is well known that improvement is sometimes effected by cutting off a portion of the pole tips, thus decreasing the pole arc and consequently the armature distortion. This is often an impracticable modification because of the higher field excitation required and hence the extra heatings. The best way to overcome this fault of too high reactance voltage is by use of interpoles, as suitably proportional interpoles provide good commutation under all conditions.

The interpoles, which are small intermediate pole pieces, provided with series windings, give a cross magnetization, which opposes that created by the armature windings, thus preventing that displacement of the field, which is often the source of sparking. Interpole motors are practically valuable for use in industrial plants, where they are required to operate over a great range of speed. They are also being used extensively as railway motors.

Magnetization Curve and Relation of Speed to Excitation.

The magnetization curve (sheet No. 3) was plotted to the same scale as the curves showing the relation of speed to excitation. From formulae E equals $S d V p / 10^8 - 60 - 2p'$ V equals $E/d \times K$, where (K) is a constant and where (p) equals the number of poles, (p') the number of paths in parallel, (S) equals number of conductors and (d) equals induction. Since V equals $E/d \times K$, it is evident that when the counter E. M. F. is constant, the speed varies inversely as the magnetic induction, which is the condition when the machine is running light.

Curves 1 and 2 in Plate I were plotted with speed as abscissa and field current, as the coordinate. 1 was taken without the interpoles connected, while number 2 was taken with the interpoles connected. The curve taken without the interpoles connected, has higher speeds for the same values of field current than the one taken without the interpoles connected. This is due to the fact that the flux of the interpoles works against the magnetism of the poles, thus reducing the flux. Therefore, the motor has to run faster to generate the same counter E. M. F. that it did without the interpoles connected.

From (A) to (B) curves # 1 & 2, the machine is running slow with heavy field, and is working above the knee of the magnetization curve, where the iron shows the effects of saturation. For high speeds, the machine is working on the straight part of the curve, where the permeability is high. The curves (A) & (B) almost coincide until the lower part of curves are reached; here there is a marked separation, due to the

fact that for low values of field current the field is weak, hence the demagnetizing action of the interpole is greater in proportion than for stronger fields.

The magnetization curve is straight for the high speeds and shows, but slightly the saturation effects at low speeds.

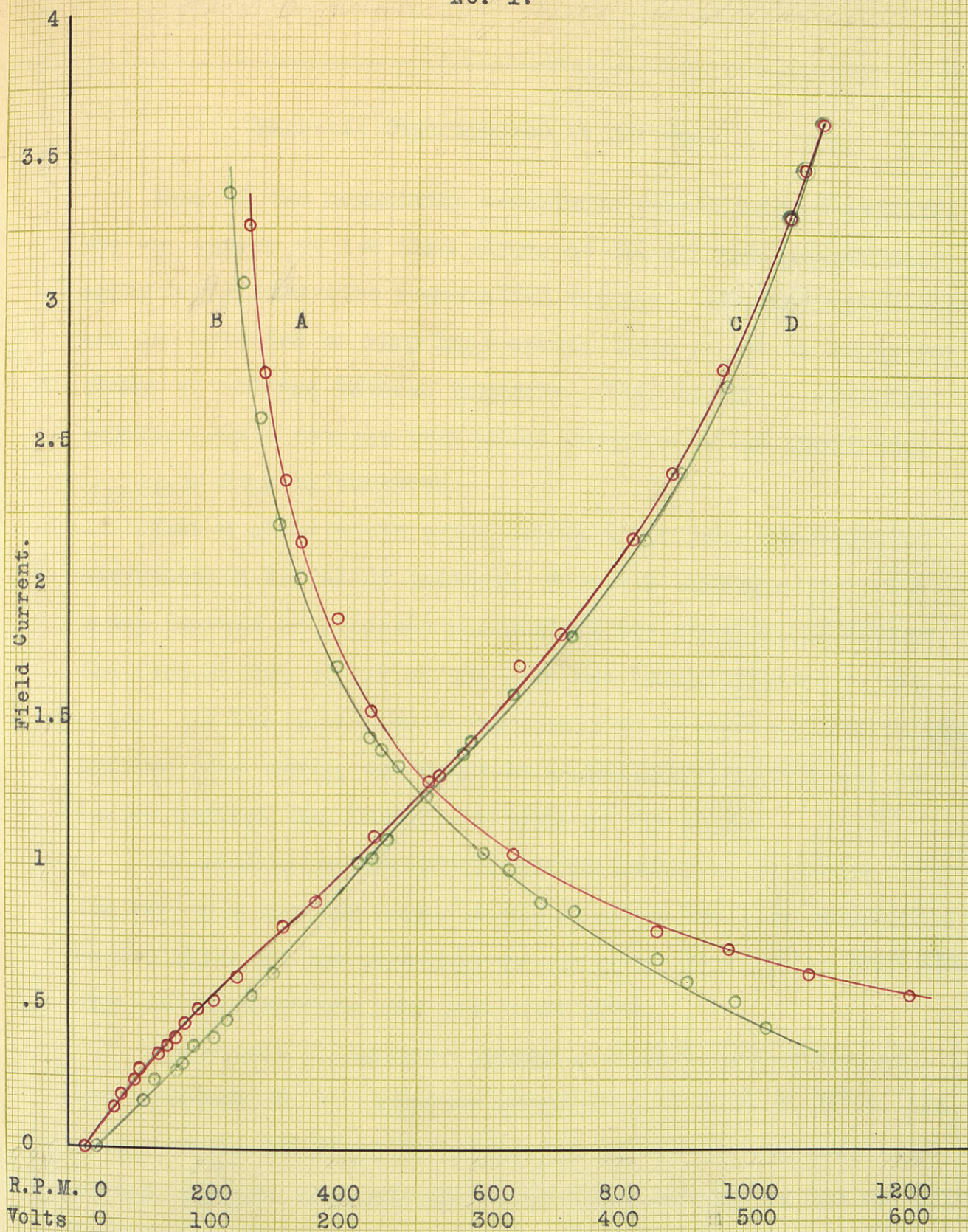
Data For Magnetization Curve.

Ascending				Descending	
E. M. F.	Field A M P	E.M.F.	Field A M P	E.M.F.	Field A M P.
10	0	512	3.3	512	3.54
32	.15	524	3.45	470	2.76
38	.2	536	3.62	432	2.4
48	.25			408	2.16
53	.28			358	1 82
67	.35			316	1 62
71	.37			287	1 46
78	.47			268	1 32
85	.45			228	1 1
94	.5			218	1 05
100.5	.57			186	.88
120	.62			166	.78
137	.71			150	.7
152	.79			132	.62
175	.875			116	.55
206	1.05			104	.48
217	1.1			92	.42
260	1.33			84	.38
280	1.44			80	.32
310	1.57			66	.3
350	1.87			58	.26
400	2.17			475	.2
428	2.4			115	0
466	2.75				

Relation of Speed to Excitation.

With Interpoles		Without Interpoles	
Field Cur.	Speed	Field Cur.	Speed.
3.27	262	3.38	239
2 74	289	3.06	256
2 38	315	2 58	280
2 39	315	2 22	308
2 14	338	2 02	336
1 8	388	1 71	386
1 55	438	1 47	436
1 42	476	1 35	472
13	518	1 24	512
1 18	616	1 04	594
1.04	636	.99	630
.87	678	.83	724
.77	842	.66	842
.7	944	.58	884
.61	1060	.52	958
.54	1202	.44	1000

No. 1.



Magnetic Distribution in Air Gap.

Many of the commutator troubles in direct current machines are due either to too high values of the voltage between segments or to excessive commutation voltage. If shunt-wound motors are operated at very high speeds there is apt to be an increase of voltage between segments. This is due to armature reaction which becomes very great relative to the field when the field flux is weakened.

When a shunt wound motor is run at no load the magnetic distribution is fairly uniform. When the armature carries a heavy current it produces a magnetomotive force which weakens the flux on one corner of the pole and strengthens it on the other. If the main flux is very weak as in case of high speeds, and the load heavy, the armature magneto-motive force may actually reverse the flux on one side of the pole.

The winding on the interpoles is connected in series with the armature and the turns so proportioned that the magnetomotive force of the interpole is greater (from 14% -- 40%) than that of the armature over the brush area.

The object in using an excess of magnet-motive force at the interpole is to cause the generation of an E. M. F. of the proper value and sign, to reduce the current in the short-circuited coils to zero and set up an equal current in the opposite direction. This current produces the flux that is essential to perfect commutation. The induction effect of the current in the short-circuited coil tends to retard the reversal of current in the coil.

Magnetic Distribution in Air Gap at 280 R. P. M.,
No Load, with Interpoles.

Magnetic Degrees.	Voltage	Degrees	Voltage	Deg.	Voltage	Deg.	Volt.
0	0		162		164	720	1.5
	5	250	148		176		
	12.5		135	500	188		
	20		112		192		
	33.5		96		210		
50	.51		83.5		206		
	67.5	300	66		208		
	83		46	550	204		
	102.5		32		196		
	124.		21		184		
100	147		13		172		
	162	350	9		156		
	176		0	600	140		
	184		1		124		
	200		6		104		
150	204		15.5		86		
	208	400	29.5		71		
	208		48	650	53.5		
	203		62.5		38		
	200		81		25		
200	200		98		10		
	198	450	122		7		
	189		134	700	3		
	176		150		1.5		

Magnetic Distribution in Air Gap at 280 R. P. M,
No Load, Without Interpoles.

Deg.	Voltage.	Deg.	V.	V..	Deg..	V..	Deg.	V.
0	0			140		152	720	0
	2	250		126		172		
	5.5			108	500	186		
	11.5			92		194		
	31			75		202		
50	46			56		208		
	62	300		41.5		208		
	82.5			27	550	205		
	93			11		195		
	121			5		184		
100	141			1		180		
	163	350		.1		175		
	176			0	600	160		
	184			1.2		144		
	195			6		132		
150	203			12.		108		
	208	400		23		88		
	205			43	650	69		
	205			58		52		
	203			68		36		
200	197			94		21		
	188	450		102		11		
	176			125	700	5		
	156			140		1		

Magnetization Distribution in Air-Gap at 700 R. P. M.,
No load, with Interpoles.

D.	V.	D.	V.	D.	V.	D.	V.
0	0		160		133	700	35
	4.75		147		140		3
	12	250	129		171	720	00
	15		111		185		
	37		92	500	198		
50	53		68		201		
	70		55		213		
	88	300	52		213		
	107		38		210		
	126		22	550	197		
100	143		11		196		
	160		6		184		
	177	350	.5		173		
	188		.5		156		
	198		3	600	138		
150	205		11	600	119		
	208		19		101		
	210	400	34		84		
	208		40		69		
	205		67	650	52		
200	200		83		36.5		
	192		100		24		
	176	450	120		13		

Magnetization Distribution in Air Gap at 700 R. P. M.,
No load, Without In terpoles.

D	V.	D.	V.	D.	V.	D.	V.
0	0		152		136	700	12
	8		132		152	700	4
	17	250	116		166		-1
	26		102		182	720	-1
	295		86	500	198		
50	54		70		209		
	74		56		214		
	92		38		215		
	110	300	24		212		
	126		15	550	200		
100	148		5		196		
	160		1		187		
	180	350	-1		176		
	188		-2		170		
	203		4	600	160		
150	212		11		147		
	212		18		117		
	126	400	33		103		
	208		51		183		
	200		68	650	66		
200	194		82		54		
	184		101		36		
	164		122		24		
		450					

Magnetic Distribution in Air Gap at 1000 R. P. M.,
No Load, With Interpole.

D.	V.	D.	V.	D.	V.	D.	V.
0	0		137		152	720	1.5
	2	250	124		169		
	10		104	500	180		
	16		87		192		
	34		69		204		
50	50		58		206		
	68	300	42		207		
	88		32	550	208		
	104		22		204		
	118		13		200		
100	138		16		191		
	152	350	26		176		
	170		11	600	160		
	180		5		147		
	186		3.5		131		
150	198		8		110		
	204	400	20		93		
	212		36	650	77		
	204		54		60		
	199		72		43		
200	196		93		33		
	192	450	106		21		
	178		121	700	12		
	154		134		4		

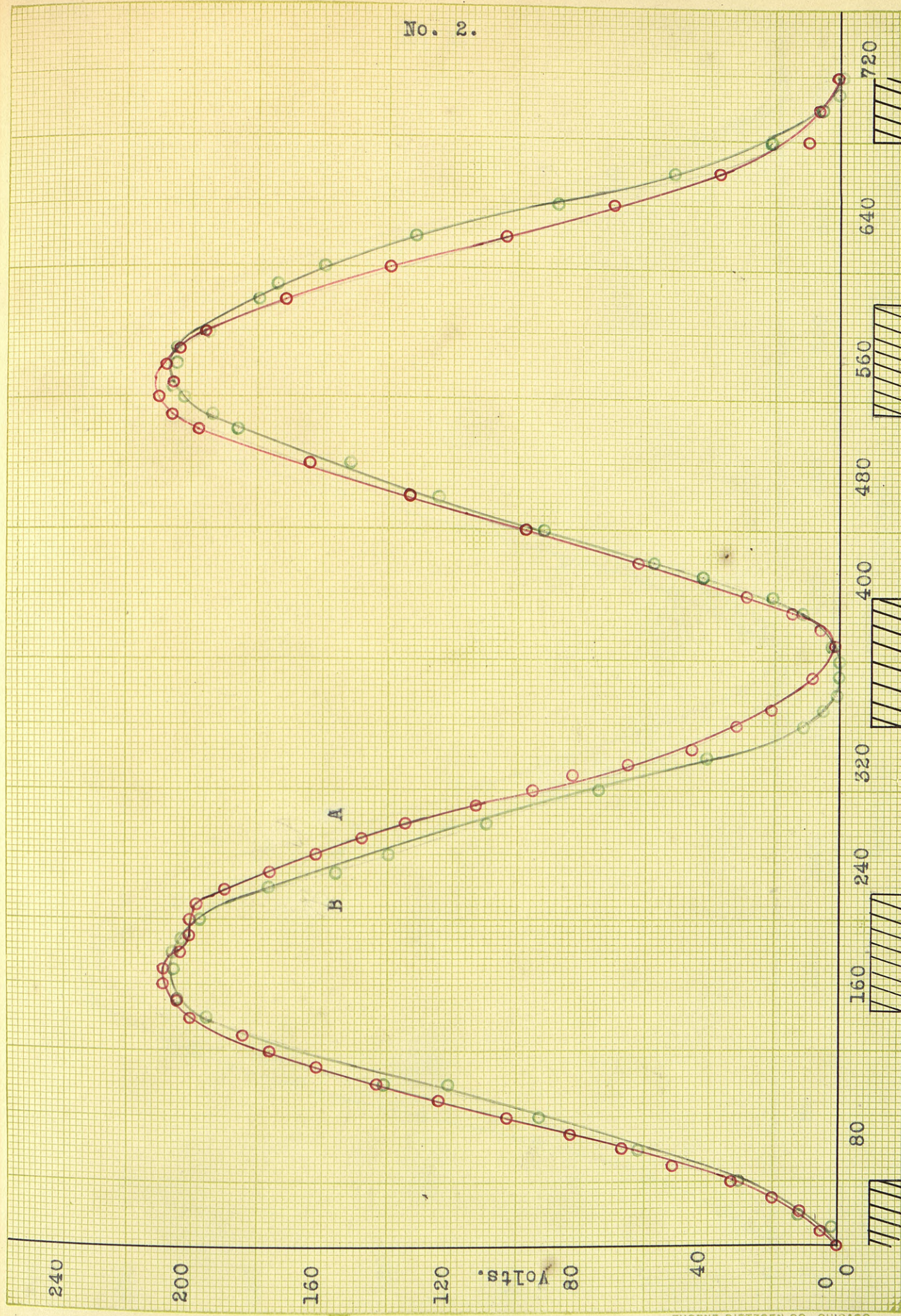
Magnetic Distribution in Air Gap at 100 R. P. H., No
Lead, Without Interpoles.

D.	V.	D.	V.	D.	V.	D.	V.
0	5		120		186	720	-3
	14	250	104		203		
	26		87	500	210		
	39		72		220		
	52		56		224		
50	72		42		222		
	84	300	25.5		210		
	92		17	550	204		
	128		3		187		
	147		-4		172		
100	164		-5.5		166		
	184	350	-3		160		
	196		1	600	140		
	200		9		126		
	212		21		103		
150	212		33		87		
	220	400	47		65		
	216		64	650	52		
	208		82		39		
	196		100		24		
200	188		124		11.5		
	176	450	140		3		
	158		154	700	-4		
	148		174		-5		

Magnetic Distribution of Air Gap, at 1000 R. P. M.,
Full Load, with Interpoles.

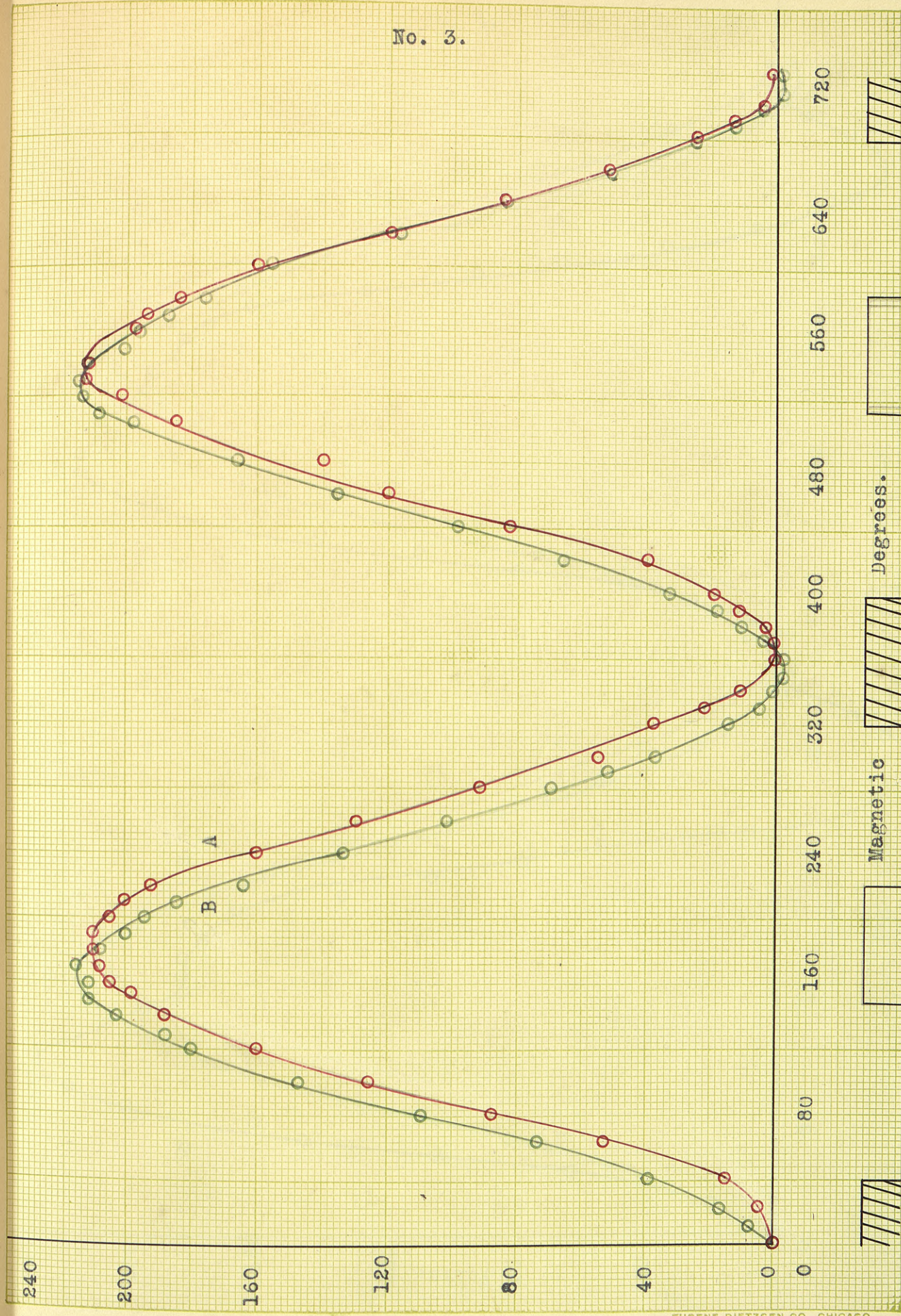
C.	V.	D.	V.	D.	V.	D.	V.
0	0		55		216	720	.9
	5	250	9		208		
	21.5		-10	500	208		
	47.5		-27		200		
	63.5		-37		196		
50	106.5		-41		194		
	147.5	300	-40		188		
	162		-33	550	184		
	202		-22		178		
	220		-10		164		
100	236		-.9		128		
	232	350	1.5		94		
	216		1	600	67		
	208		1.7		35		
	196		27		-8		
150	184		27		-24		
	184	400	51		-32		
	184		82	650	-34		
	178		112		-30		
	182		142		-22		
200	168		164		-8		
	136	450	192		-1		
	108		210	700	1		
	80		216		1		

No. 2.

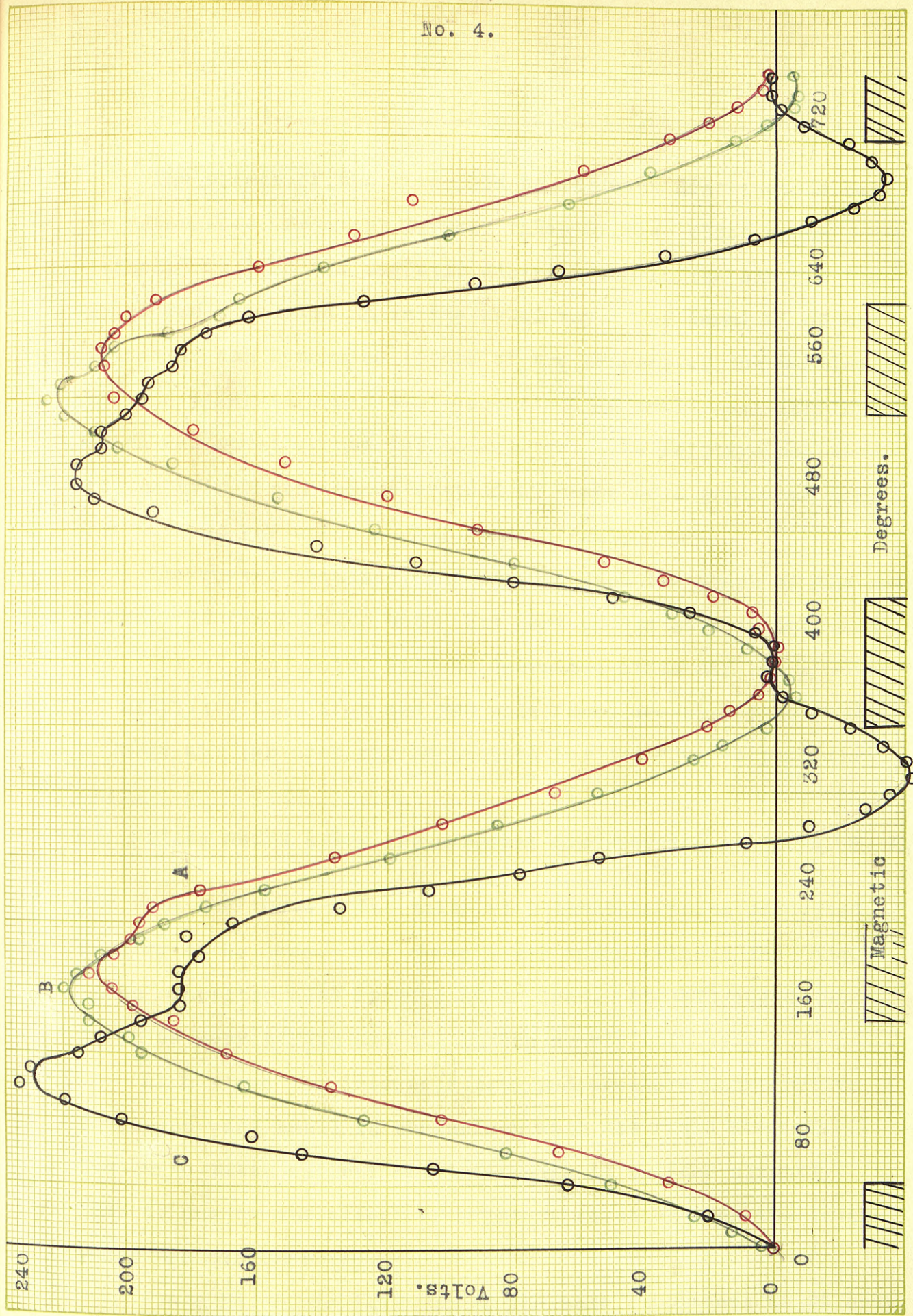


EUGENE DIETZGEN CO., CHICAGO.

No. 3.



No. 4.



EUGENE DIETZGEN CO., CHICAGO.

The effect of the interpole on the flux distribution can be determined from the current taken by the pilot brush method. To find the magnetic distribution in the air gap the motor was connected up in the usual way. One terminal of the voltmeter was connected to one of the brushes of the machine and the other terminal was connected to a small auxiliary brush which was moved around the commutator. Its relative position to the main brush was determined by means of a graduated arc. The machine was under normal conditions.

The curves obtained, depend also upon the shape of the pole faces. If the air-gap under any part of the pole is increased the flux at that point will be decreased since air has a lower permeability than iron and the pole faces are shaped so that a large air gap area may be secured for the flux to pass through.

Plate No. 2 shows the magnetic distribution at 280 R. P. M. The data for curve A was taken with the interpoles connected, running at no load. The curve B was taken without the interpoles connected also running at no load. At this speed the field is very strong and the curves nearly coincide.

At no load the interpole lead and armature magnetomotive force was very small in comparison with the field strength. The curve taken without the interpoles is shifted slightly. This is due to the effect of armature reaction when the interpoles are disconnected.

Plate No. 3 was taken under the same conditions as #2 only the speed was 700 R. P. M. In this case the intensity of the

field flux is much reduced and the armature magnet-motive force is greater in proportion to the field flux than when the motor was run at a lower speed. On this account the resultant flux without the interpole, is distorted more from that with the interpoles and there is a negative reading before the brush is reached. The effect of the interpoles begins to show in this curve. Since there are a few negative readings when the interpoles are disconnected, it is evident that for this speed the brushes are not in the neutral axis.

Plate No. 4 was taken at 1000 R. P. M. Curve A was taken with the interpoles connected. The distribution is fairly uniform. Curve B was taken under the same conditions but without the interpoles connected. At this speed the intensity of the field is greatly reduced and the armature magnetomotive force is much stronger in proportion to the field flux than it is for the lower speeds. On this account the resultant field is much more disturbed. Curve (C) shows the distribution with the interpoles at 1000 R. P. M. and full load. In this case the field is much distorted. This is due to the great magnetomotive force of the armature. This large magnet-motive force in the armature is caused by the heavy armature current which acts at 90 degrees to the field flux. This curve shows the effect of the interpoles in the a, b, c, part of it. These overcame the action of the armature magnet-motive force in the vicinity of the coils under commutation and set up a flux in the right direction. This produces the requirements for sparkless commutation.

This brushes could not be shifted and on that account we could not load the machine with the interpoles disconnected. Since the field is so greatly distorted, the neutral axis would be shifted through a large angle and there would be violent sparking at the brushes without the interpoles. In curve (C) the maximum voltage was obtained at 100 electrical degrees from the brush. This was the position of greatest distortion of flux.

Efficiency of the 20 H. P. Westinghouse Inter-
pole Motor by stray power method.

This method is used chiefly because it is more economical and more accurate. It is also sometimes difficult to load large motors to full load. While small machines may be tested by use of the prony brake, it is not practical for large machines, because of the large amount of heat generated by the friction of the brake on the pulley. Another difficulty with the prony brake test is that it is not accurate because of the many sources of error, the chief error being the difficulty of getting a balance on the scales at the same time the readings are taken. Under heavy loads there is a tendency for the brake to vibrate, thus making it difficult to get a correct balance on the scales.

The simplest method for determining the stray power loss of a motor is to run the motor without a load at the prescribed speed, and observe the field current, and the power required to drive the motor. Let I_a be the armature current, R_a the resistance of armature and interpole winding, and E_x the voltage between the terminals of machine. Then the stray power (S) equals $E I_a - R_a I_a^2$. This stray power loss includes all losses except $R I^2$ losses. These losses are;

1. Eddy current and hysteresis losses, which are chiefly in the armature core, due to reversals of magnetism as the armature rotates.
2. Friction losses in the bearings and at brushes.
3. Air friction loss or windage, due to the fanning action of the rotating armature.

The armature loss will be $R_a I_a^2$ and the shunt field loss will be $E_x I_s$, where I_s is the field current. The efficiency of a motor is the ratio of the power output divided by the power intake of the motor. In other words, the efficiency of a motor is equal to the power intake minus losses, divided by the power intake.

Data for stray power test on Westinghouse 20 H. P. Inter-
Pole Motor.

No.	Speed.	Es.	Ex.	Is.	Ix.	Cons- 2 watts.
1	300	198	220	2.53	6	625
2	300	198	220	2.53	6	625
3	400	204.8	220	1.73	6.4	675
4	400	204.8	220	1.73	6.4	675
5	500	210.5	224	1.73	5.5	575
6	500	210.5	224	1.7	4.4	450
7	500	210.25	223.5	1.7	4.4	450
8	600	211.5	223	1.15	4.6	462.5
9	600	211.5	223	1.15	4.6	462.5
10	700	212.5	222	.95	5	525
11	700	212.5	222.5	.95	5	525
12	800	213.8	222.5	.83	5.2	545
13	800	213.8	222.5	.83	5.2	545
14	900	214	222	.73	5.7	600
15	900	214	222	.73	5.7	600
16	900	214	221	.65	6.5	675
17	900	214	221	.65	6.5	675
18	1000	212	219.5	.65	6.5	675
19	1000	212	219.5	.65	6.7	700
20	1000	211.5	219.5	.65	6.7	700
21	790	210.25	220	.83	5.25	545
22	595	208	219.5	1.13	4	400
23	595	208	219.5	1.13	4	400
24	402	204	220	1.75	3.175	375
25	275	194	219.5	2.9	4.75	475
26	275	194	219.5	2.9	4.75	475

Resistance of armature

Room temperature equals 24° C.
Commutator temperature--47° C.

Arm. Resistance.

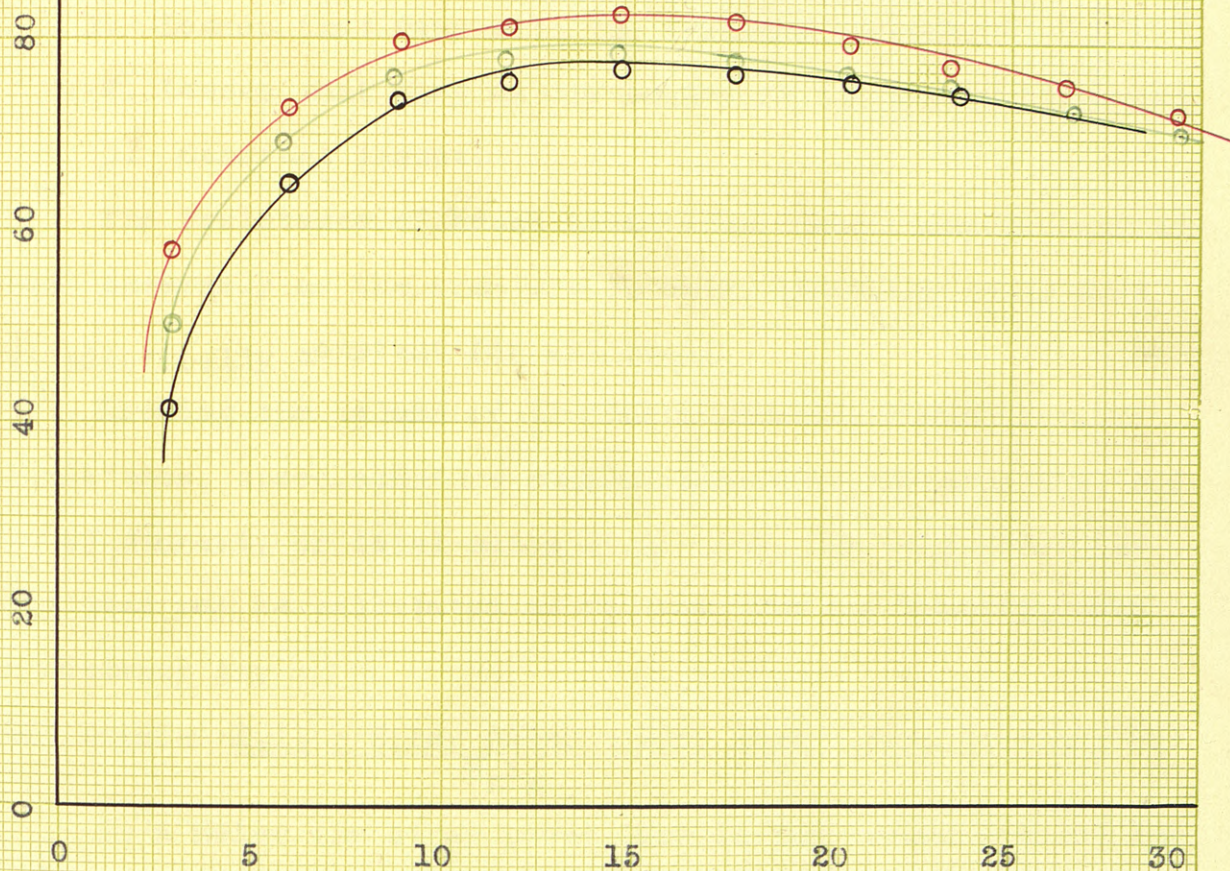
24 5 Res equals .48)
84 16.8 " " .50) Res equals .49.
Interpole
7 16.8)
7 16.4) Res. equals .041.

No. 5

Efficiency Curve

A at 300 R. P. M.
B at 600 R. P. M.
C at 1000 R. P. M.

Efficiency Per cent.



H. P. Output.

In the stray power method the various losses of the machine are first determined and then the efficiency of the machine, for the different loads are calculated. That is, to get the efficiency at any assumed load, the total losses for that load must be calculated and then knowing the input, the output and efficiency can be calculated.

In the case of the motor, at constant speed, and at normal working temperature, there are three kinds of losses:

1. Losses that vary with the armature current.
2. Losses that vary as the square of the armature current.
3. Constant losses.

The resistance of brush contact has been found to vary almost inversely as the armature current, hence the brush drop is practically constant for all loads.

Knowing the values of the field current, field drop, or resistance, speed, armature current, drop over the armature, and total current, or total watts at no load, the efficiency for any load may be calculated as follows: For any load (I_x) the efficiency is;

$$\text{Eff. equals } \frac{E_x I_x - \text{Stray power} - \text{Fld. loss} - \text{Arm. loss } (I_a^2 R_a)}{E_x I_x}$$

In a motor the stray power loss is the torque loss of the motor. If the value of the induction factor is constant, the torque loss will vary inversely as the armature current; this is evident from the equation T equals $1.41 \phi Z' I_a$. By increasing the induction factor the armature current becomes less, thus increasing the efficiency. As the speed increases the efficiency decreases, because the stray power increases, due to

friction which is nearly constant; eddy currents which vary as the square of the speed and the square of the magnetic induction.

The hysteresis varies as the speed and as the 1.6 power of the magnet induction; and inwindage varies as the cube of the speed, hence it will take a larger armature current to run it, thus having a larger $(I_a^2 R_a)$ loss.

The highest efficiency was gotten at a speed of 600 R. P. M., the lowest efficiency being at 1000 R. P. M., while at 300 R. P. M. the efficiency was between the two. The higher the speed the higher the value of the stray power loss, hence the lower efficiency at 1000 R. P. M.

The reason that at 1000 R. P. M. speed, the efficiency is higher than at 300 R. P. M. is that to make the motor speed up the field current is reduced, hence the field loss is lessened. The reducing of the field current reduces the flux, hence since the hysteresis loss varies as the 1.6 power of the magnetic induction and directly as the speed, the increaseⁱⁿ speed may be of such value that the hysteresis loss does not increase as fast as the field loss decreases.

Also, since the eddy current losses varies as the square of the speed and as the square of the magnetic induction, the square of the magnetic decreased faster than the square of the speed increased, hence the higher the efficiency at 600 R. P. M. After 600 the stray power losses begin to increase more rapidly than the decrease in the field loss.

The efficiency is a maximum for varying loads when the con-

stant losses are equal to the variable losses, that is, when $I_a^2 R_a$ equals the stray power plus the field losses.

Rating of the Interpole Motor for Measurement of Power.

The intake is measured with instruments, and the output calculated by multiplying by the efficiency for that particular load and speed. A shunt motor is most convenient for general purposes, because it is capable of a wide range of speed control, by varying the field current.

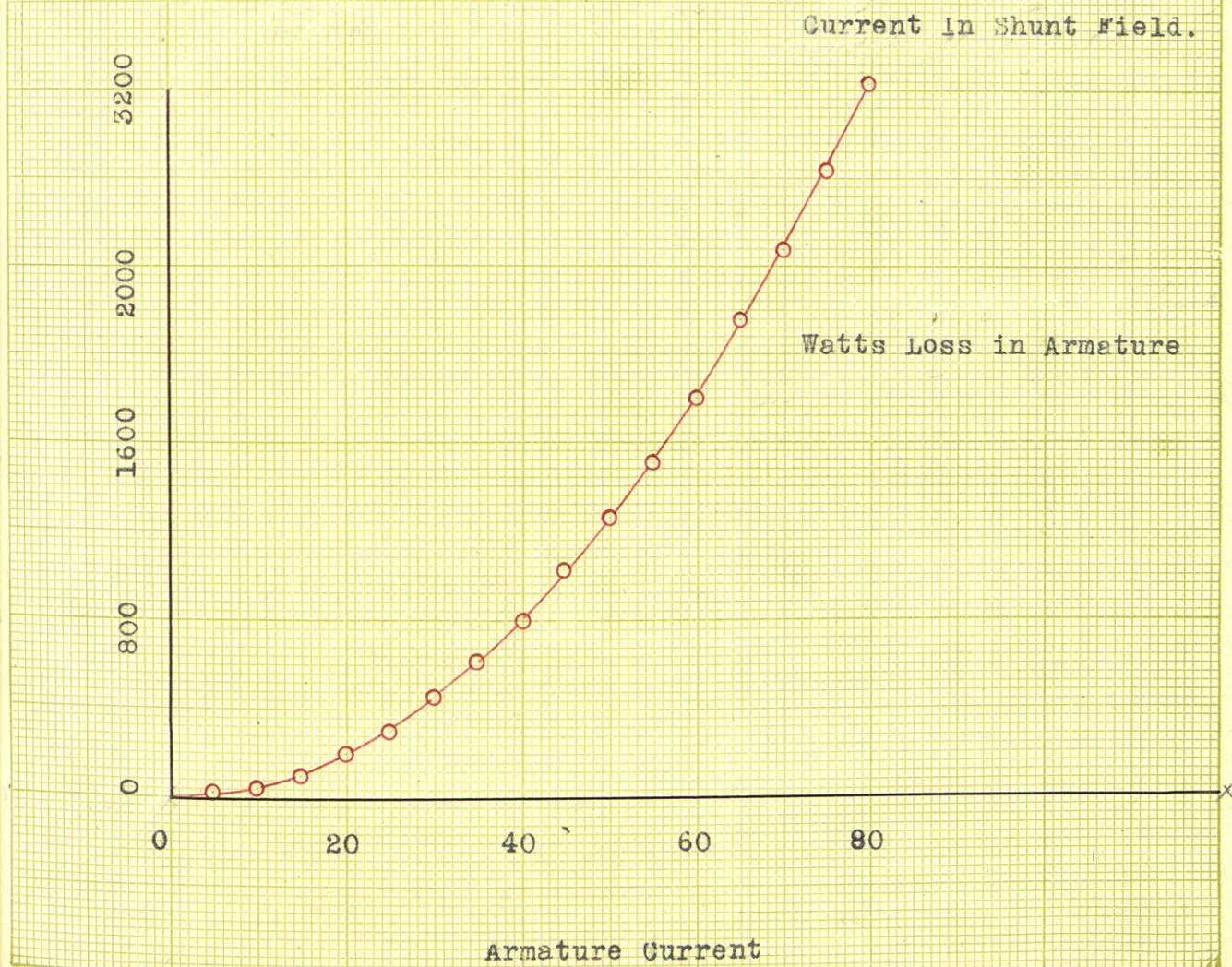
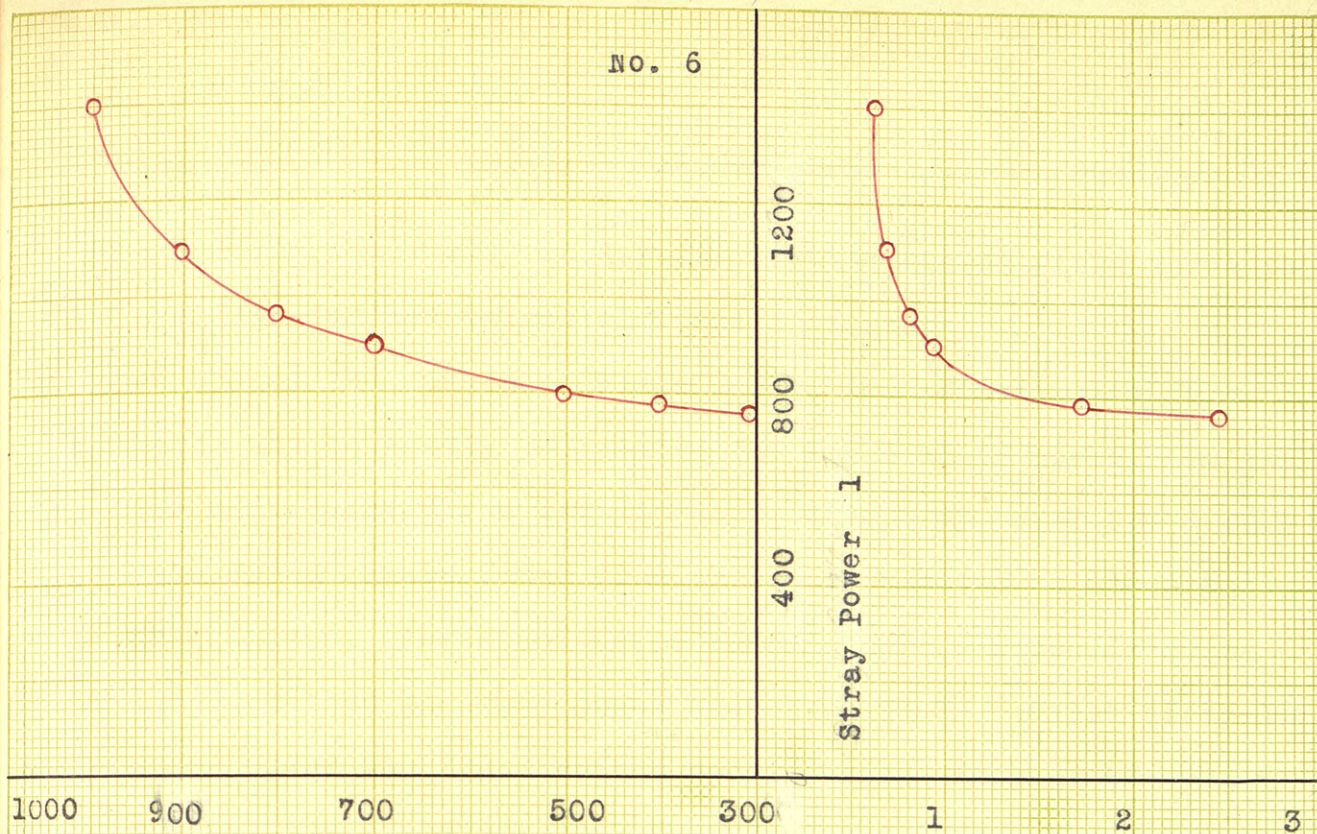
If used for constant load the motor should be rated at normal working temperature and should not be used as a dynamometer unless heated up to running temperature. If used for a short only it may be rated cold.

The interpole motor was run at speeds varying from 250 R. P. M. to 1000 R. P. M. and the losses determined for each speed. Curves were plotted for stray power and armature loss. ($I_a^2 R$) The resistance and rise in temperature were noted. A curve was plotted with I_a as abscissa and $(I_a^2 R_a)$ as ordinates. This curve takes the form of a parabola since its abscissa are plotted to current (I) and its ordinate to armature loss ($I^2 R$), it is in the form of X^2 equals cy , which is a parabola.

This 2nd curve was plotted with R. P. M. and stray power. This curve is a curve of the second degree, sloping upward since windage varies as the cube of the speed eddy currents as the square of the speed; hysteresis loss and friction vary as the speed.

The other curve was plotted with field current (I_s) as abscissa, and stray power as ordinates. Since the greater the field current the greater the flux and the slower the speed

No. 6



the stray power will be low for high values of field currents and high for low values of field currents.

From the curves on Plate # 6, the efficiency of the motor may be easily calculated for any load or speed. To get the efficiency for a certain load, the stray power for a certain speed may be found from the curve plotted to speed and stray power. The shunt field current may be found from the curve plotted to stray power and shunt field current since the stray power was found on the other curve. Knowing the field current the field loss may be calculated. From the curve plotted to load current and Watts loss in armature, the armature loss for any load may be found. Then the efficiency may be obtained from the formula:

$$\text{Eff. equals } \frac{E I_x - \text{Stray power} - \text{Fld. loss} - \text{Arm. loss.}}{E I_x}$$

Conclusions.

We would conclude that the field for the interpole motor is limited by certain conditions as follows: Under constant load, where one constant speed is required, the brushes may be set in a certain position and the motor can be designed with the temperature rise as the limiting factor; in this case the addition of interpoles would only be an unnecessary expense, that would be practically useless under these conditions. But in case the load is subject to rapid fluxations or where a heavy over-load must be carried for short intervals of time, the interpoles will produce the conditions for good commutation. It is said that momentary overloads of several hundred percent will be commutated satisfactorily due to the action of the interpole flux upon cross magnetization at the point of connection.

There are great prospects for interpoles in high voltage railway motors. This is due to the fact that the best point in favor of interpoles is in the ability of the machine to withstand momentarily, heavy overloads without sparking troubles. Also another point in favor of interpole motors for railway work where various speeds are required and used, is the ability of interpole motors to run at variable speed with perfect commutation. In places where the space for the motor is small and a motor of large capacity is required, interpole motors with artificially cooling apparatus would seem the only way to overcome the difficulty as the capacity of the motor would not be limited by sparking or by heating. Therefore, small motors of large capacity can be obtained that will work satisfactorily.

The employment of high voltage directly to the motor commutator makes it desirable to obtain some means of limiting the tendency of flashing at the commutator, since such tendency is increased by any abnormal field distortion. The use of the interpoles tend to decrease the field distortion, and may be said to work automatically, since they are in series with the armatures; the greater the distortion the greater the action of the interpoles.

The following are some of the advantages of the interpole motor over the common motor, where widely varying speeds are required and variable loads necessary:

1. Sparkless commutation, even on heavy overloads.
2. Flashing at commutator eliminated.
3. Less wear on commutator.
4. Cleaner and safer motor because of reduced carbon and copper dust from the brushes and commutator.
5. Much less heating of the commutator.
6. Greater current density in brushes.
7. Increased life of brushes.
8. Increased efficiency and free running capacity because of lower core and commutator losses.
9. Greater facility in design of large motors, especially as regards commutation.
10. Possibility of successfully using higher voltages.
11. Possibility of increasing service capacity of motor by use of cooling apparatus.
12. Longer life of motor.

Goheen & Welsh, '08.