Thesis

Subject;- The use of the Rotary Converter in Substations.

by

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THE USE OF THE ROTARY CONVERTER IN SUBSTATIONS.

In street or interurban railway service, when the distance from the central station becomes greater than five or six miles, the copper losses over the trolley become excessive, and it is necessary to reduce these losses to a minimum. This is done by generating alternating current at from 2000 to 7000 volts, or if a higher voltage is desired a step up transformer is used. This high potential is transmitted to a substation situated at some convenient place on the line. Here the line voltage is steped down by a transformer to something below 1100 and converted into direct current. This conversion may be made by one of three ways. (1). The alternating current may be fed into a synchronous or induction motor which is belted or direct connected to a direct current generator. (2). A motor-generator may be used. This is a machine with two seperate armature windings on the same core, one being connected to slip rings through which alternating current is fed and opperates the machine as a synchronous motor, driving the other winding as a direct current generator connected to a commutator. (3). The alternating current may be fed into a rotary converter, direct current being taken off at the other end. It is about this machine that I wish to write. The rotary converter as far as purpose is concerned is simply the commutator of a direct current rotating at some distance from the generator. But with it as with any commutator it must rotate at the same cyclic speed as the generator. To accomplish this the principle of the synchronous motor is used, for the synchronous motor will run at synchronous speed if it runs at all. So the rotary converter is essentialy a synchronous motor in the respect that it has a magnetic field in which rotates an armature winding connected slip rings by leads which are taped on at regular intervals, there being as many rings as there are phases in the circuit.

Since the armature is wound on a drum it is mesh connected making the winding continous. The relation between the alternating and direct current and E.M.F. varies only as the number of phases and is independent of the field excitation and the number of armature conductors. This is true whether the machine is opperated as a double generator a direct converter or an inverted converter. This relation may be developed as follows.

If e = Maximum E.M.F. generated by any one armature conductor $e \cos\gamma$ = E.M.F. produced by that coil at the instant it is angle   from the position of maximum E.M.F. (Fig. 1).
Now if there are "s" conductors in unite angle of the armature in the angle d there will be sd conductors, and the e.m.f. produced by the conductors included in the angle $d\gamma$ $e' = es \cos\gamma \, d\gamma$. In a converter with "n" rings the angle between the taps will be $\frac{2\pi}{n}$ Thenif E = the alternating current voltage between rings $E_{max.} = 2\int_0^{\frac{\pi}{n}} es \cos\gamma \, d\gamma = 2es \sin\frac{\pi}{n}$
But since the brushes subtend an angle π the e.m.f. produced between the drushes $E' = 2se\int_0^{\frac{\pi}{2}} \cos\gamma = 2se$
Substituing in the equation for maximum alterneting e.m.f.
$E_{max} = E' \sin\frac{\pi}{n}$ and E effective $= \frac{E' \sin\frac{\pi}{n}}{\sqrt{2}}$
Substituing for the value of "n" we obtain the following table of alternating and direct e.m.f. relations both theoretical and experimental values.

phase	theoretical relation	experimental relation
single	.707	.712
three	.612	.621
quarter	.500	.509

The differance between the theoretical and the experimental values is due to the fact that the air gap flux is not evenly distributed as was assumed in the theoretical discussion. Now if we nelect losses of the machine the input and output in watts must be equal, and if $I =$ energy component of the alternating current, and I' the direct current

then E effective $I = E'I'$

Substituting in the e.m.f. equation we get

$$\frac{E' \sin\frac{\pi}{n} I}{\sqrt{2}} = E'I' \quad \text{and} \quad I' = \frac{\sin\frac{\pi}{n} I}{\sqrt{2}}$$

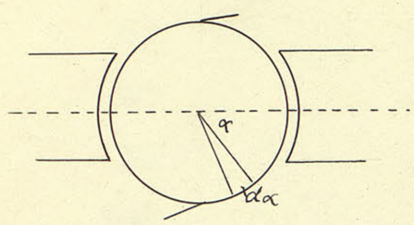


FIG. 1.

Variation of field current has the same effect upon a rotary as it does upon a synchronous motor. Since it can not change the speed as it does no a direct current motor, the only effect that it has is to vary the power factor of the alternating current line. This can best be shown by Fig 2.

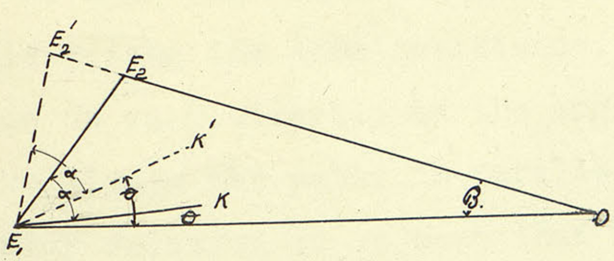


FIG. 2.

and 90 degrees for the quarter phase. This is done by using six rings, taping them in at the positions shown by the bars Fig. 3. Since it is a four pole machine there is two taps connected to each ring, 180 circular degrees being equal to 360 electrical degrees. The electrical angle and the resistance between taps is shown by the following table.

Taps	degrees	resistance
1 to 2	90	.044
2 to 3	30	.0204
3 to 4	60	.0327
4 to 5	60	.0327
5 to 6	30	.0204
2 to 6	180	.059
6 to 1	90	.044
1 to 3	120	.052
1 to 4	180	.059
2 to 5	150	.0572
3 to 5	120	.052
4 to 6	90	.044
5 to 1	120	.052
2 to 4	90	.044

From this it is seen that the resistance corresponds to the angle the same angle giving the same resistance. We could not expect the resistence to vary directly as the angle, owing to the fact that there are always two paths in parallel through the armature. From the angular relation it is seen that for single phase connection 1 & 4 or 2 & 6 would be the rings used. For three phase 1, 3 & 5: and for quarter phase 1, 2, 4, & 6.

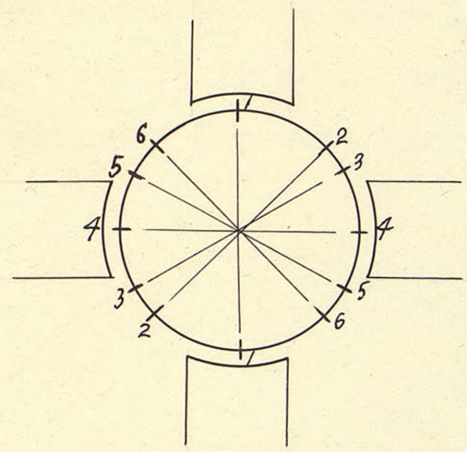


FIG 3.

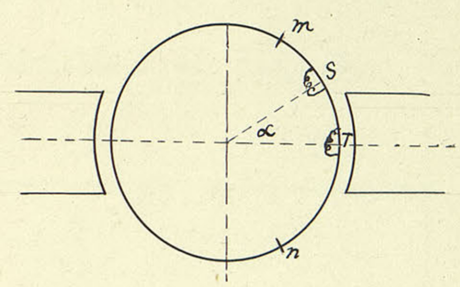


FIG. 4.

If we consider a bipolar converter(Fig. 4.) and let E = direct current voltage and I = direct current, the current in any one armature coil due to the direct current will $= \frac{I}{2}$

If I' is the effective alternating current in any one phase, the maximum value will be $I\sqrt{2}$ and from previous development

$I' = \dfrac{I\sqrt{2}}{n \sin \frac{\pi}{n}}$ The alternating current in a coil "s" which is situated at an angle γ from the coil midway between the two adjacent tap of an "n" phase converter will be $I_s = 2 I' \sin (\beta - \gamma)$ where is the angular displacement of the coil in its rotation. For if $\gamma = \beta$ $\sin(\beta - \gamma)$ will equal 1 or the coil "s" will be in its maximum position at "T". Substituting in the value of I' we have $I_s = \dfrac{2 I \sin(\beta - \gamma)}{n \sin \frac{\pi}{n}}$.

Now at the instant when the coil "T" which is midway between the two adjacent ring taps reaches the position shown in Fig. 4. its alternating current is a maximum and also it is in the middle of its rectangular direct current wave. These two waves will be 180 degrees apart. For if we consider the alternating and direct current flowing in two separate conductors, the alternating current being that of a motor and the direct that of a generator the two will flow in opposite directions, as the conductors will be rotating in the same field in the same direction. From the hand rule it is seen that the currents will flow in opposite directions. The wave forms will resemble that of Fig. 5.

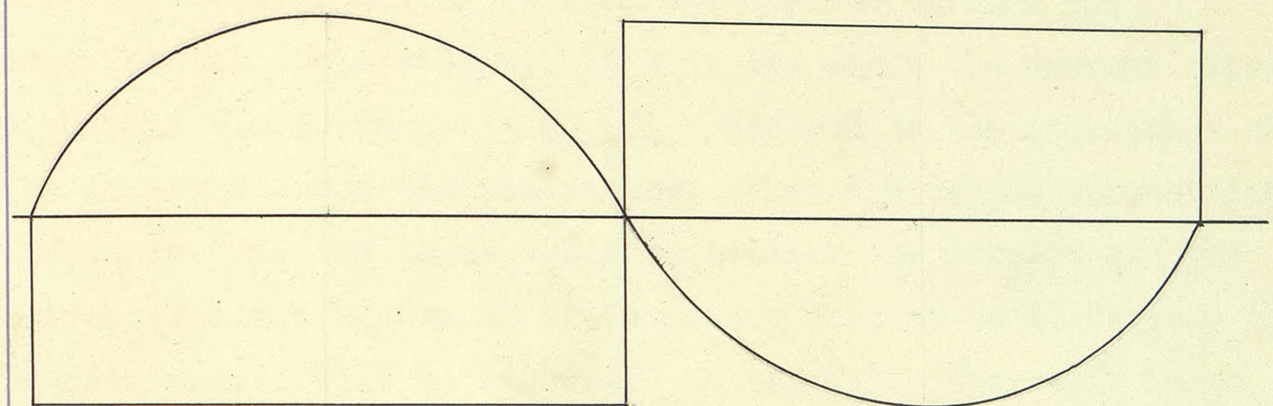


FIG. 5.

The resultant wave form which is the shape of the wave of the current that actualy flows is shown in Fig. 6. In a single phase converter the maximum point of the alternating current will be equal to the direct current, and the resultant will be zero at the point of maximum alternating current.

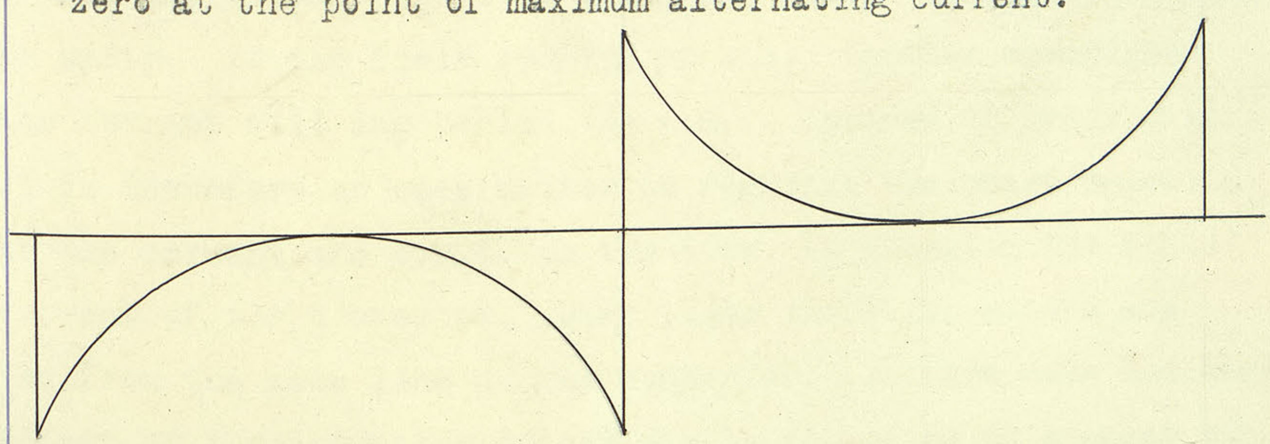


FIG. 6.

In a poly phase converter the direct current will not equal the maximum alternating current , and while the general form of the resultant will be the same as Fig. 6. it will not zero at the middle of the wave.

Let OE_2 = the counter e.m.f. of the motor.

OE_1 = the impressed e.m.f.

Then E_1E_2 will be the vector differance of the two, or the effective e.m.f. acting to send the current through the impedance of the armature. If γ is the angle the current makes with this e.m.f. tan $= \frac{2 \quad fL}{R}$ Where L is the inductance of the armature and R the resistance. Then E_1K is the current line and angle Φ is the phase relation between the current and the impressed e.m.f. Now if the exciting current be increased, the counter e.m.f. will be increased to say E_2'. This will throw the effective voltage to E_1E_2', and since angle γ is constant for any machine, the current line will take the direction E_1K' and the phase relation of the current to the impressed e.m.f. will be angle Φ. So it is seen that by changing the field current we have varied the power factor from cos Φ to cos Φ' Now if the counter e.m.f. be decreased from OE_2 the angle Φ will grow smaller and may be made equal to zero, and the power factor maximum or unity. If the field current be still farther diminished the current will lag behind the e.m.f. instead of leading it. It is therefore an easy matter to regulate the phase relation of the current and e.m.f. on the line by changing the field current of the converter. Many times induction motors are fed from the same line as the converter. In this case the laging effect of the induction motors may be rectified to a great extent by over exciting the rotary field, which would tend to cause a leading current.

Since the cinverter tested was designed to run on single, three, or quarter phase, the slip ring leads are taped on to the armature winding at such places as to give the electrical angle between taps 180 degrees for the single phase, 120 for the three

Now with any other coil "s" (Fig. 4.) the direct current reverses as the coil passes under the brush, and since the alternating current is the same in all the coils between any two adjacent taps, it will not be zero when the "s" passes under the brush but when the coil "T" does. From this it is seen that the alternating and direct current will not be 180 degrees apart but will be displaced from this by an angle equal to the angle between the two coils "s" and "T". This displacement will be greatest in the coil nearest the tap, and will be equal to $\frac{\pi}{n}$ where "n" is the number of phases of the circuit. In a three phase converter $\frac{\pi}{n} = 60$ degrees and the two wave forms will be 120 degrees apart. The relation of the two and their resultant is shown in Fig. 7. and 8.

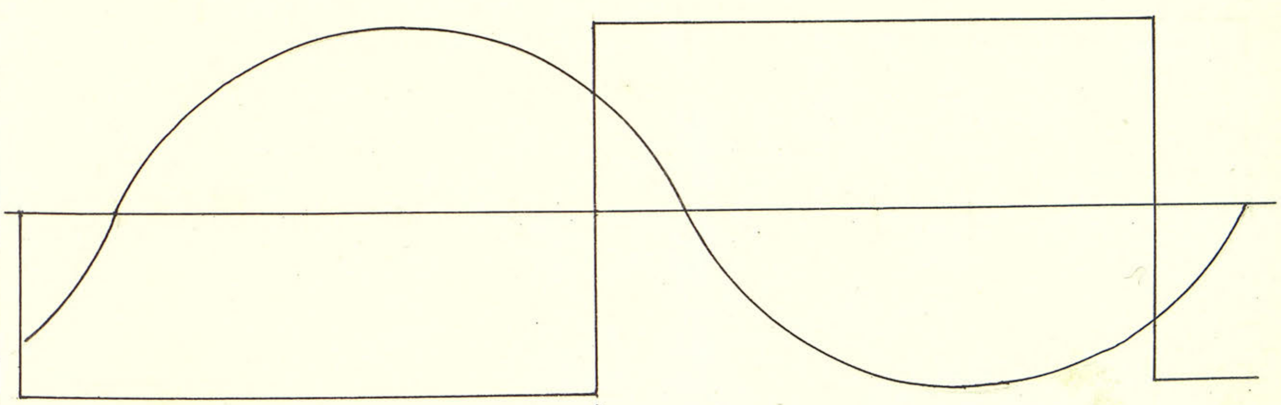


Fig. 8.

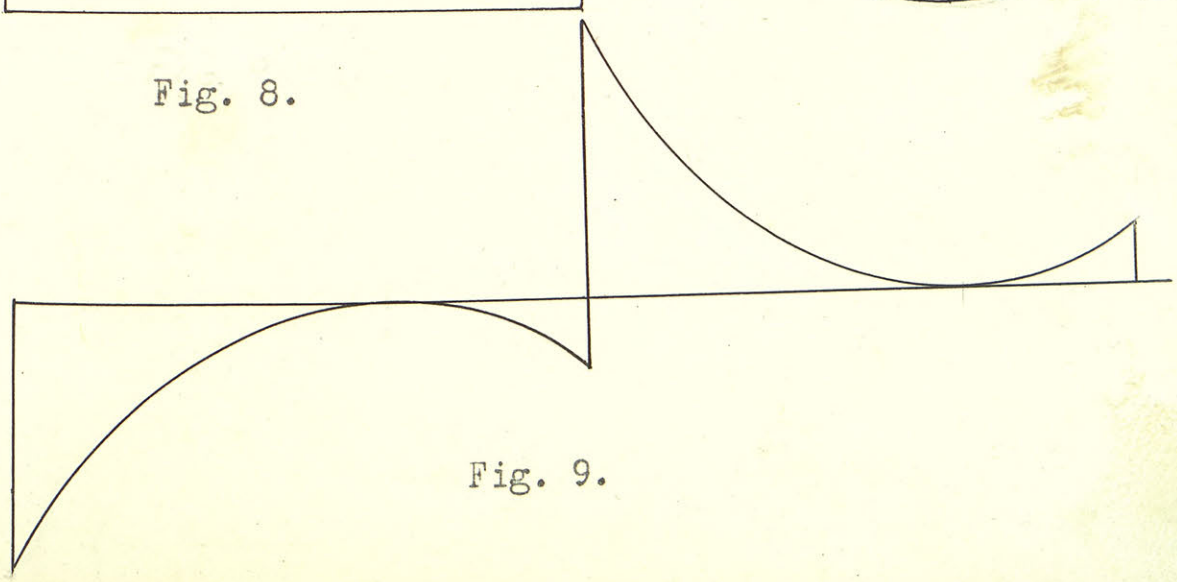


Fig. 9.

Since in the equations for current we considered the position of the coil with respect to the taps, the resultant current will be the differance of the two currents, that is;

i the instanious current in any coil "s" will be

$$i = \frac{2\, I'\, \sin(\beta - \gamma)}{n \sin\frac{\pi}{n}} - \frac{I}{2}$$

$$= \frac{I}{2}\left\{\frac{4 \sin(\beta - \gamma)}{n \sin\frac{\pi}{n}} - 1\right\}$$

The effective value of this

$$I_0 = \sqrt{\frac{1}{\pi}\int_0^{\pi} i^2\, d\beta} = \frac{I}{2}\sqrt{\int_0^{\pi}\left\{\frac{4 \sin(\beta - \gamma)}{n \sin\frac{\pi}{n}} - 1\right\} d\beta}$$

$$= \frac{I}{2}\sqrt{\left\{\frac{8}{n^2 \sin^2\frac{\pi}{n}} + 1 - \frac{16 \cos\gamma}{n\pi \sin\frac{\pi}{n}}\right\}}$$

In a three phase converter this becomes

$$I_0 = \frac{I}{2}\sqrt{\{1.186 + 1 - 1.958 \cos\gamma\}}$$

In the coil midway between the two taps $\gamma = 0$

$$I_0 = .2375\, I$$

In the coil nearest the tap $\gamma = 60$ degrees and

$$I_0 = .549 I.$$

The relative copper losses in the armature of a rotary converter as compared to that of a direct current generator is

$$\frac{I_0^2}{\frac{I}{2}} = \frac{4\, I_0^2}{I^2} = \frac{8}{n^2 \sin^2\frac{\pi}{n}} + 1 - \frac{16 \cos\gamma}{n\pi \sin\frac{\pi}{n}}$$

Intergrating this between the limits $\gamma = 0$ & $\gamma = \frac{\pi}{n}$

$$\int_0^{\frac{\pi}{n}}\left\{\frac{8}{n^2 \sin^2\frac{\pi}{n}} + 1 - \frac{16 \cos\gamma}{n\pi \sin\frac{\pi}{n}}\right\} d\gamma = \frac{8}{n^2 \sin^2\frac{\pi}{n}} + 1 - \frac{16}{\pi^2}$$

In a three phase converter this becomes equal to .555.

It has been many times shown that in an alternator the cross magnetizing effect of the armature ampere turns is due to the component of the current that is in phase with the e.m.f. If the current and e.m.f. were in phase the current would reach maximum when the poles due the armature current were directly between the poles of the field. If the current and the e.m.f. are not in phase the armature poles will become maximum when they partly under the field poles. If the current is laging the armature ampere turns will oppose those of the field. If leading they will assist the field. If Φ is the angle of lag of the current behind the e.m.f. I cos Φ , the energy component of the current, will produce the transverse reaction, and I sin Φ the wattless component, will produce the direct opposing reaction

In the rotary converter we have not only to take into account the reaction of the alternating current but that of the direct current as well. Now by neglecting the losses of the machine the energy ampere turns of the alternating current will equal the ampere turns of the direct current, and as shown before the two will be opposing each other. Thus the reaction of one is neutralized by the other and the cross magnetizing effect will be zero. By referance to Fig. 9. if the outer belt of conductors represent the direct current ampere turns, and the middle belt the energy ampere turns of the alternating current, it can be shown by the hand rule for direction of current that where ⊕ is the conductore carying current out of the plane of the paper and those marked O are those carrying current into the plane of the paper, and that these are marked correctly in the figure. Since the wattless current is laging I sin Φ is 90 degrees behind I cos Φ. We can let the inner belt of conductors represent the wattless ampere turns marked as they are tending to assist the field. If the current was leading the reverse would be true and the wattless current would oppose the field.

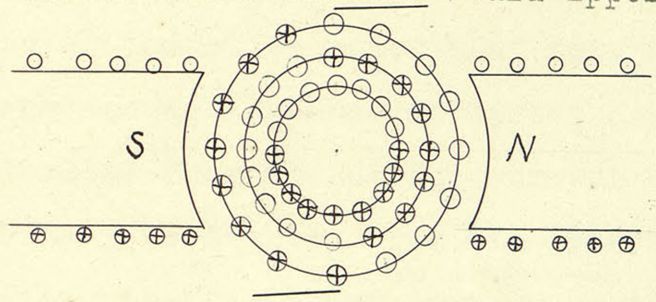


FIG. e.

It is seen that the effect of this wattless ampere turns is not uniformly distributed over the pole face but is stronger in the middle as there are more turns acting there. If the current is laging there is an increasing of the flux at the middle. If leading there will be a weakening of the flux at the middle. Then we conclude from this that we neglect the losses there is no skewing effect of the rotary field, and the direct current field may be set in the neutral position for all loads, or with just enough lead to give a commutating field of the right strength.

Since the torque that causes the armature of the converter to rotate is produced by the action of the field upon the armature conductors carrying an alternating current, and since the field is constant in one direction; in order to produce a constant directional torque, each conductor as it passes under a pole must be carrying a current in the same direction as that carried by the conductor that just proceeded it, the same as in a direct current motor. But unlike the later the frequency of the current in the armature is not goverened by the speed of the motor but the frequency is fixed as it comes from the line. So in order to have a constant directional torque the motor armature must be rotating at the same cyclic speed as the

the generator supplying the line. From this it is clear that to start a rotary converter it must be first brought up to speed. This may be done by one of three ways (1). It may be belted or direct connected to an induction motor that acts as a primmover. (2). It may be connected to a source of direct current supply . and opperated as a motor from the direct current end. (3). A polyphase converter may be started from the alternating current end by open circuiting the field and turning on the alternating current supply. When this is done the converter will come up to speed, the field being magnetized by the armature ampere turns each phase exciting the field for the phase that follows. After the machine is up to speed the field may be closed and the machine opperated as a synchronous motor or a converter. One objectionto this method is that on starting an alternating current flows through the direct current line. And as the field changes in direction with a frequency equal to the differance of the cyclic speeds of the motor and generator, the motor is liable to fall into step with the direct current terminals reverse to what they were during the last run.

With the other two methods of starting the alternating current supply switch is left open until the motor is synchronized. By synchronizing is meant not only bringing the motor up to cyclic speed but also having the e.m.f. of the machine directly opposed to that of the line. This will give an e.m.f. that will be near to that required to opperate the machine. If the switch was closed when the two e.m.f. were acting together instead of in opposition, the resultant would be the sum of the two which would send a tremendous current through the low resistance of the converter armature, and might burn it out.

There are several methods of synchronizing, the simplest one being by the use of incandescent lamps of the line voltage connected accross the main switch as shown in Fig. 10. It is seen that there are t o lamps in series in every circuit, so the lamps will only get half voltage when the converter is standing still. When the armature is rotating at synchronous speed the e.m.f. opposing the lamps will be dark, if the e.m.f. are acting together the lamps will burn as though on full voltage. If the armature is rotating but not at synchronous speed the lamps will be alternatly bright and dark with a frequency equal to the differance of the frequenciesof the e.m.f.s. So the main alternating current switch must ~~never~~ be closed only when the lamps are dark.

Rotary converters like synchronous motors are apt to vary back and forth accross the speed of synchronism,. This is called hunting, and may be caused by a variation of the load on the rotary itself, or by a variation of the supply current. This later may be due to the generator or to another converter or synchronous motor on the line hunting. If a load is suddenly thrown on the converter the armature will drop a little behind the current phase. This causes the angle between the impressed and the counter e.m.f. to increase, which results in a greater effective voltage. This is the cause of the larger current which is necessary to pull the load. As the inertia of the armature is very great in some of the larger machines, this droping back will not stop when the angle is sufficient but will go on past, causing a heavier current to flow than is necessary This heavy current produces a strong torque which throws the armature ahead. When once started to hunting the armature is soon surging back and forth, which becomes not only annoying but dangerous, for the machine is much more liable to be thrown out of step with the usal results.

Converters as they are made today have this hunting evil rectified to a great extent. This is done by puting a heavy bar of copper over the pole faces and extending between the poles. Then if hunting starts the armature flux surging back and forth over this bar sets up eddy currents in it whose magnetic effect is to damp the action that caused it. The machine tested is equiped with this bar and the best result is shown by the fact that the converter could not be made to hunt by variation of load.

Let us refer again to Fig. 2. the synchronous motor digram.. As the load come on the converter the angle β will increase, that is the armature will be pulled farther behind the current cycle. This will give the effective e.m.f. a new direction making the angle E_2 E_1 0 smaller, And as explained before angle remains constant, if the current was in phase with no load the line E_1K, the current line will fall farther behind the e.m.f. as the load increases. To prevent this the converter is compounded, that is the current from the brushes is passed through a few series turns on the field. Then as the load increases the field is stronger excited which tends to make the current lead. With the correct number of series turns the angle of lag may be kept very near zero thus automaticaly keeping the power factor near unity.

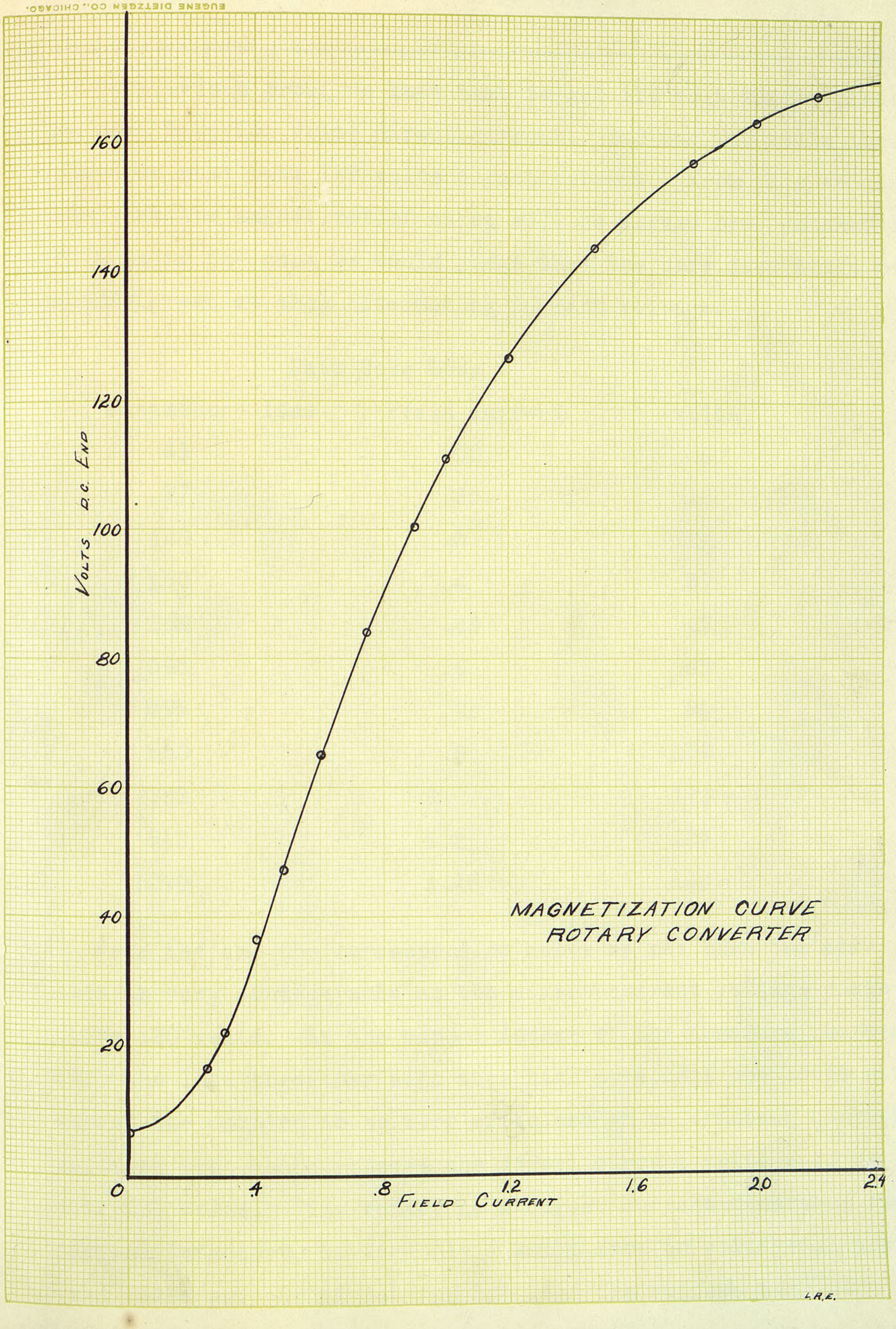
The rotary converter tested and whoes characteristic curves appear below, was of 7.5 Kilowatt capacity. 4 poles 1800 rev. per min. Direct current amperes 62.5 volts 120 Alternating current cycles 60. Commutator has 96 segments width of segment 5/30". active length 3".

Field bore 9.5". Armature of laminated discs, has 48 slots 12 conductors per slot. # 10 B. & S. G. Resistance brushes .056 Shunt field has 1749 turns per pole # 18 B.W.G. double cotton covered. Hot resistance 70 ohms.

Considering the rotary as an all purpose machine as well as one to take the place of two for the conversion of alternating current into direct, we will first consider it as a generator. The magnetization of the machine is not brought up to the knee of the curve to give the rated voltage on the direct current end, as can be seen from the accompaning curve and data.

DATA MAGNETIZATION CURVE

Field current	Volts d.c.
0	6
.25	16.5
.3	22
.4	37
.49	47
.6	65
.7	84
.9	100.5
1	111
1.2	127
1.48	144
1.8	157.5
2	164



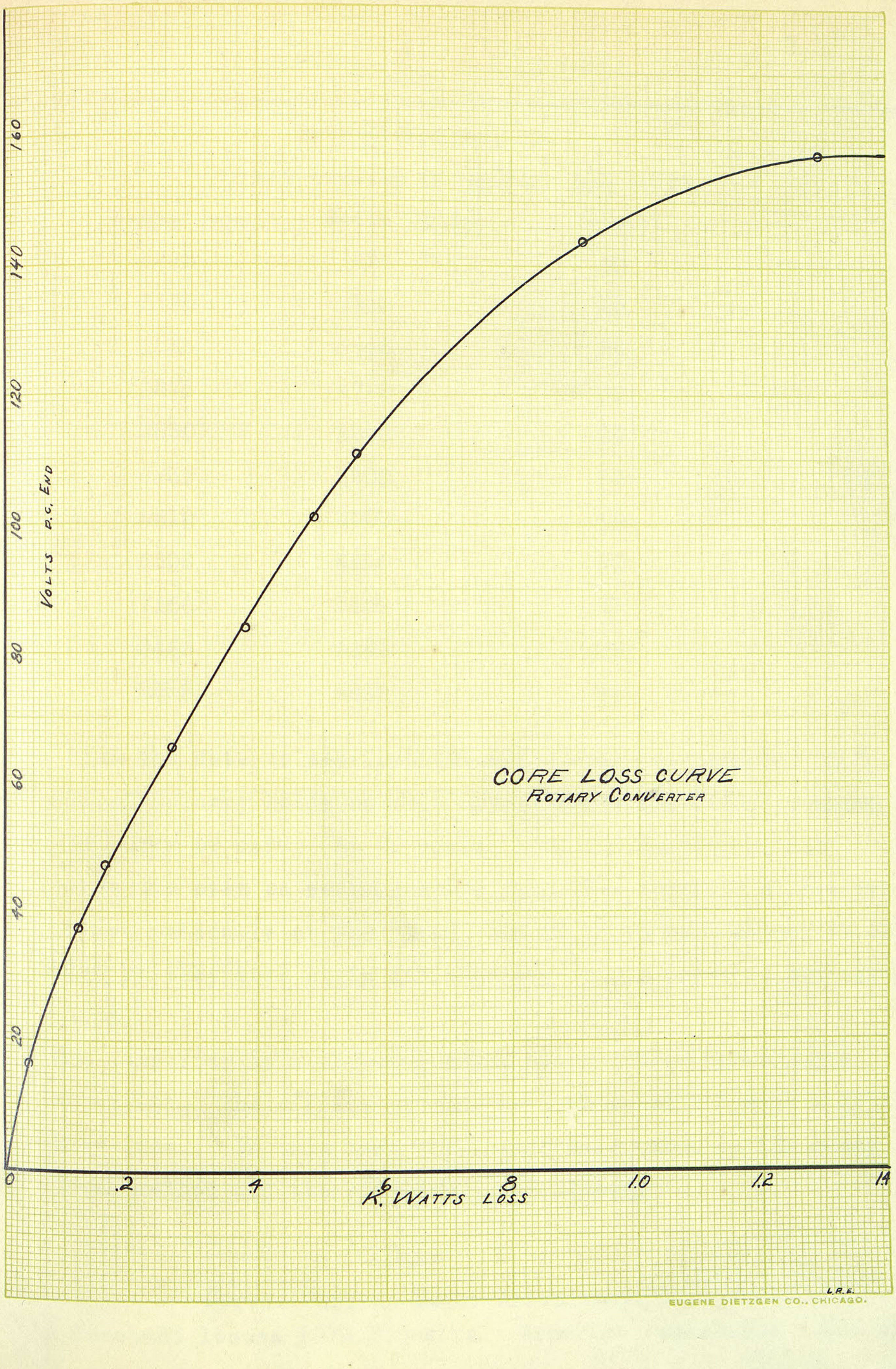
MAGNETIZATION CURVE
ROTARY CONVERTER
VOLTS D.C. END
FIELD CURRENT
0
.4
.8
1.2
1.6
2.0
2.4
20
40
60
80
100
120
140
160
L.R.E.

By previous proof we know that to get 110 volt single phase we must have 155 volts direct current. And for 110 volts three phase we must have 187 volts direct current. From this we can see that the magnetization curve will be worked near saturation. This being the case we would judge that the core loss would be rather great at this alternating current voltage.

Data Core Loss

WattsOcore loss	Field current	volts
41	.00	6
97	.25	16
128	.3	22
160	.4	37
268	.49	47
395	.6	65
495	.75	84
550	.9	100
783	1	111
912	1.2	127
1299	1.48	144

From the and the corresponding curve we see that the core loss is very considerable as the direct current voltage rises above 120 volts. As the copper losses of the armature increase with the load togeather with this high core loss one could not expect the machine to be very efficient on alternating current voltages that would require the direct current voltage to be over 125 volts. The rotary as a direct current generator runs very satisfactory, having only a small drop in voltage as the load comes on. Or if set for 3/4 load the voltage will vary but little with reasonable variation of load.



CORE LOSS CURVE
ROTARY CONVERTER
VOLTS D.C. END
K. WATTS LOSS
0
.2
.4
.6
.8
1.0
1.2
1.4
20
40
60
80
100
120
140
160
L.R.E.
EUGENE DIETZGEN CO., CHICAGO.

Data Efficiency as

Direct current Generator 110 volts

Watts Input	Watts Output	% eff.
1725	000	00
2120	885	28
2586	1140	34
2875	1720	39
3880	2200	56
4730	2900	61
5810	4000	68
6500	4520	69
7160	5150	73
8460	6190	73
9350	6810	74

From the data we see that the efficiency only reaches 74 % . The efficiency holds up well untill below 1/4 load, as shown by the curve or data. At 50 % over load the heating is not excessive even on several hours run. The sparking at the brushes is not noticable at full load, and it is an easy matter to set them so they work quite satisfactory in one position for all lo loads.

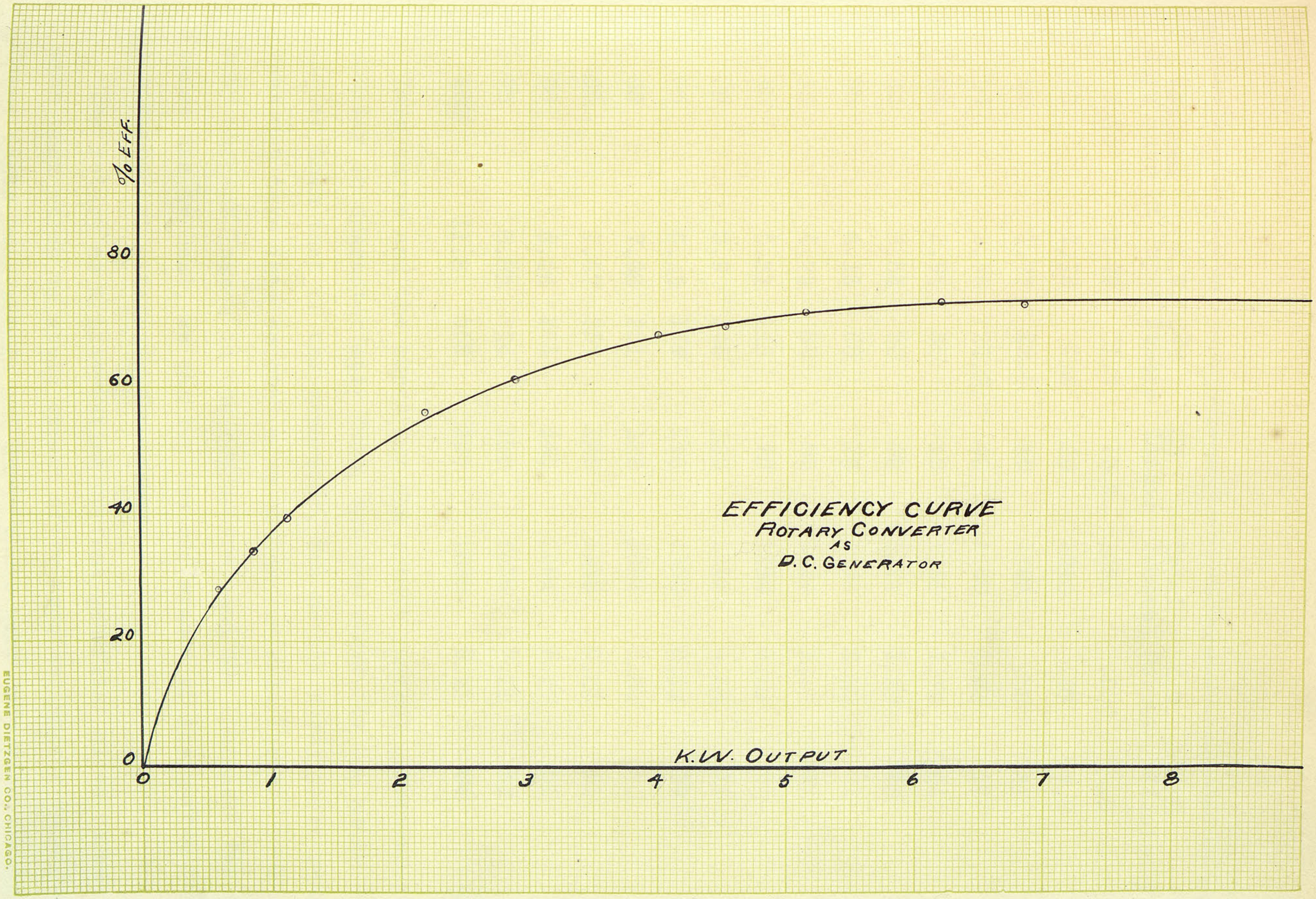
The converter as a direct current motor proves to be quite efficient. The efficiency runs as high as 82.5 % with a slight over load. In this test the losses were taken by the stray power method and the efficiency calculated.

Data

Durect Current Motor Efficiency.

Constant losses 1070.75 watts. Armature resistance .056 ohms

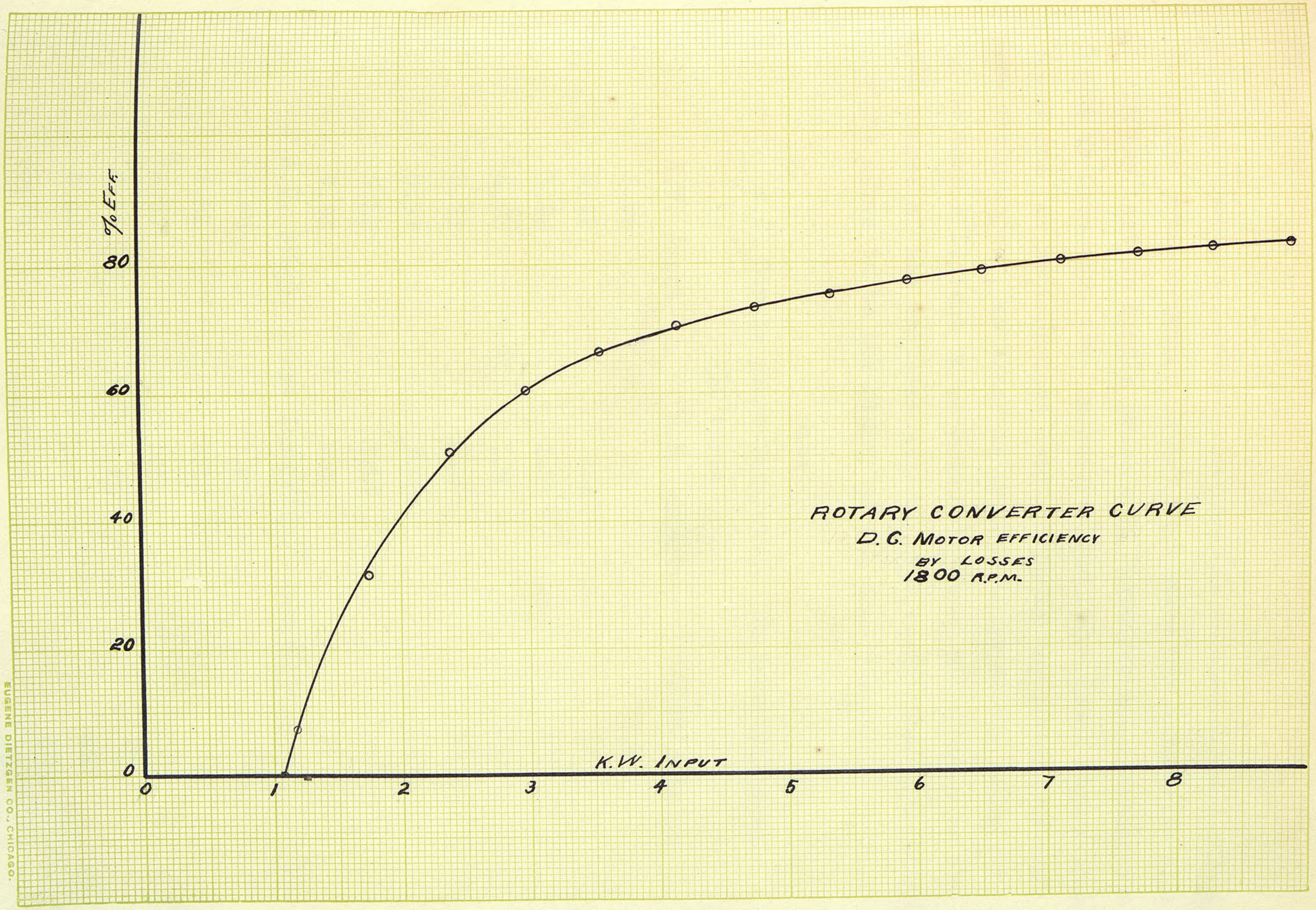
Brush drop 2 volts.


EFFICIENCY CURVE
ROTARY CONVERTER
AS
D.C. GENERATOR
% EFF.
80
60
40
20
0
K.W. OUTPUT
0
1
2
3
4
5
6
7
8

Assumed line current	K.W. Input	C^2R losses	CR losses	Total losses	K.W. Output	% Efficiency
9.25	1.09	3.7	16.5	1091	.000	.0
10	1.18	5.6	20	1096	.08	7.0
15	1.77	12.6	30	1103	.55	31
20	2.36	22.8	40	1140	1.21	51
25	2.95	35	50	1155	1.79	64
30	3.54	50	60	1181	2.35	66
35	4.13	68	70	1209	2.92	71
40	4.72	89	80	1240	3.47	73
45	5.31	113	90	1284	4.02	75
50	5.9	140	100	1310	4.58	77
55	6.49	169	110	1350	5.12	79
60	7.08	201	120	1392	5.68	80
65	7.67	237	130	1438	6.23	81
70	8.26	274	140	1484	6.77	82
75	8.85	314	150	1534	7.21	82
100	11.8	560	200	1830	9.97	84

This curve and the curve for the direct current generator are similar in characteristic form, but the curve for the motor runs higher than that of the generator, but as the stray power method does not take into account some of the variable losses, such as eddy current losses in the conductors, and the increased resistance due to heat, we can lay the differance of the curves to the method of obtaining the losses.

The rotary as a alternating current generator gives curves near that which we would expect after considering the core losses These tests both single and three phses were made with the terminal voltage at 110 which caused excessive core losses .


ROTARY CONVERTER CURVE
D. C. MOTOR EFFICIENCY
BY LOSSES
1800 R.P.M.
% EFF.
80
60
40
20
0
K.W. INPUT
0
1
2
3
4
5
6
7
8
EUGENE DIETZGEN CO., CHICAGO.

It is the great constant losses that makes the curve rise slowly.

In the test on single phase with inductive and noninductive loads we fine that the inductive load curve comes higher than the curve for noninductive load. This is the reverse to what one would expect, as there is nothing to cause the converter to be more efficient on an inductive load, while there is the C^2R losses of the wattless current that would cause the noninductive curve to be the higher of the two.

Data

A.C. Single phase Generator. Noninductive load.

110 volts

K.W. Input	K.W. Output	% Efficiency
2.86	.0	0
3.42	.62	18
3.96	1.2	30
4.63	1.8	39
5.21	2.4	46
5.97	2.96	50
6.56	3.59	56
7.06	4.2	59

A.C. Sihgle phase Generator. Inductive load.

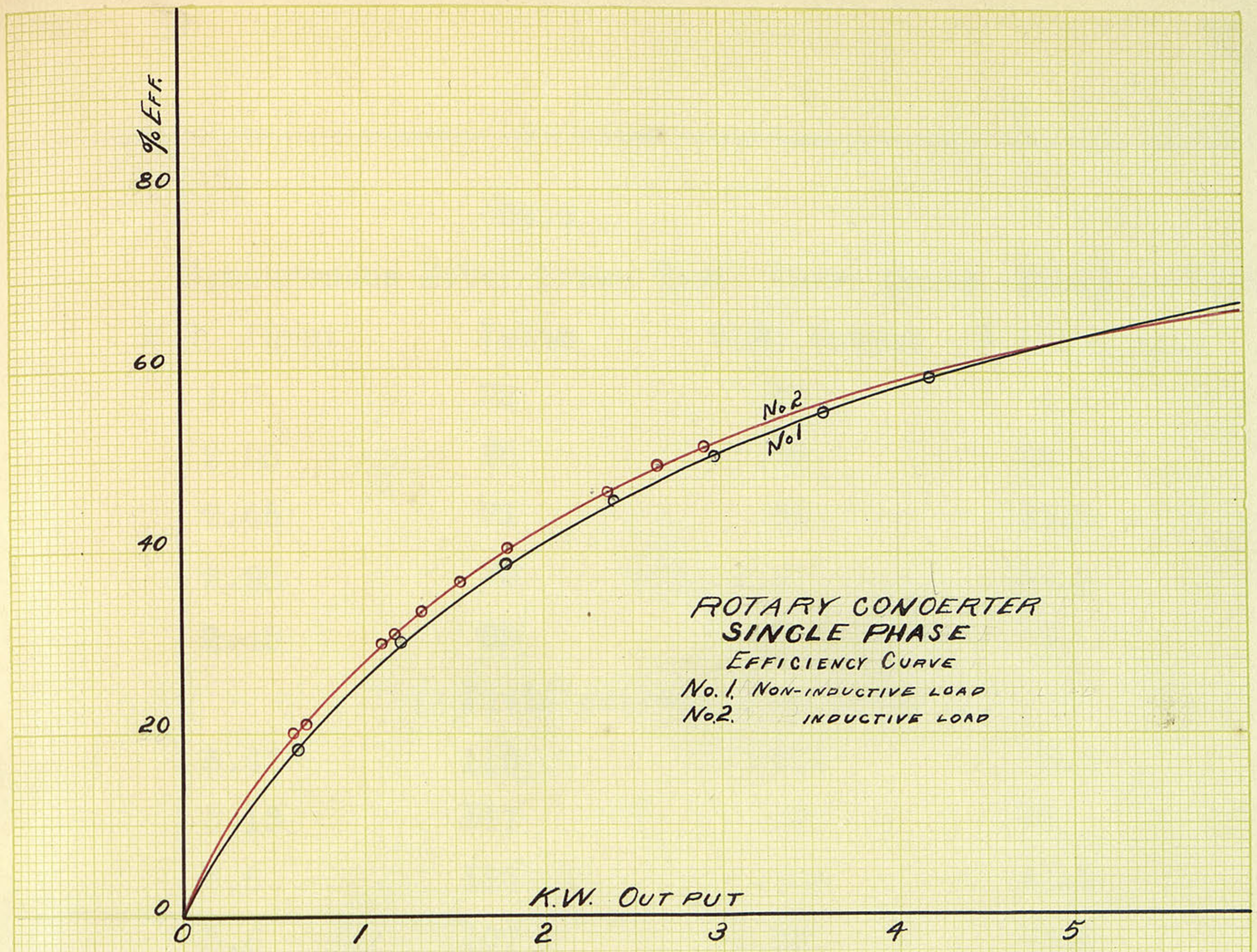
2.46	.0	0
3.81	1.18	31
3.97	1.32	33
4.15	1.53	36
4.44	1.8	40
5.15	2.4	46
5.35	2.65	49
5.7	2.92	51

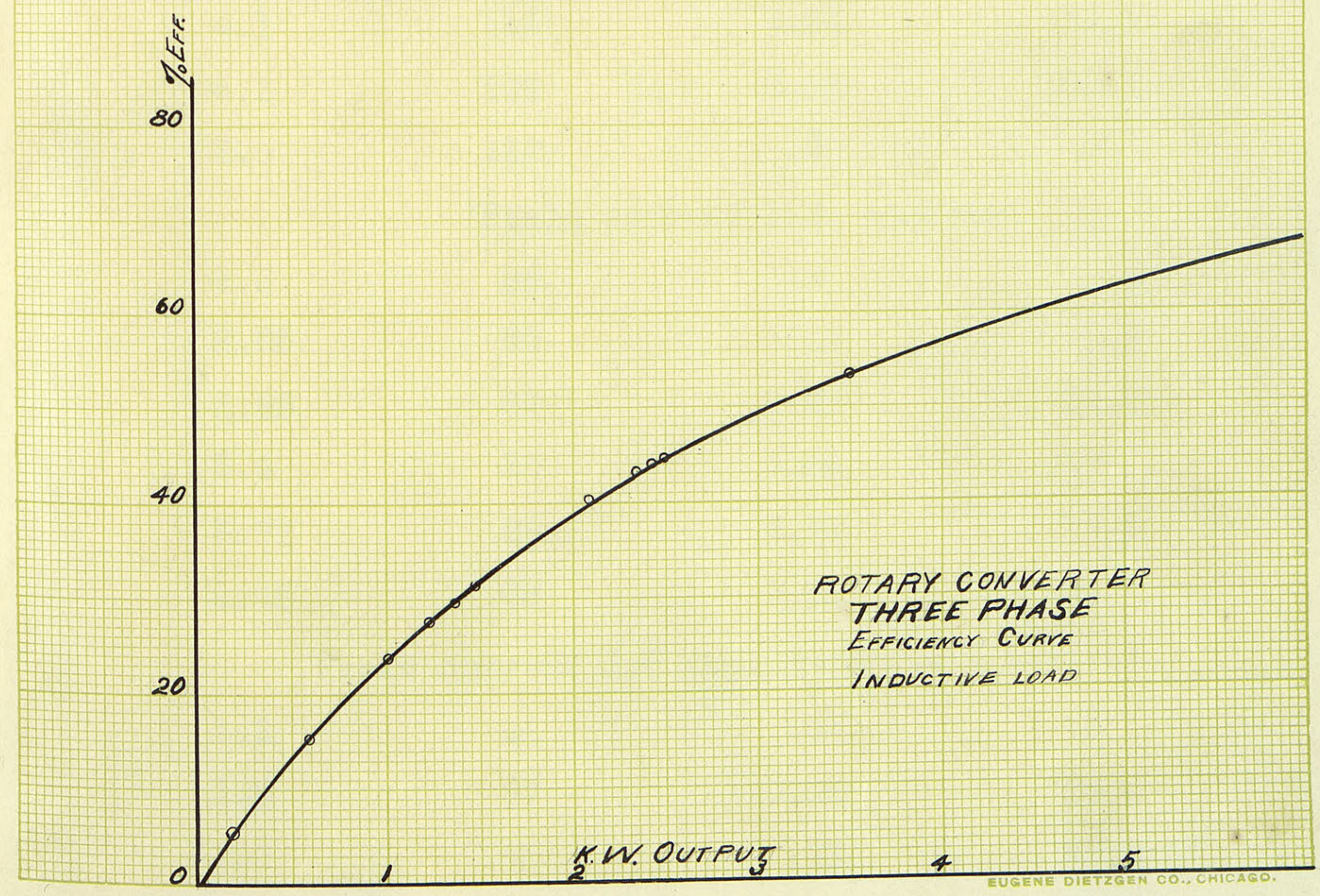
Data

A.C. Generator Three phase. Inductive load. 110 volts.

K.W. Input	K.W. Output	% Efficiency
2.71	0	0
3.31	.185	6
4.45	1.23	28
4.55	1.36	30
4.65	1.47	32
5.12	2.09	41
5.45	2.35	43
5.52	2.43	44
5.62	2.5	45
6.62	3.55	53

The rotary as a synchronous motor, with brake test, has its characteristics shown by curves. No. 1, 2, & 3. show its efficiency with differant field currents, and the point at which it brakes down, with the brake and the corresponding field current. The reason that the motor brakes down at these small loads is due to the fact that in the tests for Nos. 1, 2, & 3. the machine was self excited, and the load come on the voltage of the alternator would drop lowering the field of the motor, This caused a lagging current which in turn caused the voltage to drop. Another reason is that the brake does not give a constant grip, so that it would pull the armature out of step ca causing the motor to stop. Curve No.4. has a seperate excited field, and for this reason holds up under a considerable greater output. While No.2. holds up to the same efficiency at the same output, it can be explained in that the field was of the right strength to through the impressed voltage and current in phase.

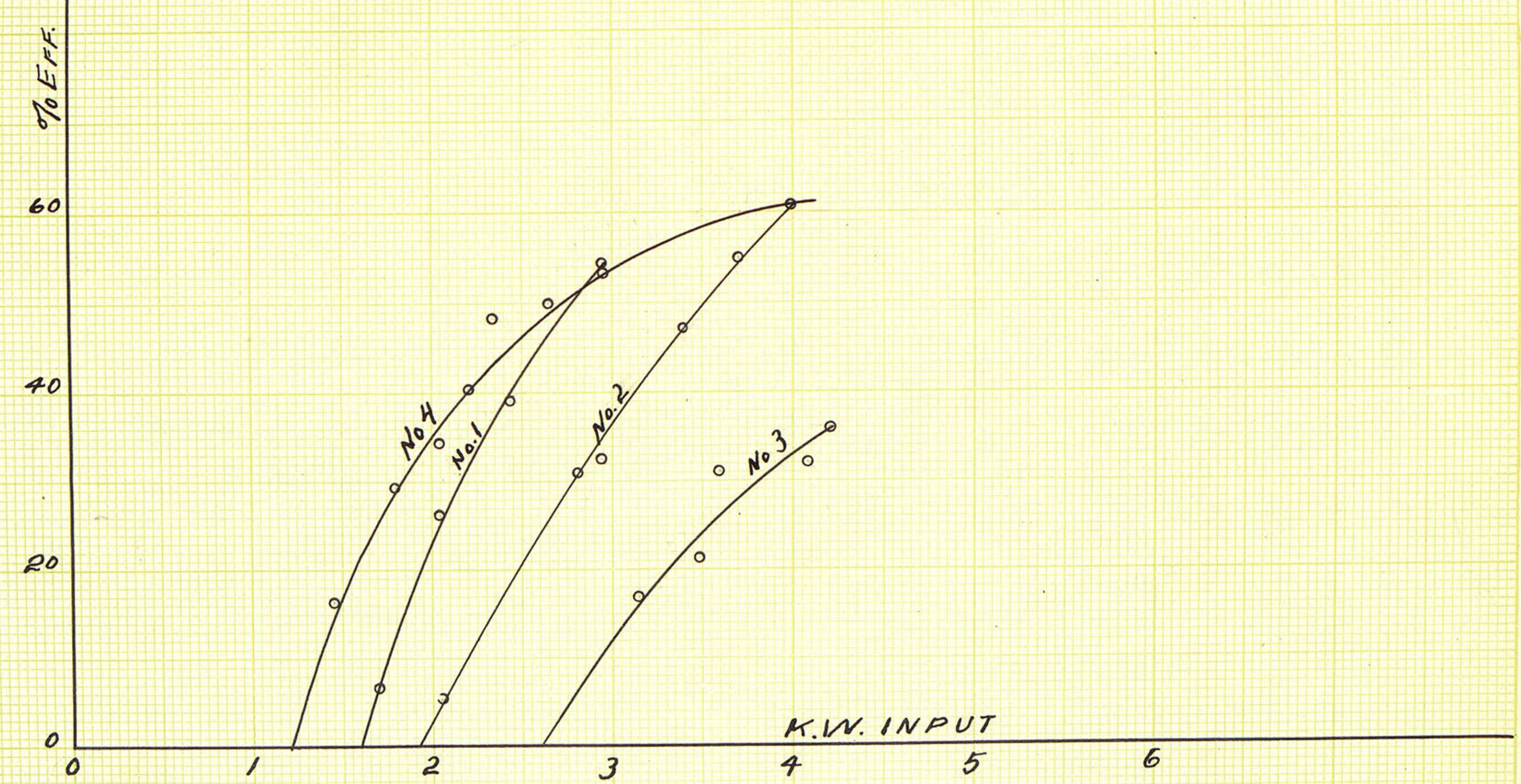

% EFF.
80
60
40
20
0
K.W. OUTPUT
0
1
2
3
4
5
No.2
No.1
ROTARY CONOERTER
SINGLE PHASE
EFFICIENCY CURVE
No. 1. NON-INDUCTIVE LOAD
No.2. INDUCTIVE LOAD


% EFF.
80
60
40
20
0
K.W. OUTPUT
1
2
3
4
5
ROTARY CONVERTER
THREE PHASE
EFFICIENCY CURVE
INDUCTIVE LOAD
EUGENE DIETZGEN CO., CHICAGO.

Data

Synchronous Motor Brake Test. Three phase. Field current 1.

K.W. Input	Volts	K.W. Output	% Efficiency
1.7	78	.11	6.5
2.05	75	.53	26.1
2.45	71	.96	39.3
2.95	70	1.6	54.3
2.45	85	.0	0
Field current 2 amperes.			
3.42	110	.212	6.2
3.15	111	.535	17
3.5	110	.748	21.3
3.6	107	1.13	31.4
4.1	113	1.34	32.7
4.2	109	1.55	36.9
2.6	112	.0	0
Field current 1.3. amperes.			
1.6	89	.0	.0
2.05	95	.11	5.4
2.95	89	.86	32.6
3.4	86	1.64	47
3.72	89	2.02	54.5
4.45	88	2.22	61
Field current 1.5 amp. Separately excited.			
1.2	96	.0	0
1.8	97	.53	29.4
2.2	96	.93	42.2
3.13	96	1.85	59
4	96	2.43	60.8



ROTARY CONVERTER
EFFICIENCY WITH BRAKE LOAD
RUN AS SYNCHRONOUS MOTOR

No. 1. FIELD CURRENT 1
No 2 " " 1.3
No. 3 " " 2.
No. 4. " " 1.5
SEPERATEL EXCITED

As a synchronous motor belted to a generator as a load the efficiency runs much higher , and carries a greater load than with the brake test. Two differant tests were run. One with a field current of .99 amperes. The other with a field current of 1.2 amperes. The former is seen to be higher efficiency and carries a greater load. Both curves have a tendency to droop just before the brake down point is reached.

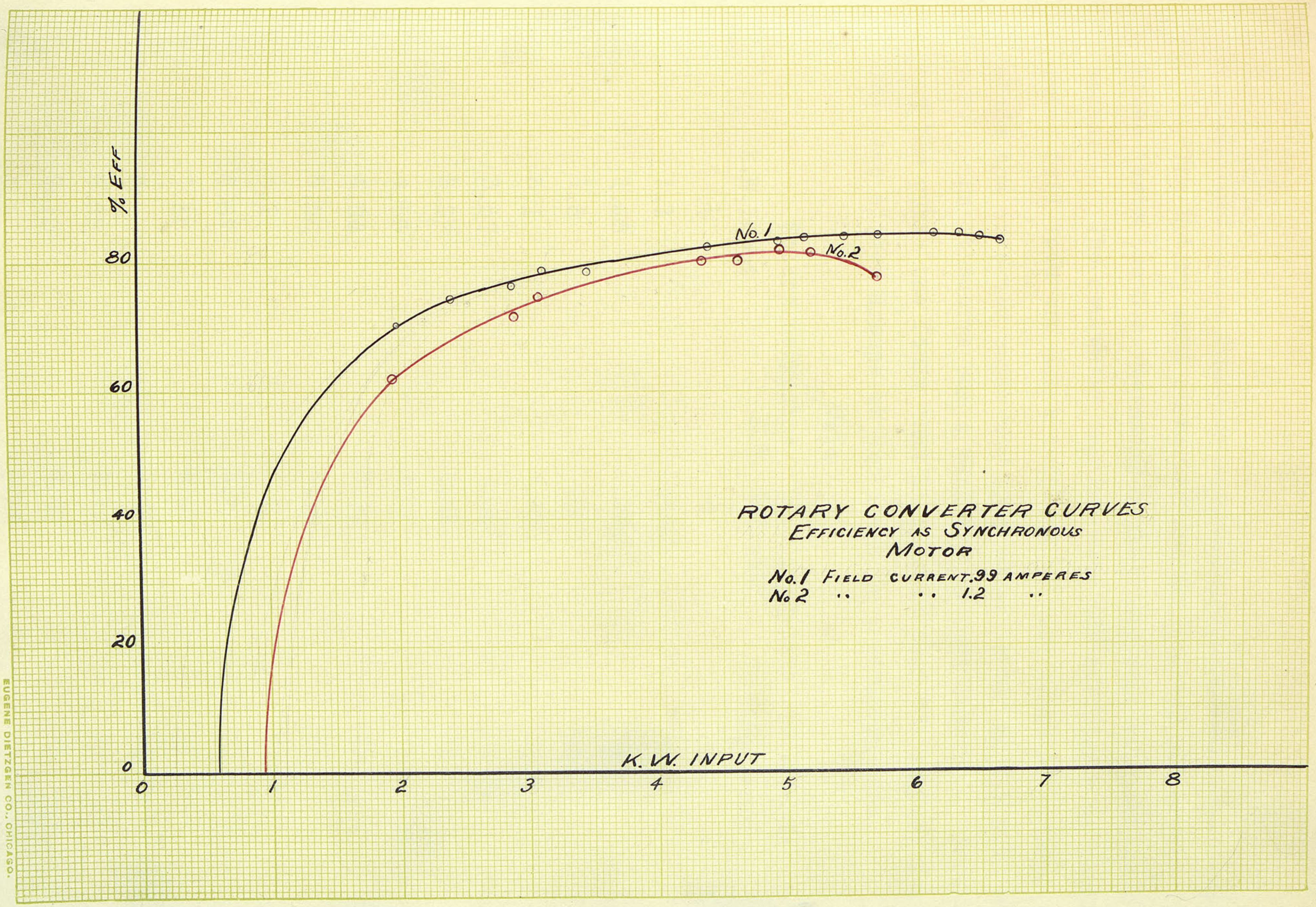
Data

Synchronous motor. Generator load. Field current .99 amps separately excited.

Total K.W. Input	K.W. Output	% Efficiency
1.98	1.4	70
2.4	1.79	74
2.82	2.15	76
3.11	2.46	79
3.46	2.71	78
4.37	3.59	82
4.92	4.08	83
5.12	4.29	83
5.42	4.54	84
6.11	5.17	85
6.32	5.3	84
6.59	5.47	83

Field current 1.2 amperes.

1.94	1.21	62
2.89	2.05	71
3.09	2.31	75
4.34	3.58	80
4.95	4.065	82
5.59	4.39	77



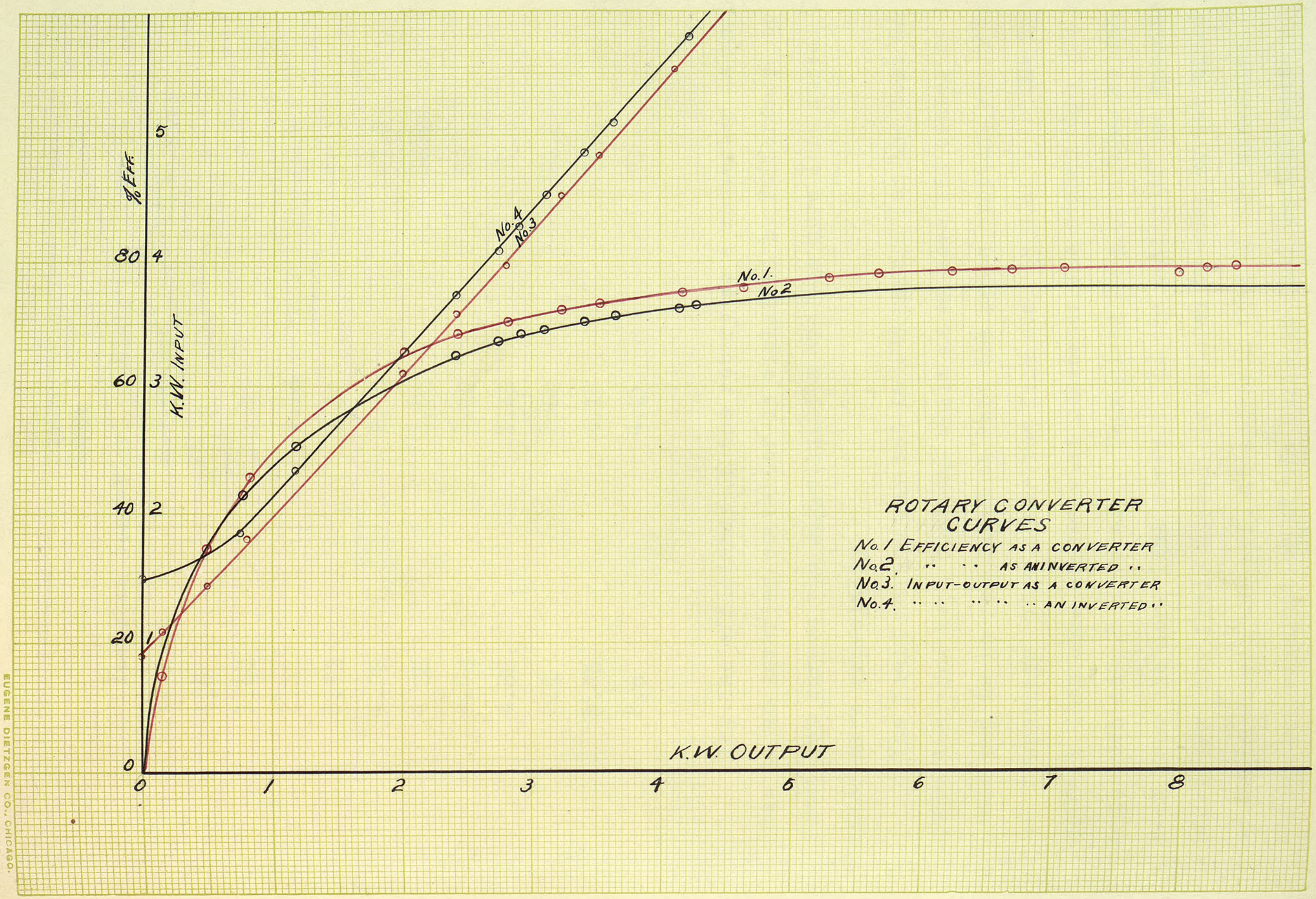
ROTARY CONVERTER CURVES
EFFICIENCY AS SYNCHRONOUS
MOTOR
No.1 FIELD CURRENT .99 AMPERES
No.2 .. .. 1.2 ..
No.1
No.2
% EFF
80
60
40
20
0
K.W. INPUT
0
1
2
3
4
5
6
7
8

The Rotary as a converter and an inverted converter. In these tests the d.c. terminal voltage was kept constant at 110 volts. The converter reaches near 80% efficiency a little above full load and has a tendency to rise slightly higher, while the inverted converter only rises to 74% at 4.3 K.W. output. But thecurve has a tendency to rise higher . Continuing the curve one finds that it reaches near 77% at full load and then either droops or continues in a straight line.

Data

Rotary converter. Field current .98 amperes

K.W. Input	K.W. Out put	% Efficiency
.9	.0	0
1.1	.168	15
1.45	.504	35
1.8	.829	46
3.1	2.035	66
3.57	2.44	68
3.97	2.81	71
4.53	3.25	72
4.86	3.54	73
5.54	4.18	76
6.1	4.6	76
6.87	5.7	77
7.35	6.27	77
8	6.74	78
8.55	7.15	79
9.12	8.03	78
10.3	8.35	78
10.5	8.4	78
10.65	8.47	79


ROTARY CONVERTER CURVES
No. 1 EFFICIENCY AS A CONVERTER
No. 2 .. .. AS AN INVERTED ..
No. 3. INPUT-OUTPUT AS A CONVERTER
No. 4. .. .. AN INVERTED ..
% EFF.
K.W. INPUT
K.W. OUTPUT
No. 1.
No. 2
No. 3
No. 4
EUGENE DIETZGEN CO., CHICAGO.

Data

Inverted converter. Field cur. .95 to 1.1 amps.

K.W. Input	K.W. Output	% Efficiency
1.5	0	0
1.84	.79	43
2.32	1.18	50.8
3.72	2.42	65
4.09	2.75	67.3
4.28	2.92	68.2
4.52	3.12	69
4.85	3.43	70.6
5.1	3.65	71.6
5.73	4.15	72.5
5.8	4.25	73

Why the efficiency of the rotary as a converter is higher than as an inverted converter is explained by refference to the first two curves the magnetization and the core loss curve. The later more especially.

The field curent was set at .98 ampere for the test as a converter and kept constant while as an inverted converter the field had to be regulated to kept the speed constant, which was not nescessary when conerting from a.c. to d.c. . The field current whenrunas an inverted converter was higher than .98 amp. byas much as .3 amperes. This gives more core loss as can be seen from the core loss curve. As the output of the machine increases the field current is reduced to keep up the speed so we would expect the eff. to approach that of the converter which upon examination of the curve we find that it does. Another reason for the difference might be accounted for in the instruments, for example if the a.c. instrument read low or the d.c. instrumenthigh it would cause the converter efficiency to be higher than the true efficiency and that of the inverted converter to be lower that the true curve.

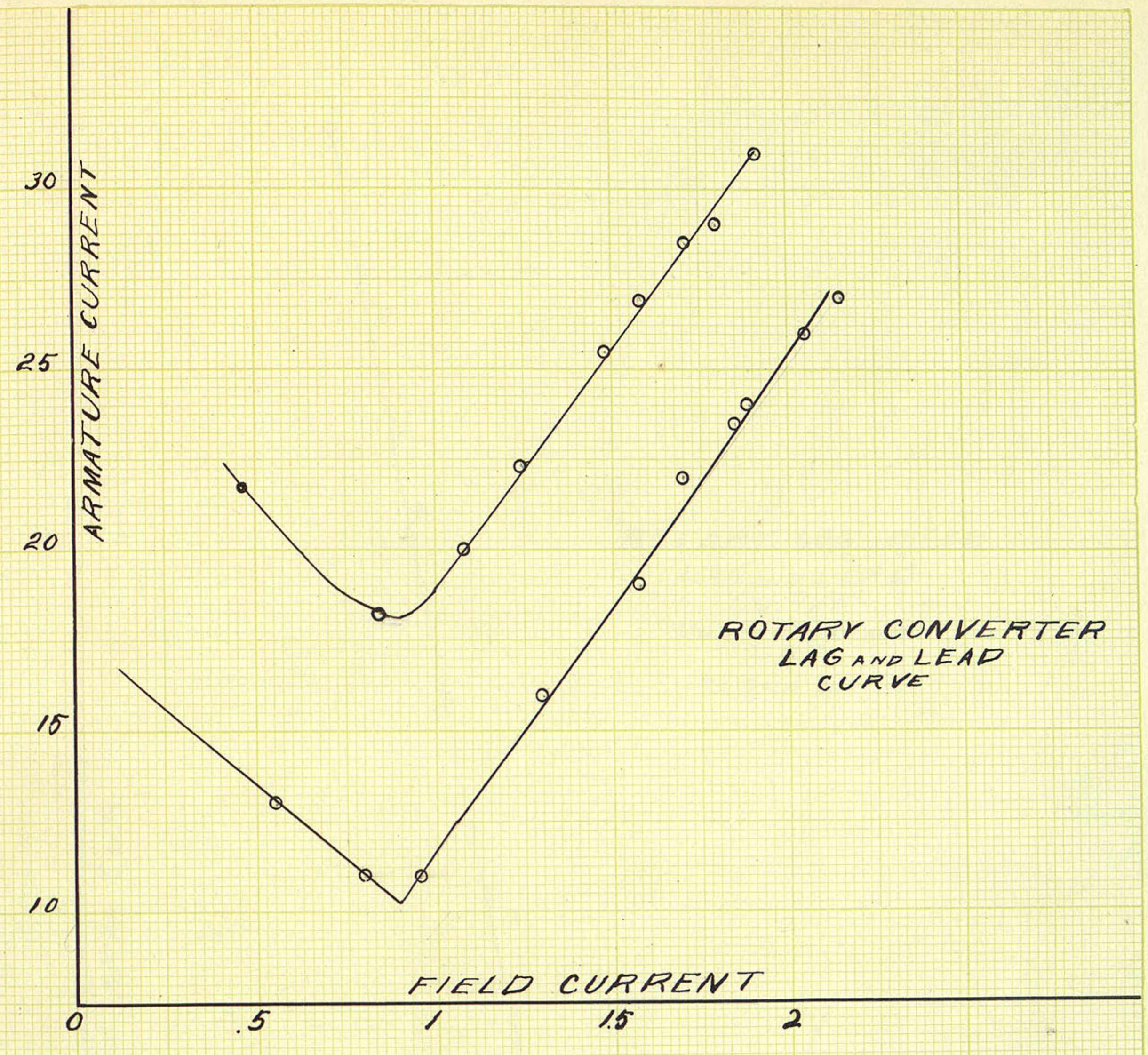
It is seen from the curve for the converter that the efficiency rises quite rapidly. Much more so than when used as an alternating current generator . The chief reason for this being that the core losses are much less because of the low voltage used.

The lag and lead curves show the proper field current to use in order that the current and e.m.f. will be in phase. It is best to have the current lag slightly on no load and full load, so it will be about in phase at 3/4 load, or the load at which the machine it most worked. But as seen from the curves the field current must not be allowed to vary much, or there will be a heavy wattless current, which is vary undesireable.

Data

Lag and lead Curves.

No Load		Light load		No load volts con. 95	
Arm. cur.	Field cur.	Arm. Cur.	Field cur.	Arm. cur.	Field cur.
13	.56	34	2.1	83	.72
11	.8	31	1.92	73	.86
11	.96	29	1.8	62	.95
16	1.29	29	1.77	51	1
19	1.58	28	1.71	42	1.1
22	1.7	27	1.59	32	1.2
24	1.88	25	1.48	28	1.3
24	1.85	22	1.25	13	1.39
26	2.05	20	1.08	10	1.5
27	2.15	18	.85	19	1.7


ARMATURE CURRENT
30
25
20
15
10
FIELD CURRENT
0
.5
1
1.5
2
ROTARY CONVERTER
LAG AND LEAD
CURVE

From these tests and from the theory developed, and knowing taht the line losses do not vary as the power transmitted but as the square of the current we can readily draw the conclusion taht if the power is to be transmitted more than a short distance it is of great advantage to transmit it at a high alternating voltage , transform it to a low voltage and then convert it into direct current by the use of the rotary converter, where it may be used in railway or electrolytic work. Its use in railway work requires the use of the supstation.

Although this machine shows a low efficiency one of larger capacity, as would be used in railway work would brobably give as high as 92 % or possibly 95 % efficiency. And as the voltage can be transmitted at 10 times the voltage used easily. This means lowering the current 10 times or reducing the losses 100 times. This gain easily overcomes the losses of the converter.

Though at present the rotary converter or substation system has a severe competitor in the single phase motor which can be opperated on voltages as high as 3500, there is still a large field for the converter. In many citys a voltage higher than 600 is not allowed on the trolley. With the substation system the high potential mains can be run in conduits where they will not endanger human life. So the rotary still has this field and will probable hold it for some time, although it is fast loosing its hold upon the interurban lines.