THE ROTARY CONVERTER.

J. T. SKINNER.   C. J. AXTELL.

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The rotary converter as a practical element in the transmission of power is a machine of comparatively recent date. Among the first practical converters noted was one exhibited at the Frankfort Exposition of 1891. This machine was of the flat ring, Schuckert make , fitted with four collecting rings outside of the bearing at the commutator end. This machine was operated successfully in its manifold and diverse functions. The rapid growth of the converter and its extension into a large field of usefulness has taken place during the past eight years. A brief comparison of its growth will be mentioned later in this discussion.

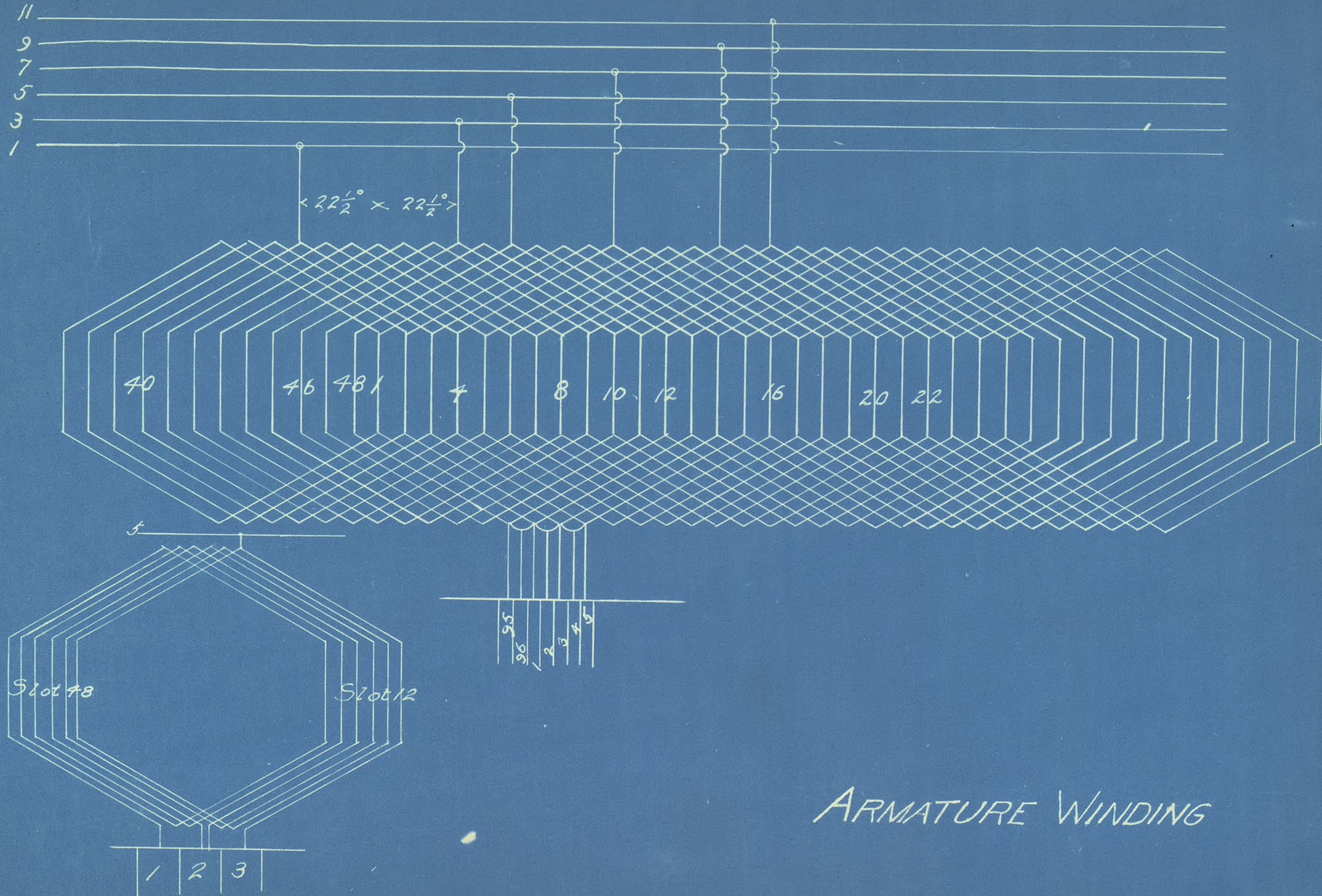
The rotary converter consists of a machine built practically the same as a continuous current dynamo, with one field, one armature, a set of bushes for each pair of poles, with the addition of two or more collector rings. The commutating device and collector rings are usually placed one at either end of the armature. The commutator and bushes are designed just the same as for a continuous current dynamo. The collector rings are connected by short taps to the armature coils. Each ring being connected to the armature winding by as many taps as there are pairs of poles. These connections being arranged at equal intervals around the armature. This is necessary since the armature coil between two taps passes through a complete cycle for each pair of poles. Thus the current in a rotary converter armature consists of a current as generated by the rotation of the armature in a magnetic field and supposed by the alternating current from the slip rings when operated as a direct converter. When the machine is operated as an inverted converter the current generated in the armature is superposed by the the current from the commutator.

In Fig. 1, Plate I is shown the general outline of the windings and plan of connections of the six phase rotary converter used in the following tests. The windings are usually precisely the same as in a continuous current machine, the only difference being the addition of collector rings and the symmetrical arrangement of the connection of the rings to the armature coils as referred to above. A converter may be arranged for any number of phases by observing the above conditions in regard to number of collector rings and armature connections. The three phase machine being the one most used at present.

In noting the conditions and plan of connections of the rotary converter we see at once that we have a machine that may be used for a number of purposes. The converter may be successfully operated under the following seven conditions: 1. To convert alternating to continuous current. 2. To convert continuous to alternating current. 3. Run as a Synchronous motor. 4. Used as a direct current shunt motor. 5. Run as a continuous current dynamo. 6. Operated as an alternating current dynamo. 7. Used to generate both continuous and alternating current at the same time.

Since the current generated in any armature coil is of a pulsating character or is an alternating current which by the use of a commutator is made continuous or when slip rings on the shaft are properly connected to the armature an alternating current can be taken off at the slip rings. When the machine is to generate or be supplied with three phase current the taps from the rings must be connected to the armature 120 electrical apart. Then when three phase alter-

PLATE I



ARMATURE WINDING

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nating current from any other machine is supplied to the slip rings the armature will rotate at exactly the same cycle speed as the generator supplying the current. A continuous current may be taken from the brushes the same as though the alternating current was generated in the converter armature itself. Hence the rotary converter may be said to be simply the commutator of a direct current machine running at some distant point from the generator. To cause this commutator to run synchronously with the generator a prime mover is needed which will keep the two machines in step. The speed of the synchronous motor is a function of the cycle speed of the generator and number of poles of the synchronous motor. Hence it is the synchronous motor action of the converter which keeps it in step with the generator. Theoretically a rotary converter could be made by placing on the shaft of a small synchronous motor, a commutator connected directly to the slip rings of short taps. However there are advantages to be gained by constructing them with an armature between the rings and commutator. Large converters for high voltages are not built for any greater number of cycles than sixty. For large converters twenty-five cycles are generally used. In large sixty cycle converters the speed must be slow on account of its size, this is accomplished by increasing the number of poles and the number of sets of brushes on the D. C. end. Since the potential between segments on a commutator is limited, with a high voltage and many poles a large number of segments will be required. The principal speed of the commutator is also limited which forbids the use of a very large commutator. Consequently the segments will be too narrow for practical construction. What has been mentioned thus far may be applied to any converter while that which follows gives the results of experiments and test of of a 7.5 K.W. Converter.

General Electric Co., Rotary Converter.

No. 64810 Type T. C. Class 4.

Form D 4 Pole.

Full load capacity 7.5 K. W.

R. P. M. 1800

Continuous current and amperes 62.5, Volts 120.

Alternating current end cycles 60.

Amperes 62.5. May be operated from 1 to 6 phase.

12 - - - - - -1" X 5/8" Carbon brushes D. C. End.

12 - - - - -3/4" X 3/8" laminated copper leaf brushes at A. C. End.

Commutator Style K 1902. Has 96 segments.

Width of segment 5/32". Active length 3".

Brushes set mid-way between poles. Field bore 9.5".

Armature of laminated discs. Has 48 slots. Width .31". Depth .94". Armature wound with No. 10 B & S double cotton covered. 12 conductors per slot, 2 single coils assembled as a double coil. Resistance of armature 0.0611 ohms.

Field spools of laminated discs, webbed type, which provides good ventilation.

Shunt wound. Has 1749 turns per pole of No. 18 B.W.G. wire, double cotton covered. Cold resistance 64.25 ohms. Hot resistance 66.65 ohms.

Normal field current .95 amperes.

Minimum field current with converter loaded - 4 amperes.

Maximum field current converter loaded - 1.4 amperes.

The rotary converter in the different experiments was started as a direct current shunt motor. To start the converter in this manner two field switches were used, one connected directly to the starting mains, the other to the rotary terminals as shown in Fig. 2 Plate II. The separately exciting circuit switch was first closed and the variable resistance in the field circuit nearly all cut out so as to have a strong field in starting. The field current used in starting was from 1.2 to 1.5 amperes. The converter was then started as a shunt motor, by the use of a starting box. After the machine had attained a fair speed the self exciting current switch was closed and the separately exciting field switch opened. The variable resistance in the field circuit was then turned in until the synchronizing lamps, which were connected across the synchronizing switch, began to grow alternately bright and dark. When the lamps are dark it shows that the E.M.F. of the converter is equal and in opposite phase to that of the generator. As the cyclic speed of the rotary is nearly that of the cyclic speed of the generator, the period of brightness and darkness of the lamps grow longer, so that it is possible to get the speed adjusted until the rotary is synchronized for several seconds at a time. During the dark period the synchronizing switch was closed and the starting box cut out, the converter running from the alternating current end only. The field current can be varied through quite a wide range under load. When running light the range is much greater than when loaded. This function of the converter will be treated elsewhere.

In sub-stations, where no storage battery of other source of continuous current is available for starting the rotary, small motor generator sets have been installed for this purpose.

The Westinghouse Electric & M'f'g Co., sometimes employ as a starter, a small induction motor geared to the converter shaft. The General Electric Co., construct all of their 25 cycle converters so that they may be started directly from the alternating current end. Special taps from the secondary of the transformers give a low voltage current for starting. The action of the current in the armature is the same as that in an induction motor. When a converter is made to start in this manner break up switches are used in the field circuit so that the fields may be open circuited to prevent the danger of puncturing the insulation by the high voltage due to self induction. These switches are closed when the machine attains synchronous speed.

In the following test the results show the effect of variation of field current. Fig. 1 of Plate II shows the plan of the connection of the instruments for the test. The motor was synchronized then the field current was varied from normal excitation down to almost zero when the converter fell out of step. After the converter was again synchronized the field current was reduced again nearly to this point and then increased step by step till the maximum allowable field current was reached. The different instruments were read for each variation of field current both descendingly and ascendingly. The results show that about eleven amperes is the minimum armature current on no load and the exciting current at this point is found to be about .936 amperes as normal excitation for converter as a synchronous motor. The other experiments show that an exciting current of .91 to .95 amperes gave good results with the rotary operated as a loaded synchronous motor or converter. The lowest field current reached was .064 amperes, the armature current at this excitation was 35 amperes. The highest field current reached was 3.1 amperes and the

PLATE 2

FIG. 1.

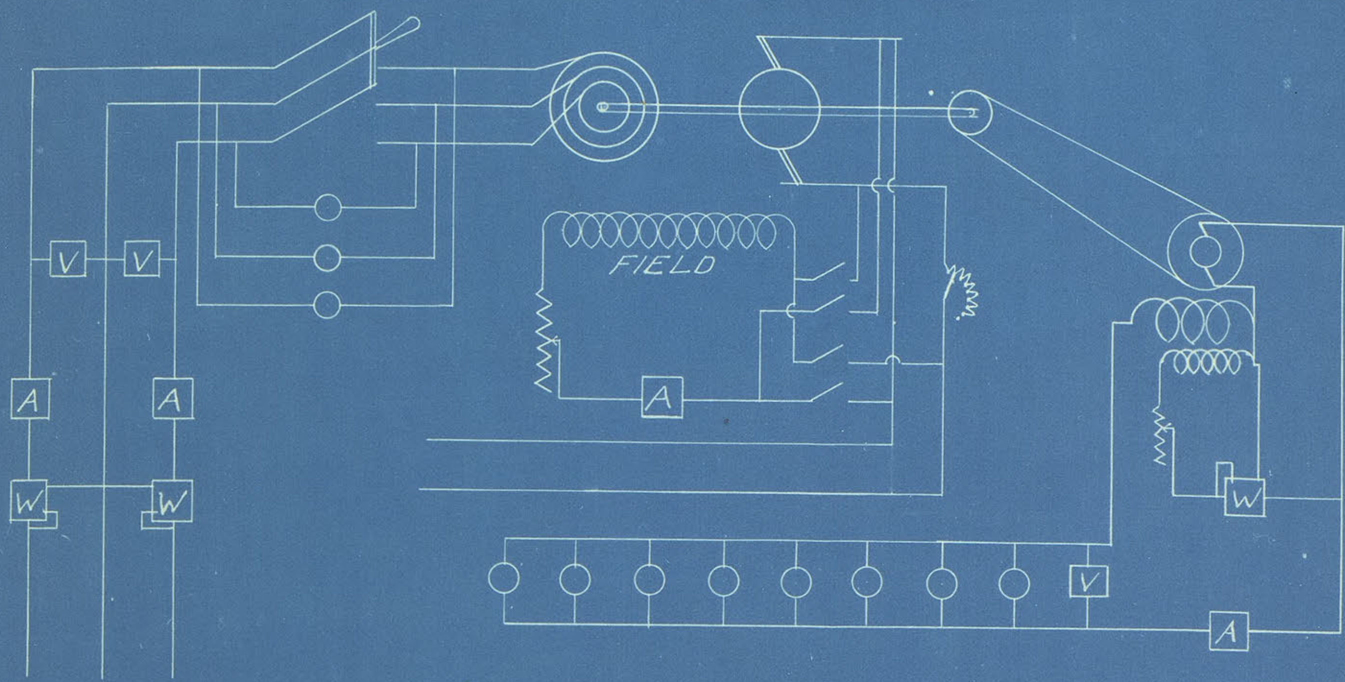
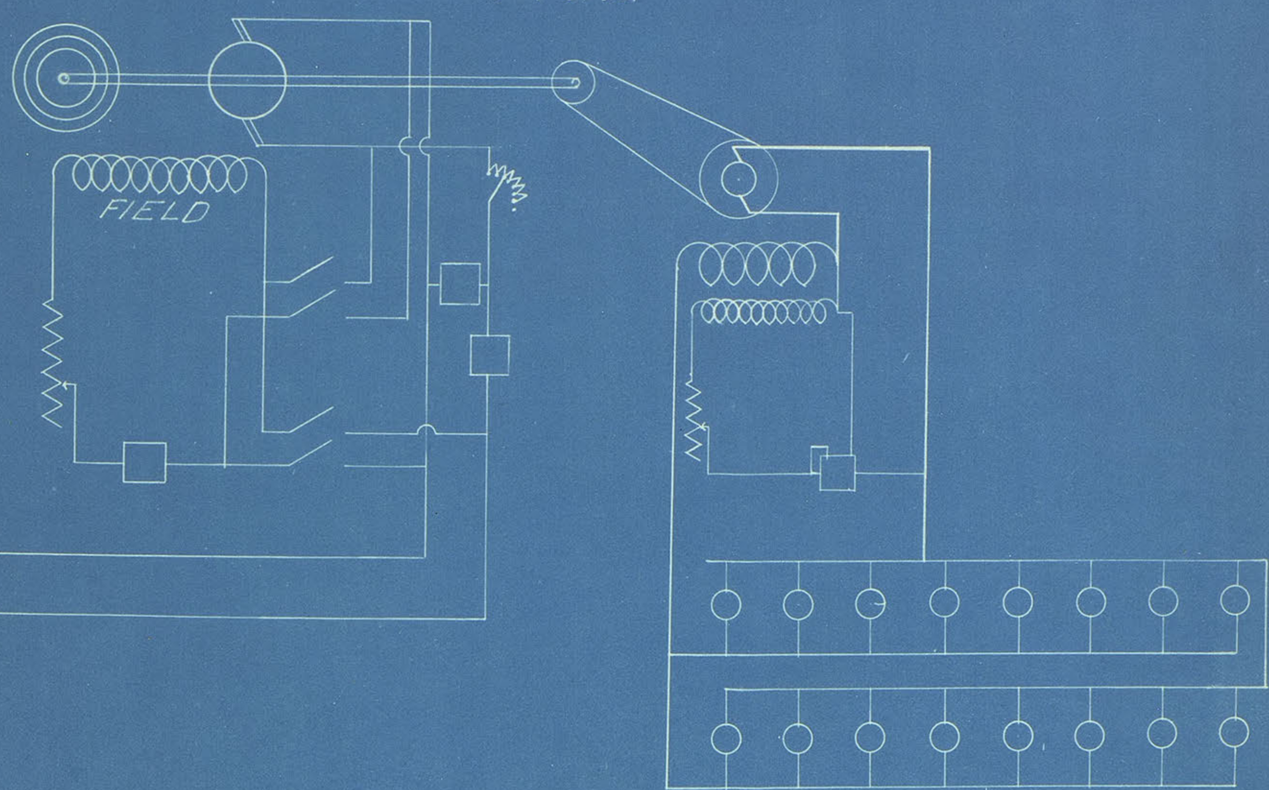


FIG. 2.



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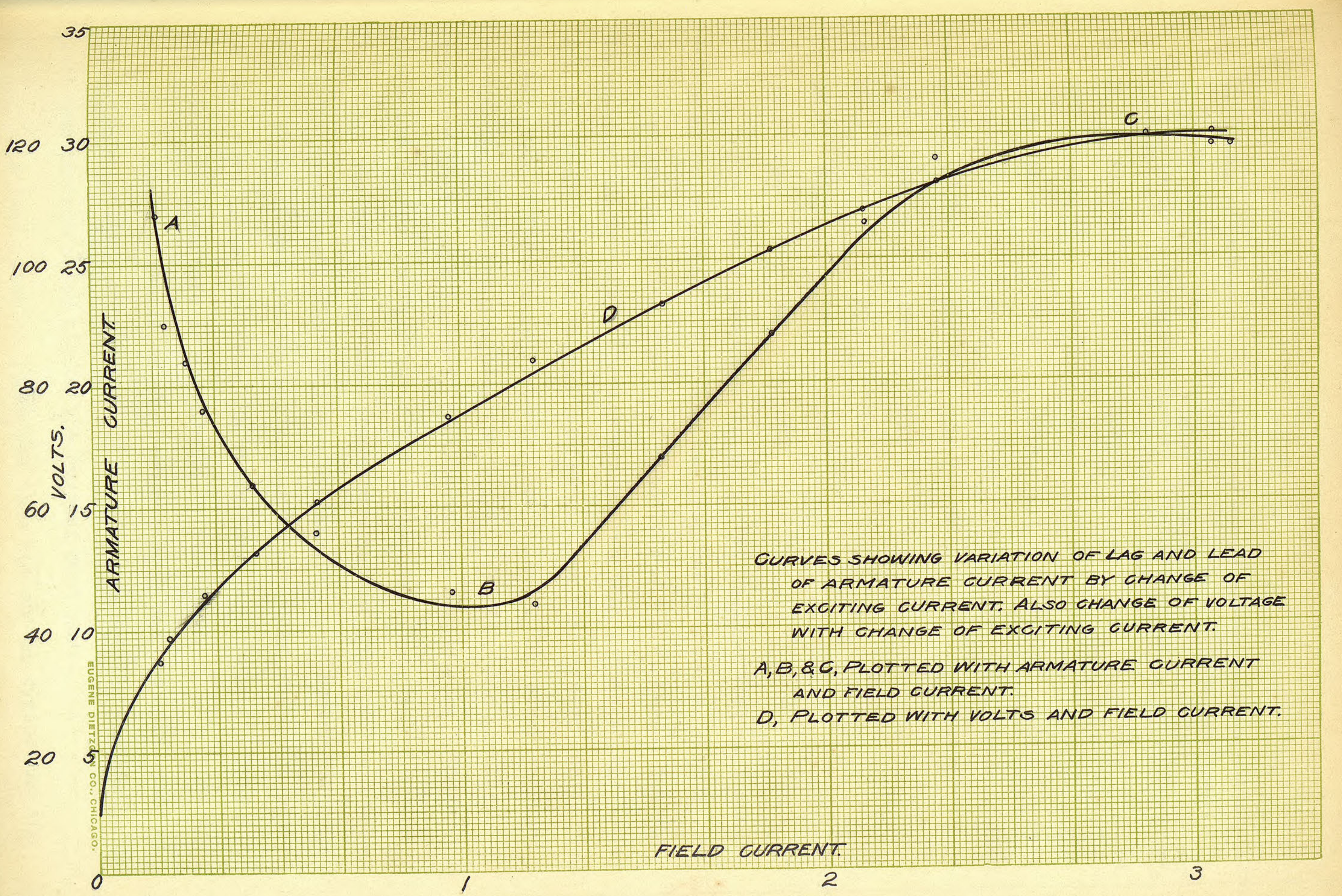
armature and the armature current at this point was 29.5 amperes. The curve shows that at some point with about 1. ampere exciting current and about 11. ampres armature current that the armature current changes from a lagging to a leading current. The armature current rises rapidly as the exciting current is gradually increased to about 2.3 amperes when the curve takes nearly a horizontal direction showing that any further increase of exciting current produces no further rise in armature current. Curve D. shows that the voltage continues to rise as the exciting current is increased and that there is no noticable change in the voltage as the current changes from a lagging to a leading current.

Data for Experiment Showing Variation of Lag and Lead of Current by Change of Exciting Current.

	(1)&(2) Volts.	(1) Arm.Cur.	(2) Arm.Cur.	Field Current.	(1)&(2) Volts.	(1) Arm.Cur.	(2) Arm.Cur.	Field Cur-
1	72.6	11.7	11.	.936	23.	29.5	30	.1
2	71.2	11.9	12.	.117	30	25.5	27	.17
3	70.5	11.95	13	.983	31.6	26.25	26.5	.17
4	66	12	14	.844	32.5	25.5	25.5	.18
5	62	12.4	16	.732	35	24.25	24.5	.19
6	58.6	13.1	17	.643	30	22.5	22.5	2.
7	54.6	14.5	17.5	.573	41.5	21	21	.25
8	52	15	19	.5	46	18.5	19	.3
9	49.8	19.5	20	.45	52.5	16	16	.44
10	48	21	21	.408	61	13.5	14	.61
11	46.3	21.5	21.5	.38	74.8	11.5	11.5	.97
12	43.5	23	23	.35	84		11	1.2
13	41	24	24	.3	93		17	1.55



35
120 30
100 25
80 20
60 15
40 10
20 5
0
1
2
3
VOLTS.
ARMATURE CURRENT.
FIELD CURRENT.
A
B
C
D
CURVES SHOWING VARIATION OF LAG AND LEAD OF ARMATURE CURRENT BY CHANGE OF EXCITING CURRENT. ALSO CHANGE OF VOLTAGE WITH CHANGE OF EXCITING CURRENT.
A, B, & C, PLOTTED WITH ARMATURE CURRENT AND FIELD CURRENT.
D, PLOTTED WITH VOLTS AND FIELD CURRENT.
EUGENE DIETZGEN CO., CHICAGO.

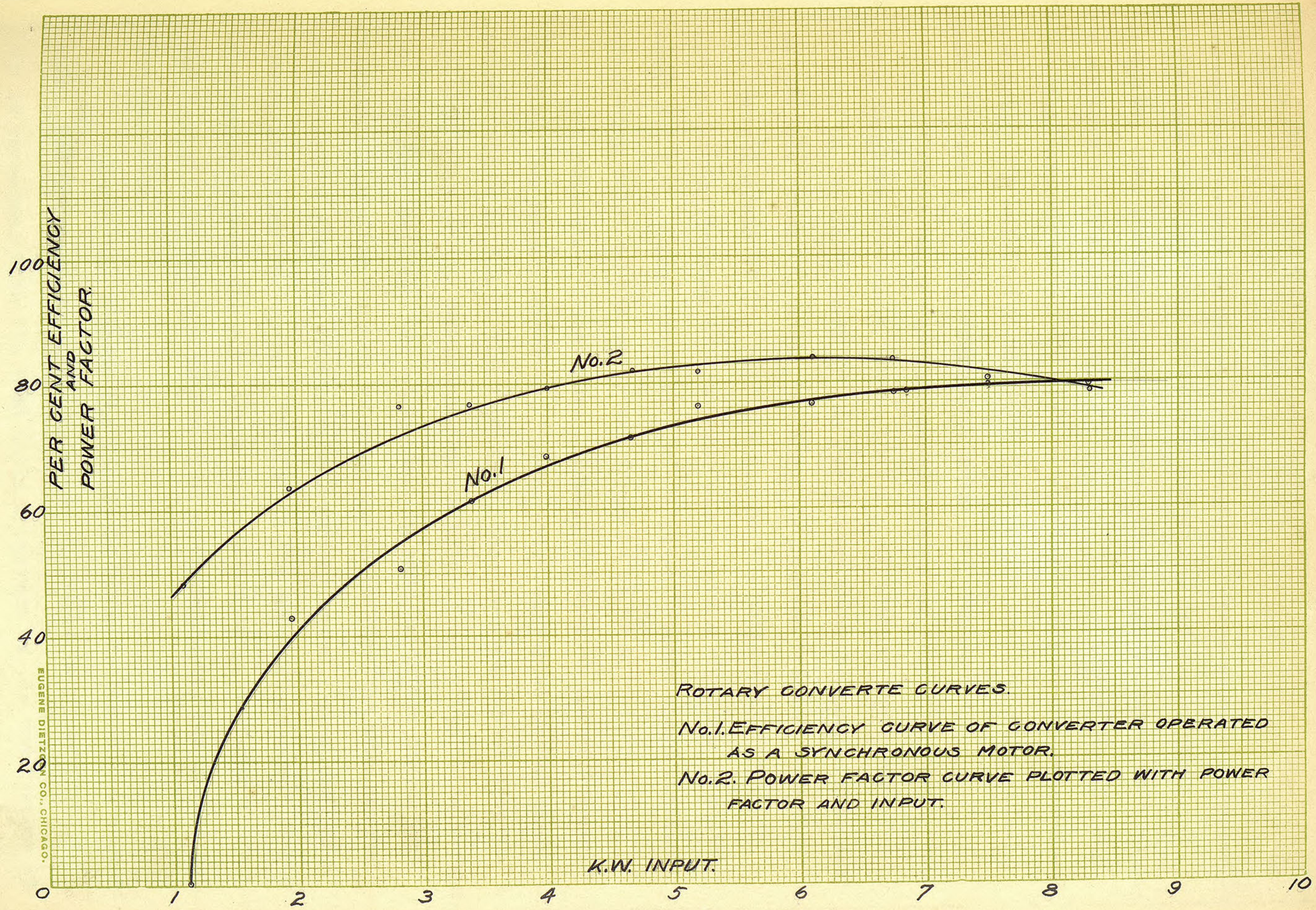
Data Continued.

	(1)&(2) Volts.	(1) Arm.Cur.	(2) Arm.Cur.	Field. Current	(1)&(2) Volts.	(1) Arm.Cur.	(2) Arm.Cur.	Field Cur.
14	39	24.5	25	.263	101.5		22	1.85
15	37	25.5	25.75	.23	112		29	2.3
16	35.3	26.25	26.5	.213	116	28.75	30	2.88
17	33.5	27	27.5	.18	120	29	29.5	3.05
18	32	27.75	28	.153	72	29	29.5	3.1
19	31	28.25	29	.123				
20	29	29	30	.11				
21	26.8	30.5	31	.086				
22	14	35	35	.064				

The rotary converter in this test was operated as a synchronous motor with the fields excited from the D. C. end. The motor was first run light and the input noted. A 4.5 K.W. Direct Current Compound wound Crocker & Wheeler dynamo was then belted to the motor and the input required to run this at no load with fields excited was noted. The difference in these two readings was the power required to run the dynamo and included the bearing friction and windage, brush friction, eddy current, hysteresis and copper loss. The dynamo was a short shunt machine but since the current required to excite the field was very small the copper loss in the armature was insignificant so was neglected in the computation. A wattmeter was connected so as to measure the watts lost in the shunt field and rheostats. This subtracted from the watts required to run the dynamo gave the constant loss in the dynamo at all loads.

The resistance of the series fields was .061 ohm and the resistance of the armature was .37 ohms giving a total resistance of .431 ohm through which all of the current must pass.

A small load of lamps was then put on the dynamo and the


PER CENT EFFICIENCY AND POWER FACTOR.
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
K.W. INPUT.
No.1
No.2
ROTARY CONVERTE CURVES.
No.1. EFFICIENCY CURVE OF CONVERTER OPERATED AS A SYNCHRONOUS MOTOR.
No.2. POWER FACTOR CURVE PLOTTED WITH POWER FACTOR AND INPUT.
EUGENE DIETZGEN CO., CHICAGO.

I 2 R loss for that load in both the armature and series field was computed. The power required to drive the dynamo is equal to the constant loss + watts load + watts in shunt field + copper loss in series field and armature. By this method the output of the synchronous motar was calculated and from this output and true watts input the efficiency of the synchronous motar was computed.

Curve No. 1 showing the efficiency of the synchronous motar at different loads, shows that the efficiency increases very rapidly on the lower part of the curve then increases more gradually as the load comes on, until the input is between 6 and 7 K.W. when the general trend of the curve is toward the horizontal direction. The maximum efficiency of the motor was obtained when the input was about 8.5 K.W. The curve still has a slight upward trend but the break-down point of the motor was found to be at this load.

This curve rises more gradually than does the efficiency curve on the direct converter, the inverted converted or the shunt motor. This is due to the fact that there is more copper drop for t the same load on the synchronous motor than on the other three machines. In this test the current was not in phase with the E.M.F. and therefore a greater current is required to produce the same torque than would be required in the direct current motor. When used as a rotary converter the current flowing in the armature is equal to the difference between the A.C. input and the D.C.output. Hence there is more copper loss for the same load on the synchronous motor than on the converter.

Curve No. 2 shows the change of power-factor with change of load. The power-factor when the motor run light was less than .5 but it increased with the load until a maximum of .84 was reached at about 6 K.W. input. From this point the power-factor decreased with increase of load. The position of maximum power factor depends upon the field excitation and upon the reaction in the circuit.

Data - showing result of a test of the converter operated as a Synchronous motor.

Input A. C. End.

	(1) Volts	(2) Volts	(1) Amperes	(2) Amperes	(1) Watts	(2) Watts	Total True Watts
1	76.4	764	16	14	260	850	1110
2	Constant	Constant	16	14	260	850	1110
3			21	19	700	1250	1950
4			21	19	700	1250	1950
5			25	23	1200	1620	2820
6			30	28	1400	2000	3400
7			35	31	1700	2300	4000
8			38	36.5	2000	2670	4600
9			43	40.5	2300	2900	5200
10			29	46.5	2700	3400	6100
11			55	50.5	3200	3550	6750
12			57	54	2700	4100	6800
13			58	54	2700	4150	6850
14			65	60	2900	4600	7500
15			70	65.8	3200	5100	8300

60 cycles. 1800 R.P.M.

OUTPUT.

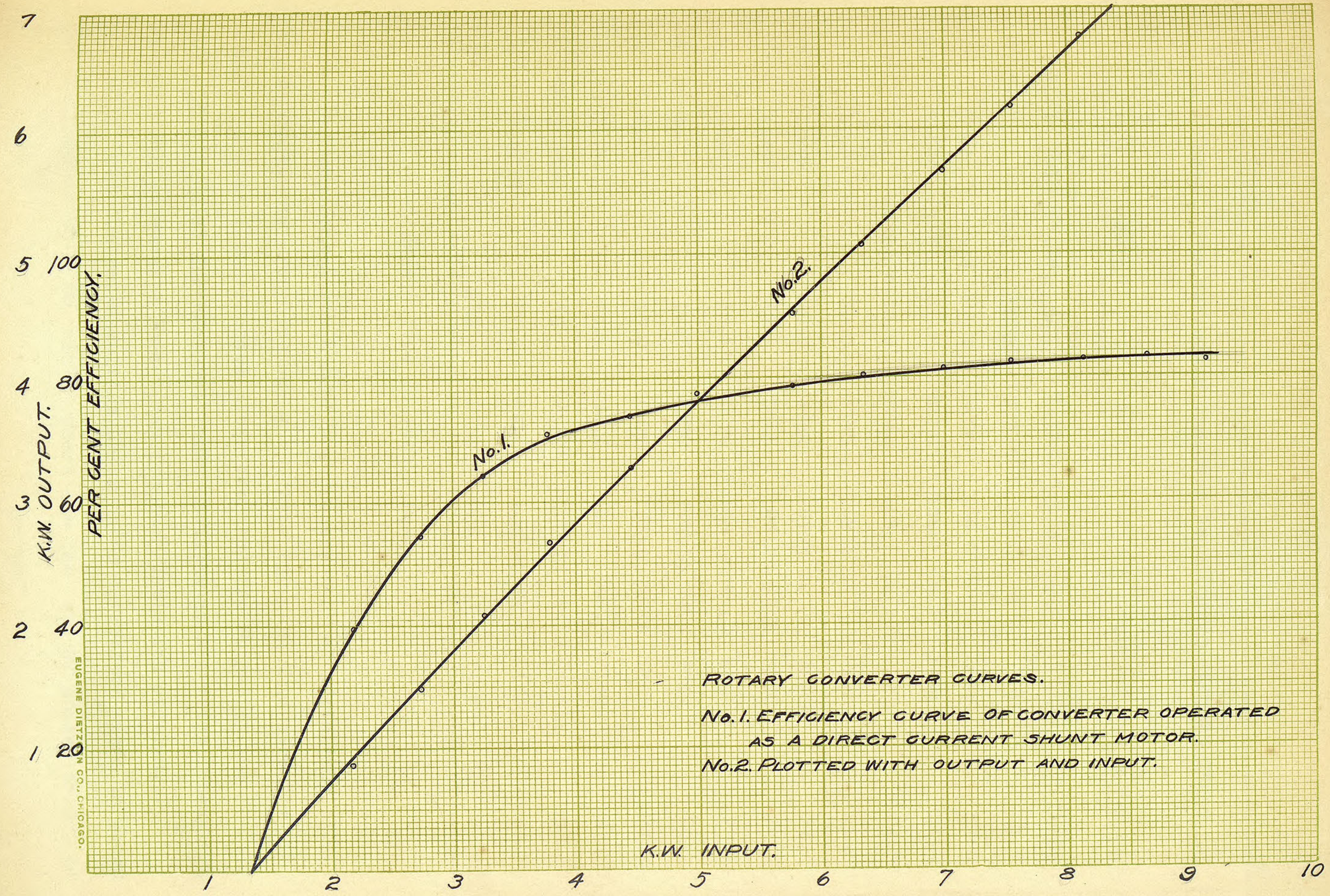
Apparent Watts	R.C. Field Current	Volts	Amperes	(Total Watts)	Power Factor	Efficiency.
2292	.955	0	0	0	48.4	
2292	.955	0	0	0	48.4	
3055	.95	110	0	840	63.8	43.1
3055	.95	110	0	840	63.8	43.1
3676	.95	110	5.35	1434	76.65	50.8
4432	.955	110	10.95	2093	76.75	61.6
5045	.95	110	16.3	2737	79.4	68.45
5690	.93	109	21	3320	82.1	71.1
6380	.925	109.75	26	3972	81.5	76.35
7292	.925	110	31	4664	83.7	7650
8055	.96	110	35.6	5292	83.8	7844
8480	.85	110	35.8	5332	80.2	78.4
8555	.85	110	35.7	5317	80	77.7
9556	.84	110	40.8	6051	78.50	80.8
10380	.82	110	44.1	6527	80	78.8

As a D. C. shunt motor the converter gave a little higher efficiency than as a synchronous motor or converter. In this experiment the converter was connected as a plain shunt motor as shown in Fig. 2 of Plate II. The field current was adjusted till the motor attained normal speed with a line voltage of 125 volts.

The efficiency was obtained as in the other tests by the electrical method. The curve shows that the converter gives a good result for a small machine. The points on the curve being more regular than in the case of a like curve for the same machine as a synchronous motor. This may be largely accounted for from the fact that it is much easier to obtain an accurate reading with the direct current instruments than with the alternating current instruments, especially when the small converter is subject to hunting.

The curve shows that the efficiency rises quite repidly from zero to 3K.W. and from 3 K.W. to 4 K.W. at times rapidly to the right where from 4 K.W. it rises slowly to 8 K.W. showing a tendency toward a parallel direction. For lack of proper equipment the motor could not be over loaded to show at what point of one load the efficiency curve would begin to drop.

The curve plotted with out-put and input gives practically a straight line. From the curve by knowing ~~the~~ either the output or input the efficiency input or output may be read directly from the curve for any point up to a little past one load.



ROTARY CONVERTER CURVES.

No.1. EFFICIENCY CURVE OF CONVERTER OPERATED AS A DIRECT CURRENT SHUNT MOTOR.

No.2. PLOTTED WITH OUTPUT AND INPUT.

1c

Data - For Converter Operated as a Direct Current Shunt Motor.

	INPUT.				OUTPUT. (C.& W.Dynamo)			
	R.C. Field Amp.	Volts	Line Amp.	Watts	Volts	Amp.	Total Watts.	Efficiency
1	1. 1.125	125	10.5	1312.5	0	0	0	0
2	1.02	125.8	17.3	2176	106.5		864	39.6
3	1.008	125	21.8	2725	106	5.95	1444	54.8
4	1.01	Constant	25.9	3240	108	11	2097	64.75
5	1.007		30.2	3775	108.5	16	2692	71.3
6	1.005		35.6	4450	107.5	20	3292	74
7	1.0075		40	5000	106.25	24.1	3880	77.6
8	1.0025		46.15	5770	108	29.5	4520	78.35
9	1.		50.7	6337	108.25	34.5	5087	80.2
10	1.		55.9	6985	105.5	89.2	5665	81.2
11	1.0011		60.2	7520	104	43.5	6189	82.25
12	1.0035		65	8125	102.25	48.15	6736	82.8
13	1.0035		69.15	8640	101.25	5279	7179	83.15
14	1.		73	9125	98	55	7528	82.5

Speed, 1780 to 1800 R.P.M.

The scheme of connections for the test of efficiency of the converter is shown in Fog. 1 of Plate III. In this case the input was from a three phase alternator and the output at the D. C. end was a load of incandescent lamps operated at 110 volts. Readings of all the instruments were taken for each variation of load.

The theoretic voltage between the successive rings is given by the formula $E_n = \frac{E_d}{\sqrt{2}} \sin$ where n = the No. of phases or No. of

PLATE 3

FIG. 1

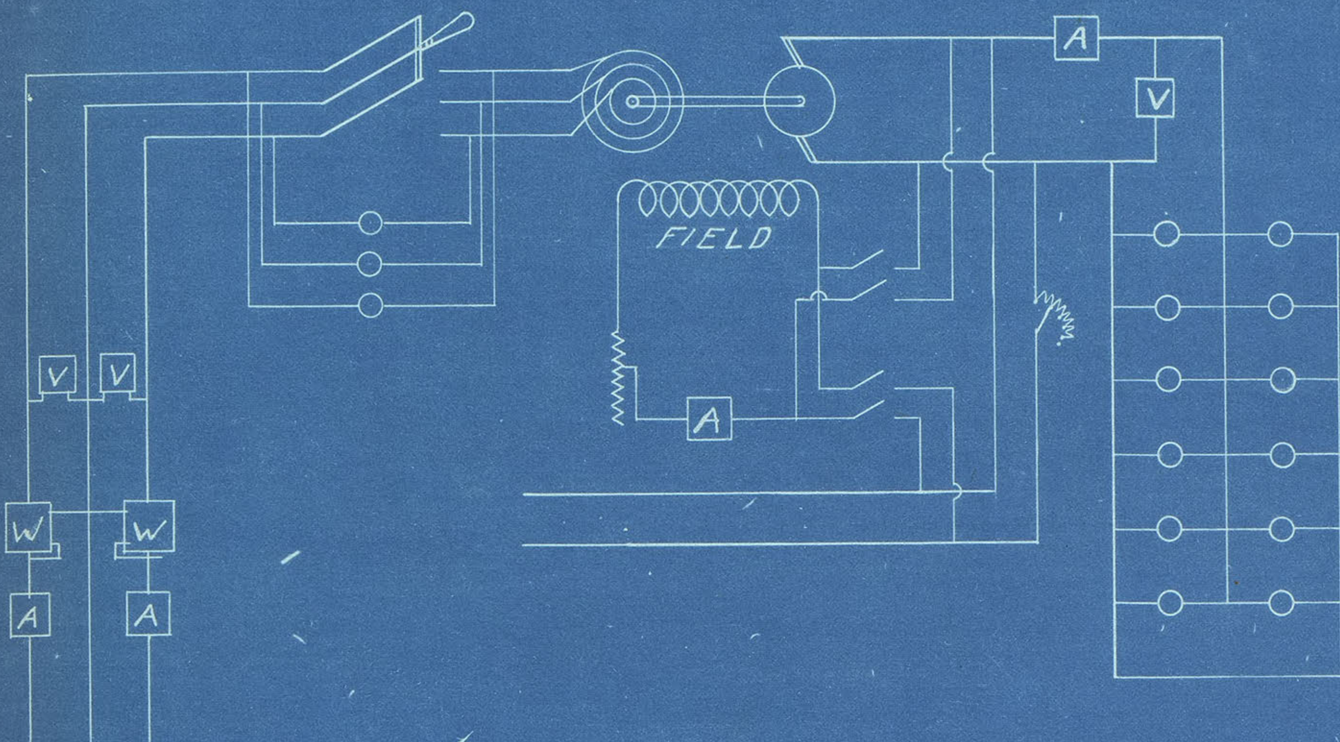
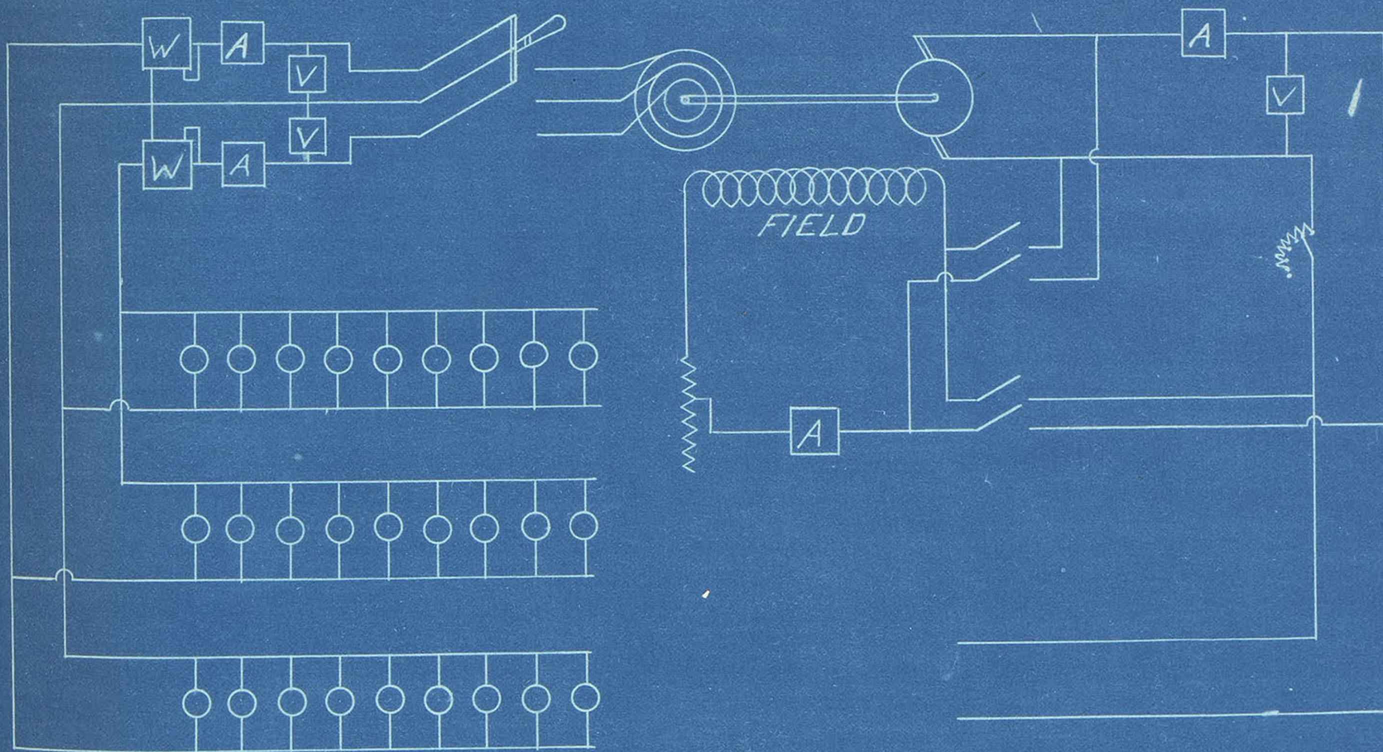


FIG. 2.



phases or No. of slip rings. En = the effective voltage between successive rings. Ed = volatage between D. C. brushes. The connecter being used as a 3 phase machine is = 3, and hence sin = sin 60°. Then sin 60 n = .612. So that E n = .612 E d.

The following table of data shows the actual E.M.F. relations with the machine operating under different loads both as a direct and inverted converter.

E.M.F. RELATIONS.

Converter			Inverted Converter.		
En A.C.End.	Ed D.C.End.	Ratio..	En A.C.End.	Ed D.C.End.	Ratio.
71	110	.645	79.25	125.5	.634
71.45	Constant	.648	79	125	.632
71.85		.653	78.75	Constant	.63
72.1		.655	78.5		.628
72.4		.6575	78.5		.628
74.5		.677	78.5		.628
75.5		.686	78.25		.626
75.35		.684	78		.624
76		.691	78		.624
77.3		.702	77		.616
77.25		.7015	76.5		.6125
77.75		.706	75.5		.604
78		.709	74.75		.598
			74.5		.596
			74.5		.591
			73.85		.59
			73.65		.59

From this we see the actual E.M.F. relation does not quite agree with the theoretic value. But there is a drop due to impedance in the armature and this increases as the load increases. The effect is the same when operated either as a converted or inverted converter.

The current relation is given by the formula

$$I\,n = \frac{\sqrt{2}\,I\,d}{u \sin \frac{II}{n}} = \frac{\sqrt{2}\;I\,d}{3 \text{ X } .866} = 5445 - I\,d.$$

The alternating current instruments were so unsteady on account of hunting that it was difficult to estimate how closely the practical result might come to the theoretical value. The armature reactions consist of direct current generator armature reactions superposed upon synchronous motor armature reactions. The direct current brushes are set so as to commutate the current in the coils mid-way between successive poles. The direct current armature reaction tends to twist the field flux in the direction of rotation, while the alternating currents in phase with the impressed E.M.F. tends to twist the field flux in the opposite direction. This result of neutralization keeps the flux fairly constant so that there is no change of excitation needed with changes of load to keep the commutator voltage constant. From Oudin the following is quoted regarding regulation of voltage by field excitation. "Like the synchronous motor the rotary converter can be used to annul self-induction of the line and the results of poor power factors of other parts of the system. For purposes of automatic compounding, the shunt wound rotary converter is useless on account of its constant power factor. The compound rotary is used to overcome the drop in the line, as well as change of power-factor, and thereby maintain constant voltage at the direct current end or for raising the alternating voltage with increase of load, and thereby, the direct current voltage. This regulation can affected without any change in the generator excitation simply by variation of the phase relationship of current and volts. The compound field of the rotary is proportioned so that at no load it is under excited. The E.M.F. of the rotary is then considerably less than the impressed E.M.F. and the current in the line is made lagging. The E.M.F. of self-induction is thereby increased so that the voltage of the system is cut down. As the load increases the excitation is increased by the rotary series fields, thus increasing the rotary E.M.F. and at some intermediate point bringing current and E.M.F. in phase so that the drop in voltage is then due to resistance only. At full load the converter is over-excited, and the rotary E.M.F. is greater than the impressed. The current is then leading and the voltage is actually higher at the converter than at the generator.

Sheldon shows that the resultant current curve of the two currents in the rotary armature is of a peculiar form and its area less than that of either curve alone. Steinmetz says that the current flowing in the armature conductors of a converter is the difference between the alternating current input and the continuous current output. Hence the armature heating is relatively small so that the overload capacity of a converter is limited by the commutator performance rather than by armature heating. Sheldon shows also that increasing the number of slip rings and number of phases increases the capacity of the converter (to quite a considerable degree) above the same machines capacity as direct current generator.

The rotary converter has two limitations which prevent its use under some circumstances, i.e. the fact that it has not a very wide range of voltage as noted above and because it is subject to hunting. The following paragraph taken from a General Electric Co., bulletin on rotary converters explains quite clearly the trouble known "hunting".

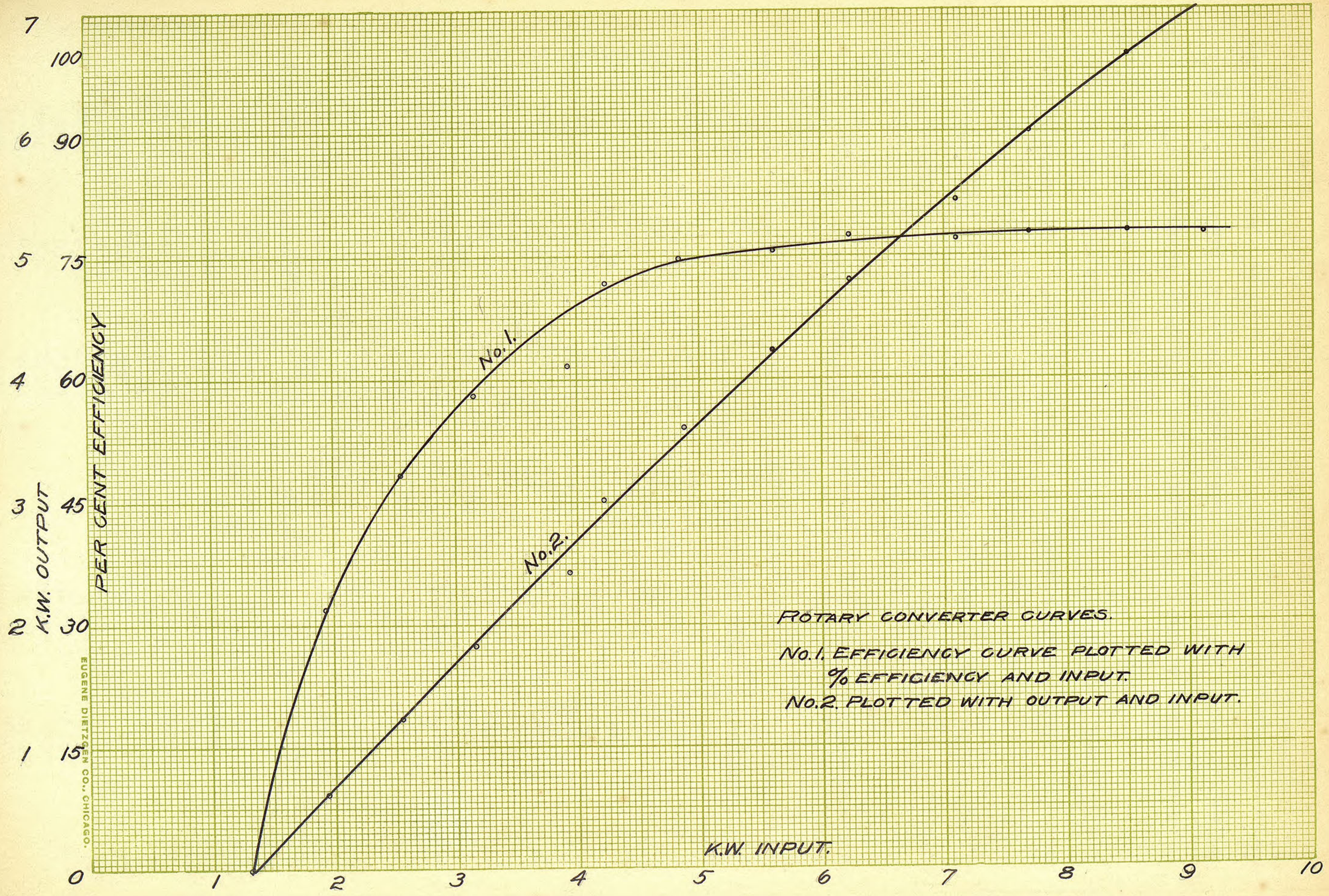
"Were it not that rotary converters sometimes cause trouble by hunting, there is hardly any doubt they would be used universally, even with the limitations in voltage control imposed by their use, instead of synchronous motor or induction motor - direct current generator sets. The question of hunting, however, is so serious that frequently it is good policy to introduce the policy of running two or three machines instead of one, even at the lower efficiency, to insure satisfactory service. Hunting is caused by many circumstances, one being that the rotation of the prime mover is not uniform, another is that converters are operated in the same network, but interlinked by lines of relatively high resistance, another that the converter has a sluggish magnetic circuit so that it cannot quickly respond to variations in impressed voltage, still another that the impressed voltage on the converter, for some outside reason, tends to fluctuate suddenly. The remedy of the first case of hunting is obviously to get the rate of rotation of the prime mover more uniform as it is found that hunting is not so serious with close governing engines and does not exist where generators are driven by turbines. Sometimes one or more induction motors with large fly-wheels are used, the tendency of the induction motor being essentially to steady the frequency by its momentum. The other cause, that of considerable resistance losses between converters or generators and converters, has a tendency to set up hunting also, cince with a slight fluctuation in current, due to various causes, the voltages fluctuate also. This fluctuation in impressed voltage will react in the rotary converter, and if the magnetic circuit is not very sensitive, cause a state of unstable equilibrium which leads to hunting. It is obvious that if the E.M.F. supplied to the armature varies suddenly, the flux also must vary at the same rate to insure the same relative position of the armature and the field. If the magnetism lags behind, the armature must take a different position from what it would have otherwise and thereby a pulsation in speed is set up and the rotary "hunts". It is therefore evident that the magnetic circuit should be as responsive as possible; in other words, all causes delay, change of of magnetism should be eliminated. As a consequence it is best to use magnetic material of low ohmic resistance such as steel, but a considerable part of the magnetic circuit is made of cast iron which has a high ohmic resistance, and damping devices are inserted not in the path of the main flux, that is in the poles but midway between the poles. This damping device is only effective when the rotary hunts, that is, when there is an appreciable armature reaction which sets up currents in the circuit formed by the bridge. When these causes are removed so far as possible there is no great difficulty with converters in well designed 25 cycle systems." The rotary converter tested has the bridge as mentioned above made of composition copper. Considerable hunting was observed which was largely due to change of speed in the prime mover.

In general what applies to the direct converter also applies to the inverted converter. It is found more efficient than boosters and is used considerably in sub-station work; using the inverted converter in connection with a step up transformer to transmit the current to some distant point. Since the alternating current voltage is always less than the direct current voltage step up transformers have to be used to raise the potential for practical purposes. In its potential control the inverted converter has not the feature of a direct converter of compounding for the load if required, so as a rule the voltage of an inverted converter will drop with the load. While to all appearances the direct converter and inverted converter are identical, yet, it is not always best to use them indiscriminatly. On account of the tendency of the inverted converter to run away, when an alternating current load of large magnitude or of very low power factor is thrownon, it is best to have them constructed with lower armature reaction than the direct converter as it gives better speed control. It is not safe to run them with out some speed limiting device or a compensated exciter belted to the rotary so that the voltage of the exciter is raised, as the machine speeds up, which in turn increases the field current of the rotary making a strong field which tends to prevent acceleration.

The inverted converter also gives some trouble when the alternating current side is operated in parellel with alternators on account of the difficulty of keeping the speed of the two machines the same.

The efficiency curve rises quite rapidly from no load to about 3 K.W. then curves regularly to the right until a load of about 5 K.W. is reached when at this point the machine gives an efficiency of 75%. From this point on the curve tends toward a parellel direction with the input line reaching 78% as the maximum efficiency which is reasonably good results for a small machine. Large converters have been built which give an efficiency of 96%.

The efficiency curve of the machine when operated as an inverted converter does not rise so rapidly but curves more to the right so that at 6.5 K.W. input it is giving the same efficiency as when used as a direct converter with an input of 5 K.W. At full load


ROTARY CONVERTER CURVES.
No.1. EFFICIENCY CURVE PLOTTED WITH % EFFICIENCY AND INPUT.
No.2. PLOTTED WITH OUTPUT AND INPUT.
No.1.
No.2.
K.W. OUTPUT
PER CENT EFFICIENCY
K.W. INPUT.
0
1
2
3
4
5
6
7
8
9
10
15
30
45
60
75
90
100
EUGENE DIETZGEN CO., CHICAGO.

(7.5 K.W.) the curve becomes flatter but still shows signs of rising at an input of nearly 9 K.W. The maximum efficiency, 80%, being attained with an input of 8.5 K.W.

The curves plotted with output and input are practically straight lines when operated either as a direct or inverted converter. There is a slight bend in either curve, but when the converter of this size hunts so easily it makes the alternating instruments difficult to read, so this might account for the variation from a straight line.

Data showing the result of a test of the converter operated as a converter.

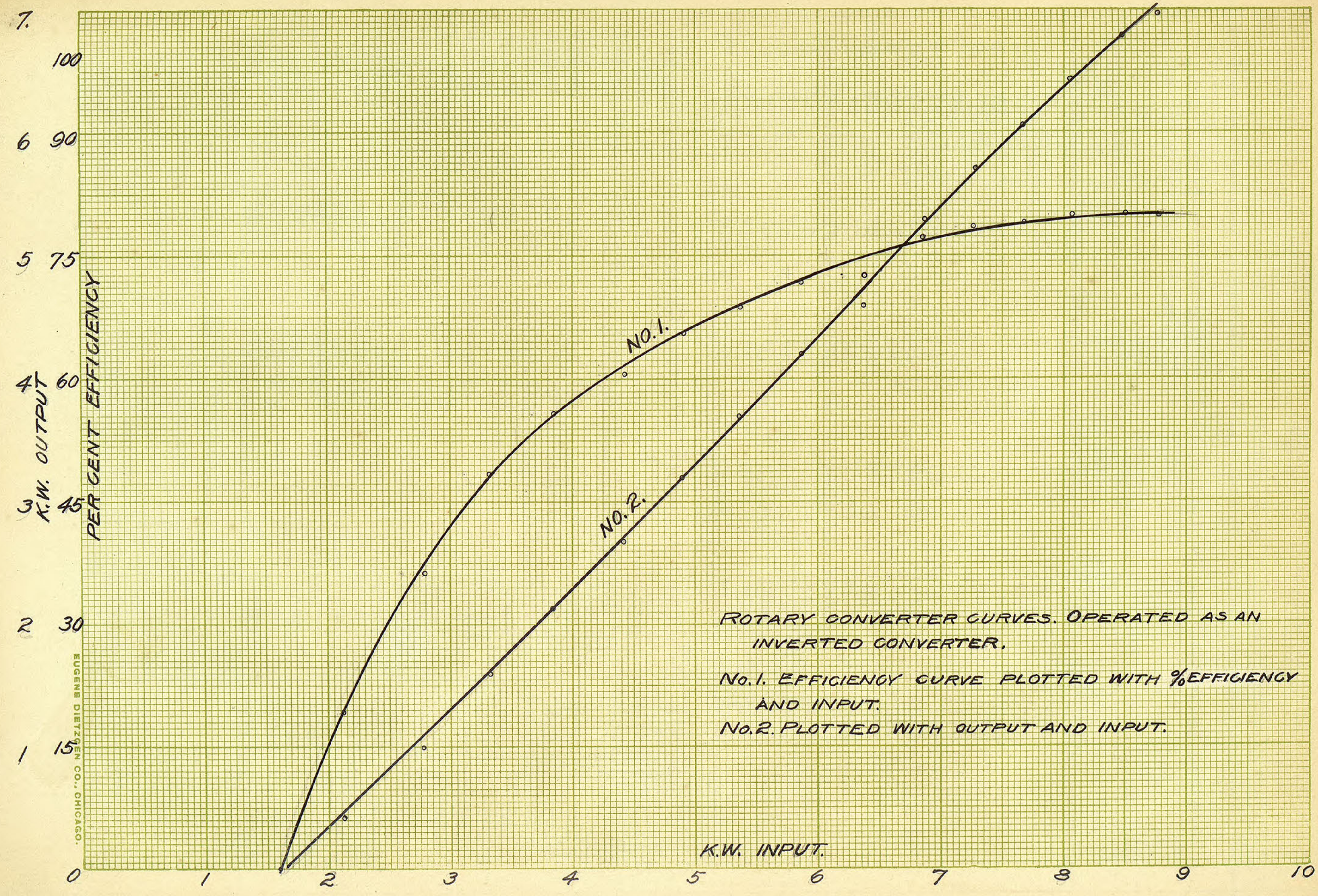
A.C. End Input.

	Amp. A.C. Field.	(1) Volts	(2) Volts.	(1) Amperes	(2) Amperes	Watts.
1.	1.53	71	71	11	12	.800
2	1.73	71.4	71.5	16	15.5	1140
3	1.84	71.7	72	20.75	20.5	1450
4	1.92	72	72.25	25	25	1740
5	2.1	72.5	73	30	30	2140
6	2.3	24.3	75.5	34.3	34.5	2300
7	2.45	75	76	39.5	39	2690
8	2.5	75.25	76.5	44	44	2900
9	2.7	75.5	76.5	49	49	3230
10	3	77	77.6	54.5	54	3750
11	3.1	77	77.5	59.5	59	4100
12	3.25	77.5	78	64.5	65	4350
13	3.5	77.5	78.5	70	71	4775

Speed was kept constant at 1800 R.P.M.

D.C. End Output.

(2) Watts	Amperes R.C. Field.	Total Watts Input	Volts	Amperes	Watts Output.	Efficiency.
500	.918	1300	110			
775	.918	1915	Constant	5.6	616	32.1
1100	.918	2250		11.6	1232	48.4
1400	.918	3140		16.6	1825	58.2
1800	.919	3940		22.2	2442	62
1900	.917	4200		27.5	3025	72
2200	.916	4890		33	3630	74.3
2700	.918	5600		38.4	4225	75.5
3000	.9135	6230		43.95	4830	77.5
3350	.913	7100		49.5	5445	76.75
3600	.91	7700		54.55	6000	77.8
4150	.91	8500		60.3	6633	77.9
4350	.91	9125		64.56	7100	77.8



7.
100
6 90
5 75
4 60
3 45
2 30
1 15
0
K.W. OUTPUT
PER CENT EFFICIENCY
No.1.
No.2.
ROTARY CONVERTER CURVES. OPERATED AS AN INVERTED CONVERTER.
No.1. EFFICIENCY CURVE PLOTTED WITH % EFFICIENCY AND INPUT.
No.2. PLOTTED WITH OUTPUT AND INPUT.
K.W. INPUT.
0 1 2 3 4 5 6 7 8 9 10
EUGENE DIETZGEN CO., CHICAGO.

Data - Showing result of a test of the Converter operated as an inverted converter.

	A.C.End . Output.					
	(1) Volts.	(2) Volts.	(1) Amperes.	(2) Amperes.	(1) Watts.	(2) Watts.
1.	79.5	79	0	0	0	0
2.	79.5	78.75			150	260
3	79	78.5		5	450	550
4	78'5	78.5	11	11	700	900
5	78.7	78.5	14.5	16	950	1190
6	78.7	78.5	18.5	19	1200	1475
7	78.5	78	21.5	22.75	1450	1750
8	78	77.5	24.25	26.4	1675	2020
9	78	78	28	29.75	1900	2300
10	77	77	32	33.8	2100	2510
11	76.5	76.5	37	38.4	2550	2750
12	76	75	42	42.5	2800	2900
13	75.5	74	46.5	47.5	3000	3050
14	75	74	51	51.5	3250	3180
15	74.7	73	55.5	56	3500	3280
16	74.3	73	59	59.5	3650	3320

D.C.End Input.

R.C. Field Amp.	R.C. Arm.Amp.	Total Amp.Input	Volts	Watts Input.	Watts Output.	Efficiency %.
1.118	11.6	12.908	125.5	1620	0	1
1.107	16.3	17.707	125	2115	410	19.5
1.112	20.8	22.212	Constant	2775	1000	36.15
1.115	25	26.415		3305	1600	48.4
1.112	29.3	30.712		3840	2140	55.7
1.118	33.8	35.22		4410	2675	60.7
1.118	37.8	39.318		4900	3200	65.4
1.115	41.4	42.815		5395	3695	69
1.113	45.4	46.813		5860	4200	71.7
1.104	49.6	51.		6375	4600	72.21
1.112	53.4	54.82		6865	5300	77.3
1.11	56.8	58.21		7270	5700	78.4
1.11	60	61.41		7675	6050	78.85
1.112	63	64.42		8050	6430	79.5
1.112	66.5	67.912		8485	6780	80
1.11	68.7	70.11		8760	L6970	79.6

Speed Constant.

Data - Showing effect of variation of field current with converter operated at full load.

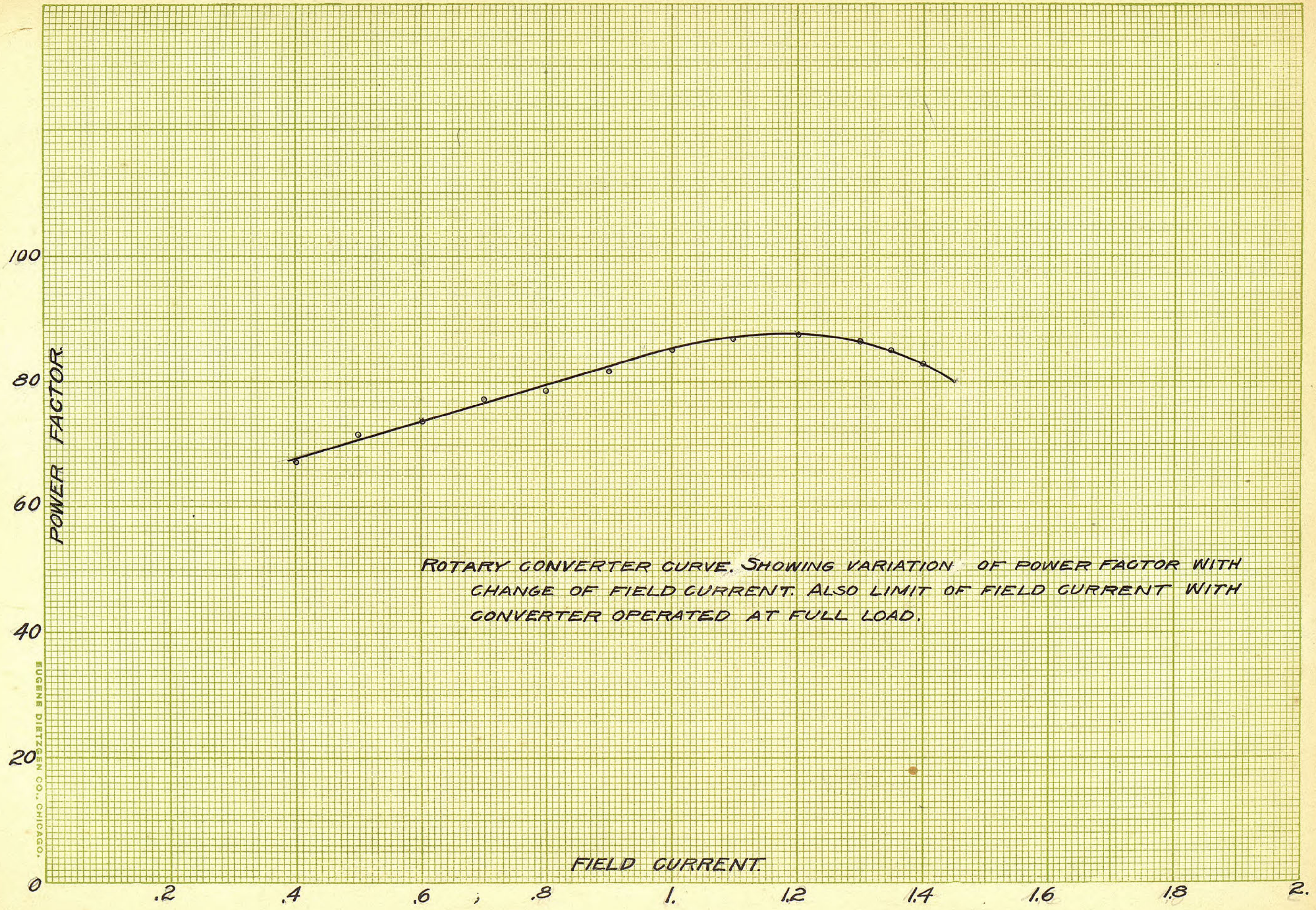
A.C.End Input.

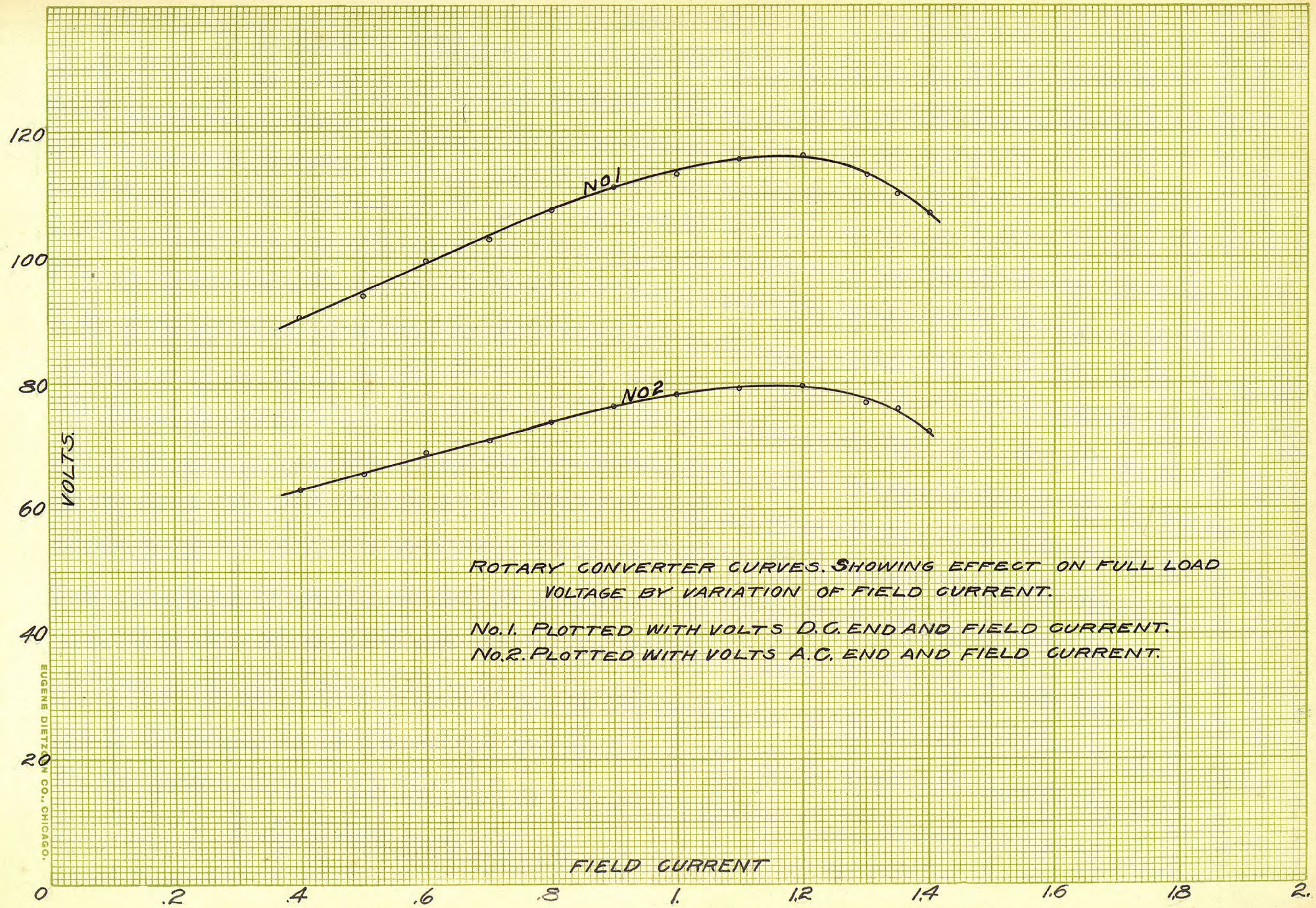
	A.C. Field Amp.	(1) Volts	(2) Volts	(1) Amp.	(2) Amp.	(1) Watts	(2) Watts.
1	4	63	64	72	72	1.700	4450
2	4	65.8	66	72	72	2100	4700
3	4	69	69	72	72	2450	4900
4	3.9	71	72	72	72	2800	4900
5	3.95	74	75.5	72	72	3200	5300
6	3.9	76.5	78	72	72	3600	5500
7	3.75	78.3	79.5	72	72	4150	5500
8	3.5	79.2	80	72	72	4500	5450
9	35	79.5	80	72	72	4800	5300
10	3.17	77	78.5	72	72	5100	4550
11	3	76	76	72	72	5300	4000
12	2.85	72.2	73	74	75	5500	3450

D.C.End Output.

Total true Watts	Apparent Watts	R.C. Field Amp.	Power Factor.	Volts	Amp.	Watts	Efficiency.
615	9145	.4	67.3	90.5	5155	4600	75.8
6800	9490	.5	71.65	94	54.5	5125	75.4
7350	9936	.6	74	99.5	58	5770	78.5
7950	10296	.7	77.25	103	60	6180	77.75
8500	10764	.8	78.25	107.5	63	6770	79.65
9100	11130	.9	81.75	111	65	7215	79.3
9650	11360	1.0	85	113	66.5	7515	77.9
9950	11460	1.1	86.8	115.5	67.75	7820	78.5
10000	11485	1.2	87.8	116	68.5	7945	787
9650	11194	1.3	86.3	113	66.5	7515	77.9
9300	10944	1.35	849	110	64.75	7122	76.6
8950	101018	1.4	82.65	107	62.5	6680	74.7

With the converter loaded the range of field current was limited between .4 and 1.4 amperes. The following curve shows the change of power factor as the field current changes with .4 amperes in the field the powervfactor was about .67. This increases gradually as the field current is increased until it is about .88 when it begins to drop. Since by changing the field current of a synchronous motor or rotary converter the current can be made either lagging or leading there must be some point where the power factor will be one.


POWER FACTOR
100
80
60
40
20
0
FIELD CURRENT.
.2
.4
.6
.8
1.
1.2
1.4
1.6
1.8
2.
ROTARY CONVERTER CURVE. SHOWING VARIATION OF POWER FACTOR WITH CHANGE OF FIELD CURRENT. ALSO LIMIT OF FIELD CURRENT WITH CONVERTER OPERATED AT FULL LOAD.
EUGENE DIETZGEN CO., CHICAGO.



120
100
80
60
40
20
0
VOLTS
NO1
NO2
.2
.4
.6
.8
1.
1.2
1.4
1.6
1.8
2.
FIELD CURRENT
ROTARY CONVERTER CURVES. SHOWING EFFECT ON FULL LOAD VOLTAGE BY VARIATION OF FIELD CURRENT.
No.1. PLOTTED WITH VOLTS D.C. END AND FIELD CURRENT.
No.2. PLOTTED WITH VOLTS A.C. END AND FIELD CURRENT.
EUGENE DIETZGEN CO., CHICAGO.

Thus this curve should rise to 1 before it begins to desrease due to the leading current in the circuit. The true curve therefore probably mkkes an abrupt turn upward until it reaches 1+ then rapidly descends. This point is probably between 1.1 and 1.2 amperes. The curves showing the rise of voltage on both the A. C. and D. C. ends are similar to the power factor curve.

As the field current on a rotary converter is increased the E.M.F. generated in the armature is increased and if the current is lagging the resultant of the armature E.M.F. and generator E.M.F. will be raised as is shown on rising part of the curves. This reaches a maximum at the same point that the power factor is highest showing that the resultant of the two E.M.F.'s is greatest whmn in phase with the current. When the current is leading a farther increase in the armature E.M.F. will give a decrease of the resultant of the two E.M.F.s so that the voltage drops quite rapidly with any further increase of field current above about 1.2 ampmres. The curves also show that it is possible by changing the field current to raise the E.M.F. of the direct current end from 91 volts to 116 volts when the machine is loaded.

The rotary converter has in the past few years come into extensive use in the operation of electric R.R. systems. This has been brought about by the tendency during recent years to use hydraulic power or to use one central station plant in a large city. Then to transmit this energy economically, alternating current s of high potential must be used. This current is distributed to substations over the city along the R.R. system and the voltage reduced by transfrmers and rectified , for the use of the motors, by rotary converters. The tendency is now to install large units of rotary converters and a storage battery. The battery is then charged by the converters during time of light load and furnish power to the current at the peak of the load.

Motor generators are also used for the conversion of the current but are much larger and more expensive to install and are not as efficient as the rotary converter and step down transformers. In some stations large synchronous motor generators sets are installed, the motor being wound for the high voltage of the line so that no transformers are necessary. The cost, however, is much higher and the hunting is as troublesome a factor as in the rotary converter. The motor generator sets, using induction motors, are sometimes installed when the speed of the generator in the control plant cannot be kept very constant. As long as such conditions exist motor generators would be more satisfactory. With the best types of modern engines very little trouble is experienced in keeping the speed constant, so that in most of the recent installations the rotary has superceded the motor generator sets.

This is shown by the increased demand for rotary converters. From August 1st, 1900 to December 31st, 1901 the capacity of converters sold and installed by the General Electric Co. was increased from 64540 K.W. to 221390 K.W. And previous to August 22, 1902 the Westinghouse Electric M'f'g. Co., had an aggregated output of over 165000 K.W.

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