Friction Losses in the Universal Joint

by Earl Carson

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TABLE OF CONTENTS.

PART I

INTRODUCTION

The Universal Joint seems to have developed from a joint known as Hooke's Joint. The most familiar form of Hooke's Joint is a pair of forks keyed at the ends of two shafts; these forks carry the bearings, in which the equal arms of a rigid rectangular cross can rotate, the arms of this cross intersecting in the points of the intersection of the shafts, so that the condition that the axes of the four turning pairs should pass through the same point is satisified. In practice the joint is made as compact as possible, the cross being sometimes replaced by a circular ring or disc having four joints projecting from its circumference. It is then termed a universal joint. When used as a coupling for power purposes, the variation in velocity ratio gives rise to vibratory and unsteady motions; and to obviate this, a double Hooke's joint or double universal coupling is used. The two shafts are not coupled directly together, but through a connecting link, the connecting link forming a Hooke's joint with each shaft. It can be shown by kinematics, that, provided the connecting link is equally inclined to the two shafts and its own forks lie in the same plane, the angular-velocity ratio of the two shafts will be constant and equal to unity at every instant. The three axes will, of course, lie in the same plane, and the plane of the forks on the two shafts, will, at every instant, make equal angles with that plane. In addition to this position, the second shaft may be parallel to the first without affecting the accuracy of the motions; nor will the accuracy depend in any way upon the magnitude of the inclination of the link and the two shafts.

The object of this test was to determine the friction losses in universal joints at different speeds, angles and loads. The test is divided into two parts.

A. 1. To check some results and conclusions arrived at on a previous test of the Spicer's Manufacturing Company's universal joint.

2. To find out what effect running the joints with the forks on the intermediate shaft at a ninety degree position would have on the friction losses and also when running with the forks in the same plane and a comparison of the two methods.

B. 1. To determine the friction losses in a universal joint manufactured by Blood Bros. Machine Company when running with the forks on the intermediate shaft in the same plane and in the ninety degree position and a comparison of the above.

2. A comparison of the losses in the Spicer joints with the losses in Blood Bros. joints.

PART II

METHOD OF TEST SUITED FOR DETERMINING THE FRICTION LOSSES IN THE UNIVERSAL JOINTS.

The method for measuring such a small quantity as the loss in the universal joint due to the offset at a small angle must necessarily be very accurate. Therefore, such methods as testing with motor drive and Prony brake, and ordinary electric dynamometer, with motor drive, are excluded on account of a large experimental error and difficulty of manipulation. Therefore, if the highest degree of accuracy is to be attained, an electrical method of some kind should be employed.

After carefully considering all electrical methods available, the best method seemed to be a slight modification of the load-back testing of dynamos and motors. In this test, the dynamo and motor of suitable capacity, voltage and speed are connected together. One machine can be operated as a motor, the other as a generator, and the output of the generator in turn may be used up by the motor and a storage battery used to supply the losses taking place in this set.

This was the method employed in the test with the exception of the storage battery, the losses being supplied from the power plant.

The method of proceedure follows:

PART III

DESCRIPTION OF APPARATUS AND METHOD OF CONDUCTING TEST

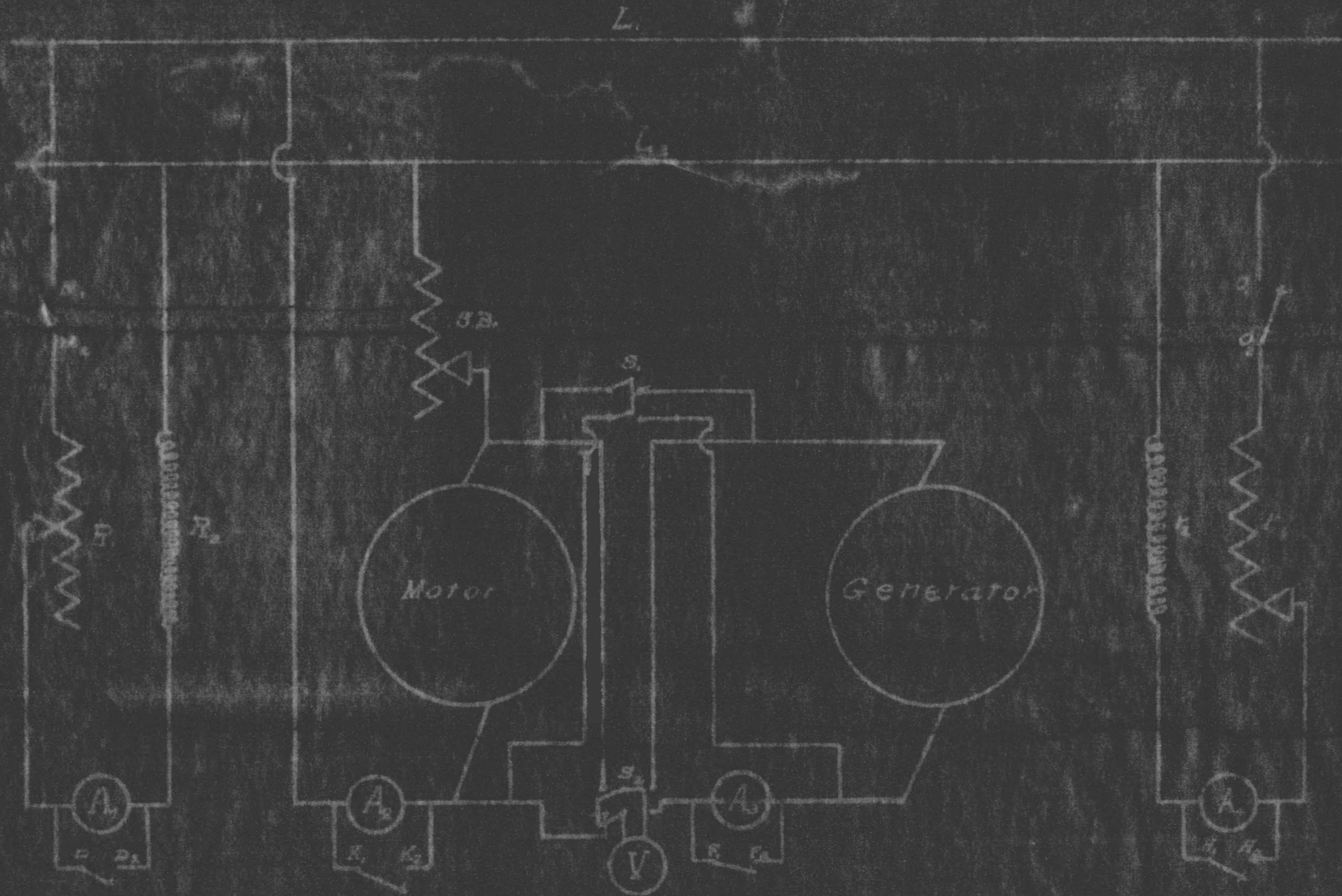
The machines used were two Siemans and Halske direct current separately excited dynamos. One whose normal load was 120 amperes, 125 volts and 1025 rev. per minute. The other machine whose normal load was 520 amperes, 125 volts, 800 rev. per minute. The machines should have been of the same size, but these two machines were the only ones available for the test. The larger machine was run as a motor and the smaller one as a generator.

After accurately leveling and lining up the shafts of the two machines and connecting them mechanically together by means of the universal joints, the two machines were wired to operate on the Kapps load-back test method.

In the accompaning diagram L_1 and L_2 are the wires which supply power from the external lines; LB is a starting box for the motor; A_1 is an ammeter in the motor field circuit and $D_1 D_2$ is a switch to shunt ammeter A_1 ; A_2 is an ammeter in the line circuit, and K_1 and K_2 is a switch to shunt ammeter A_2; R_1 and R_2 are the resistances in the field of the motor, R_2 is adjustable, $M_1 M_2$ is a switch for cutting R_1 and R_2 in or out; A_3 is an ammeter to measure the load, and $F_1 F_2$ is a switch to shunt ammeter A_3; r_1 and r_2 are the resistances in the generator field, $O_1 O_2$ is a switch to cut this resistance in or out as desired. The resistance r_1 is adjustable. H_1 is an ammeter for measuring the current in the field of the generator, and $H_1 H_2$ is a switch for shunting ammeter A_4. V is a voltmeter which by throwing switch S_2 to the left will give the voltage of the generator, and by throwing to the right will give the voltage of motor, and when the voltage of the motor and generator are the same, the machines are connected electrically together by the switch S_1. It is very important that the poles of the switch S_1 are of opposite polarity.

READINGS

Before taking any readings during any run,



WIRING DIAGRAM

the machines were run about three hours at 700 to 900 rev. per minute with the fields on each machine carrying about the amount of current at which the run was to be made.

The readings taken were those of the current supplied to the line, or readings on ammeter H_2; current supplied by the generator to the motor, or readings on ammeter A_3 and voltage of the line by the voltmeter V_1. The voltage of the generator being the same as the motor since the two machines are connected together electrically. Readings of the current in the motor field, by means of ammeter A_1 were only taken to be sure that the motor field remained constant during any set of runs made at one time. The readings off ammeter A_4 were taken only in order to see that the current in the generator field did not become too large.

The load was increased or decreased by shifting the resistance r_1 in the generator field. The product of the line current and the voltage gives the loss in watts which is taken as the normal condition when the joint is operating on a straight line. When the joint is operating at an angle, this product includes the loss, taken as the perfect or normal condition of opperation. Thus the difference between the product of the line current and voltage at any given angle and load, and the product of the line current and voltage at any given load at zero degrees, gives the loss in watts due to the transmission of that load by the joint. In obtaining the loss this way it must be assumed that there are no losses at the zero degree position and that the other conditions are constant, which would be apt to change the losses in the two machines, themselves.

One of the greatest troubles in the test was to obtain a constant voltage regulation with a given speed and load. The voltage is directly proportional to the speed, therefore if the voltage changed, the speed showed a corresponding change. This trouble was overcome by inserting a water rheostat in the lines $L_1 L_2$ so that the speed could be held constant by changing the voltage to suit the speed by means of the water rheostats.

METHOD OF DETERMINING ANGLES

The different angles at which the joints were tested were obtained by shifting the generator end of the joints. The distance to move the generator for each set of runs was obtained by getting the exact distance from center to center of each joint and using this as the base line of a right angle triangle, and the distance the generator is moved as the perpendicular of the triangle.

RESULTS OF TESTS

The best method of presenting results is undoubtedly by curves. Plates I to XX inclusive are all on the Spicer Manufacturing Company's joints. These plates are divided into groups and each group will be discussed separately.

Group I. Plates I to IV inclusive.

In this group of curves the arms or forks of the joints on the intermediate shaft are placed so that the forks of one of the joints are turned ninety degrees, thus preventing the arms of the two joints on the intermediate shaft from lying in the same plane, which according to kinematics is the wrong condition for the velocity ratio. The joints were tested this way in order to see if the results on a previous test could be duplicated, and also in order to have some available data for a comparison with data to be obtained by running with the forks on the intermediate shaft in the same plane. The data for this group of curves is taken from table one.

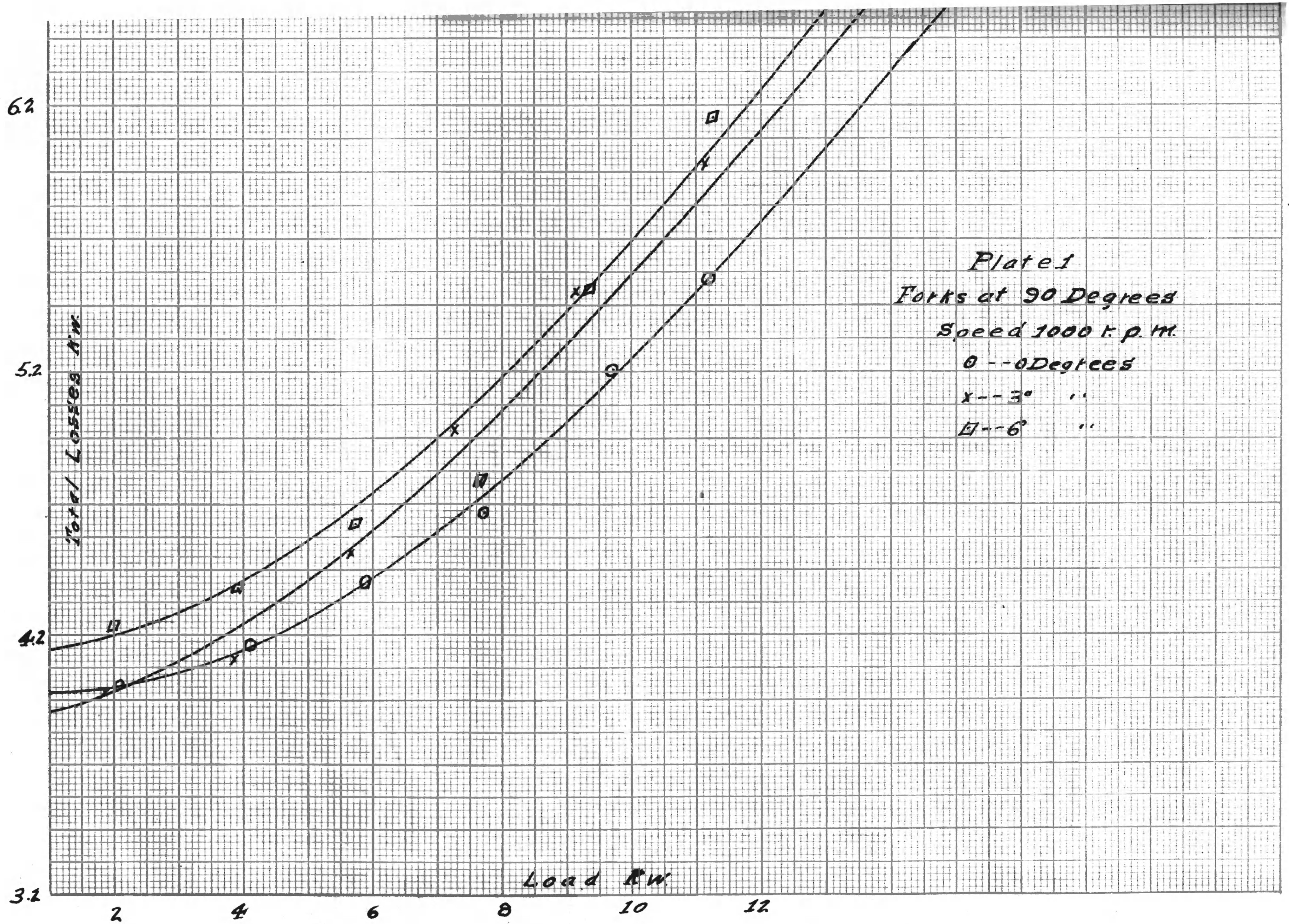


Plate I
Forks at 90 Degrees
Speed 1000 r.p.m.
0 --0 Degrees
x--3° "
□--6° "
Total Losses K.W.
Load K.W.
6.2
5.2
4.2
3.1
2
4
6
8
10
12

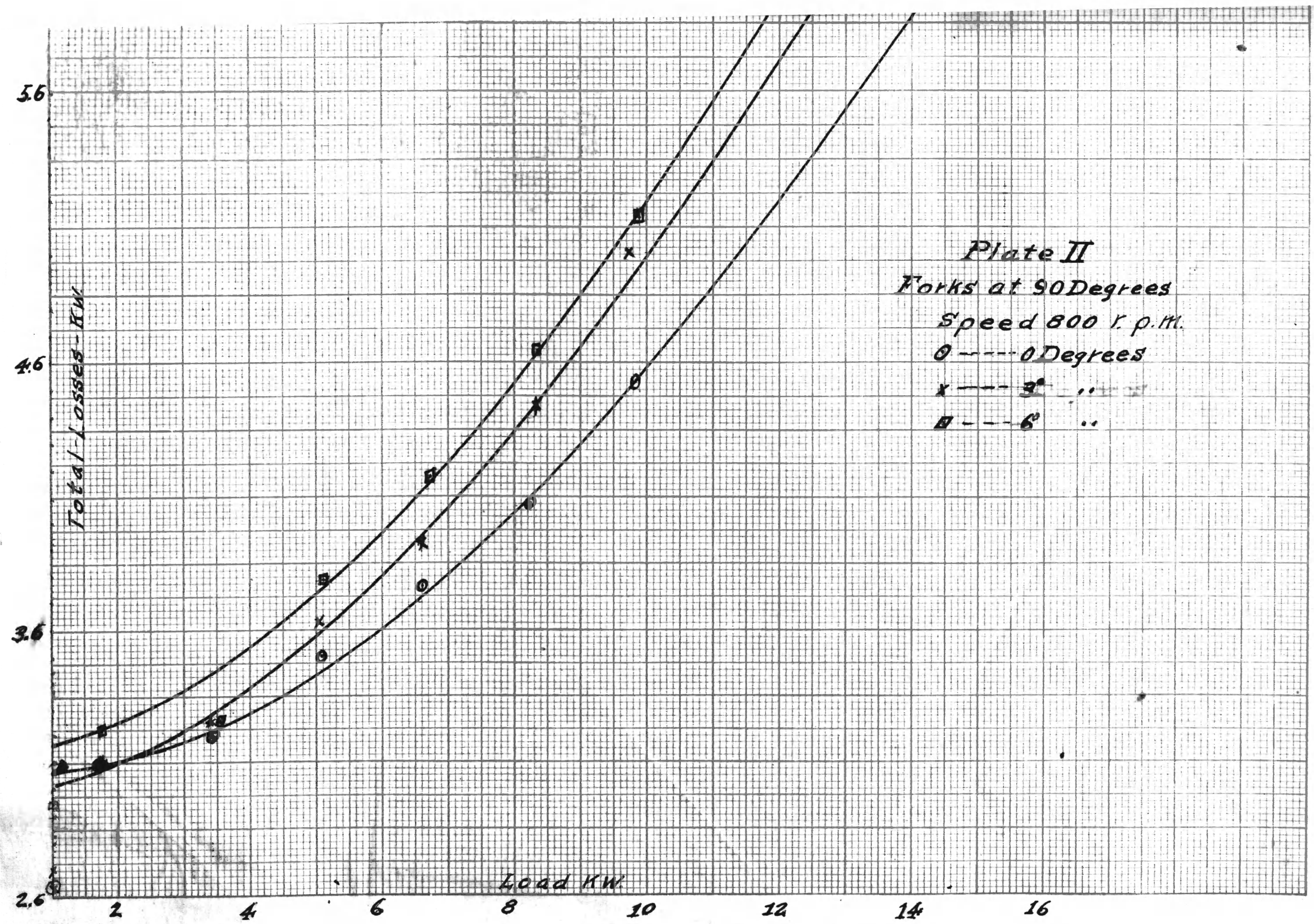


Plate II
Forks at 90 Degrees
Speed 800 r.p.m.
0 ---- 0 Degrees
x ---- 3° "
▣ ---- 6° "
Total-Losses-KW
Load KW.
5.6
4.6
3.6
2.6
2
4
6
8
10
12
14
16

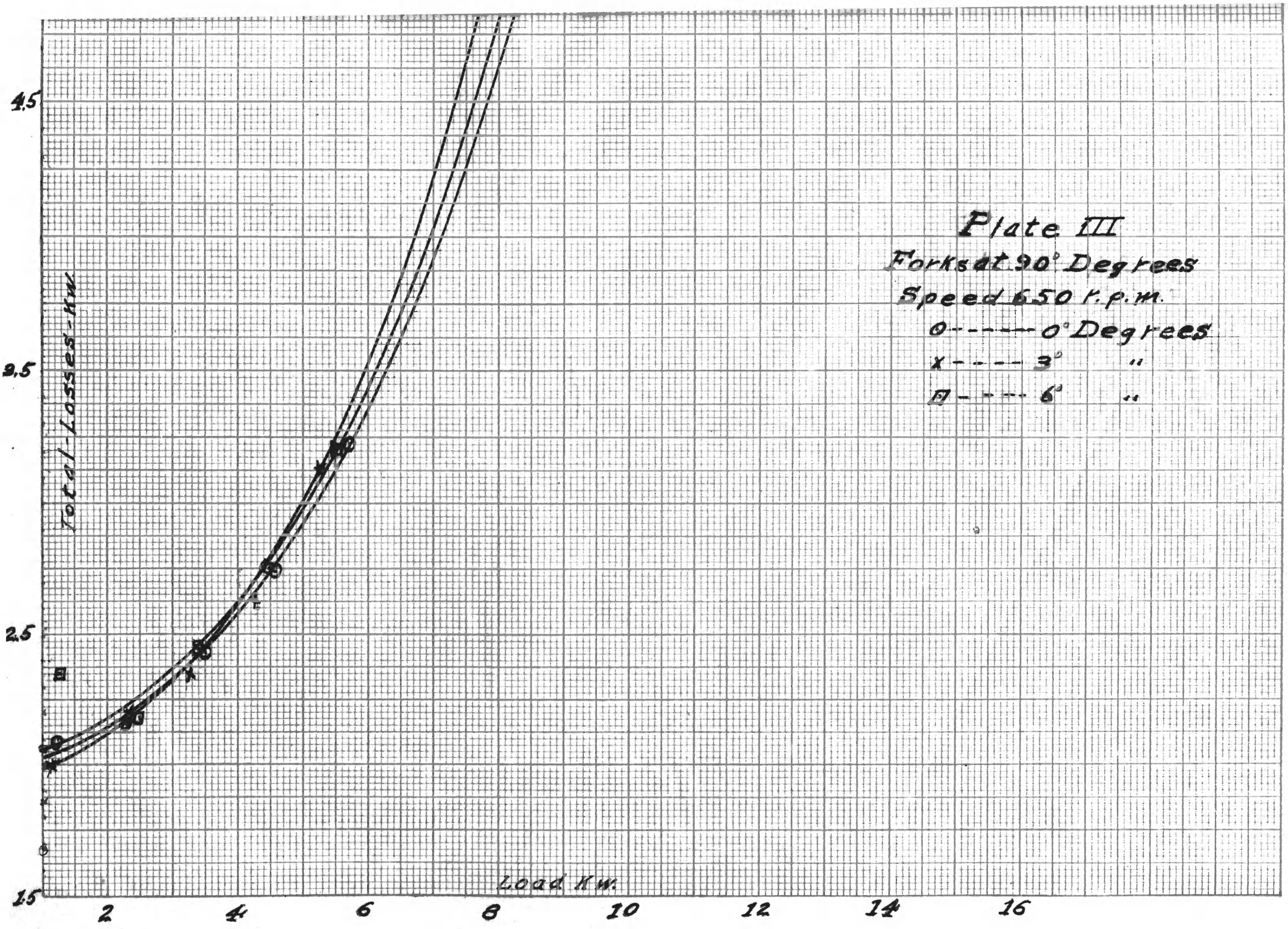


Plate III
Forks at 90° Degrees
Speed 650 r.p.m.
O ------ 0° Degrees
X ---- 3° "
⊡ ---- 6° "
Total-Losses-Kw
Load Kw.
4.5
3.5
2.5
1.5
2
4
6
8
10
12
14
16

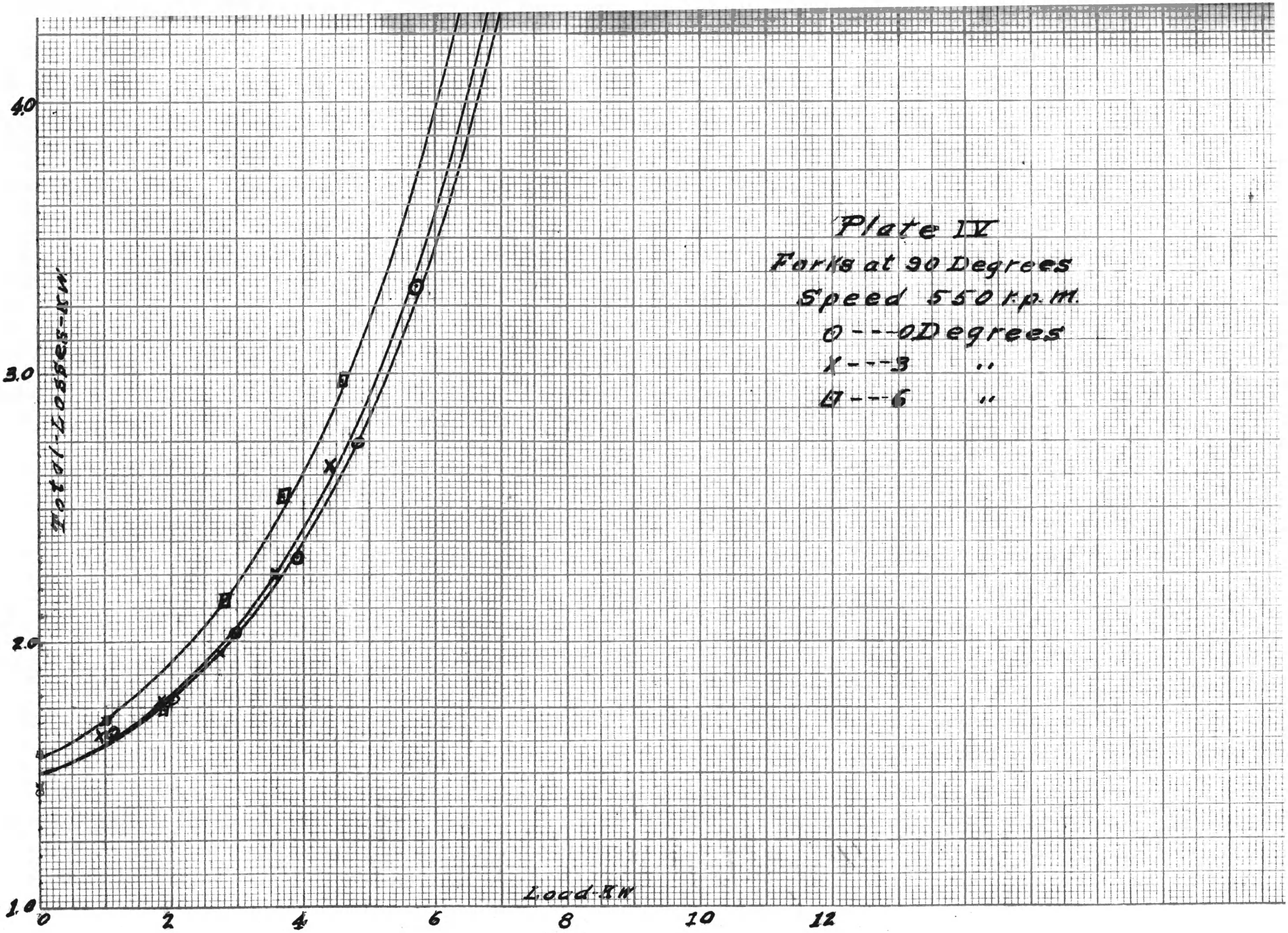


Plate IV
Forks at 90 Degrees
Speed 550 r.p.m.
O ---0 Degrees
X ---3 ''
□ ---6 ''
Total-Losses-KW
Load-KW
4.0
3.0
2.0
1.0
0
2
4
6
8
10
12

TABLE I

Speed	Angle	M.F.	L.C.	Volts	Total Loss in Watts	Load	Load in Watts
1000	0	2.0	44.0	82.5	3630	0	0
			49.6	81.6	4044	25	2044
			51.6	80.7	4168	50	4034
			55.9	78.7	4405	75	5907
			60.8	77.1	4680	100	7710
			67.4	77.5	5230	125	9700
			74.8	76.0	5682	150	11400
	3	2.0	46.2	78.9	3650	0	0
			51.1	77.7	4004	25	1940
			53.2	77.2	4110	50	3858
			60.7	75.5	4584	75	5660
			67.4	75.2	5066	100	7520
			74.7	73.5	5510	125	9222
			81.0	74.6	6042	150	11180
	6	2.0	45.3	82.0	3720	0	0
			52.9	80.1	4240	25	2000
			55.4	79.0	4380	50	3950
			60.1	77.0	4630	75	5780
			62.5	76.2	4760	100	7620
			73.1	75.1	5490	125	9380
			82.2	74.8	6150	150	11220
800	0	2.2	37.3	70.7	2631	0	0
			44.2	70.2	3100	25	1755
			47.1	68.3	3220	50	3417
			52.0	67.5	3508	75	5063
			57.1	66.0	3767	100	6600
			64.3	65.8	4230	125	8230
			72.2	66.4		150	9940
	3	2.2	38.0	71.0	2700	0	0
			44.3	70.6	3130	25	1764
			47.7	68.5	3776	50	3430
			53.0	67.8	3632	75	5080
			59.2	66.6	3938	100	6664
			66.8	66.4	4447	125	8310
			75.6	65.2	4926	150	9788
	6	2.2	41.6	71.5	2970	0	0
			44.9	71.5	3210	25	1790
			46.9	69.1	3240	50	3455
			55.7	68.0	3790	75	5100
			62.0	67.2	4170	100	6720
			69.2	67.1	4640	125	8380
			47.8	66.0	5140	150	9900

TABLE I (CONT)

Speed	Angle	M.F.	L.C.	Volts	Total Loss in Watts	Load	Load in Watts
650	0	1.9	35.6	50.4	1795	0	0
			41.7	50.5	2111	25	1261
			45.5	47.9	2181	50	2394
			52.0	46.7	2438	75	3508
			59.9	45.8	2745	100	4580
			70.2	46.0	3244	125	5758
	3	1.9	40.0	47.2	1867	0	0
			43.1	46.4	2002	25	1157
			48.1	46.0	2215	50	2302
			55.8	43.5	2362	75	3260
			62.0	42.4	2634	100	4248
			74.7	42.0	3138	125	5250
	6	1.9	40.9	50.5	2075	0	0
			47.4	49.7	2359	25	1240
			45.7	47.0	2150	50	2350
			53.1	46.2	2445	75	3460
			61.1	45.0	2750	100	4500
			73.1	44.1	3220	125	5505
550	0	1.9	33.1	43.3	1428	0	0
			38.8	42.5	1650	25	1065
			44.0	40.2	1770	50	2010
			51.4	39.7	2046	75	2968
			60.0	39.0	2340	100	3900
			70.6	39.0	2752	125	4866
			87.8	38.0	3334	150	5700
	3	1.9	36.4	40.0	1450	0	0
			42.0	39.0	1636	25	975
			47.5	37.2	1765	50	1860
			53.8	36.6	1965	75	2743
			63.2	35.7	2259	100	3576
			77.0	34.9	2685	125	4355

Group II. Plates V to X inclusive.

The joints for this set of runs were connected together so that the forks on the intermediate shaft lay in the same plane. From the data in table two, curves on the plates V to VIII inclusive were plotted. By referring to these curves, it can be seen that the losses in the joints, when working at an offset of three degrees are larger by far than when at the six degree offset. This seemed strange that the losses should be thus so, and it was decided to find the reason for this if possible to do so.

It was decided to test the joints in this position at larger offsets, but to work with them at one speed only as the same thing appeared in all the other speeds at which the joints were tested. For the data in table 3 the speed worked with was chosen to be 800 revolutions per minute, as this particular speed seemed best suited for good working conditions of our apparatus. More or less trouble seemed to come up during runs at other speeds.

While obtaining the readings during this run it was noticed that after cleaning the brushes on the commutator of the motor, that there was a drop of three amperes or more in the readings of the line current, which, when multiplied by the voltage gives the losses. This fact is clearly shown by the points plotted on plate IX. This fact was observed while working with the joints at the twelve degree offset.

This proved to us that the brushes should be cleaned at some fixed time and thus kept clean for all our readings. The commutators of both machines in all the following runs were cleaned immediately before taking any readings.

The data for table 4 were obtained by observing the precaution mentioned above and in addition a check set of readings taken for each different angle of offset. The curves on plate X are plotted from the data in table four. The curves in this plate lie very close together, thus giving us reason enough to state that the curve for the three degree offset on plates V to VIII inclusive should have fallen very close to the other curves on those plates.

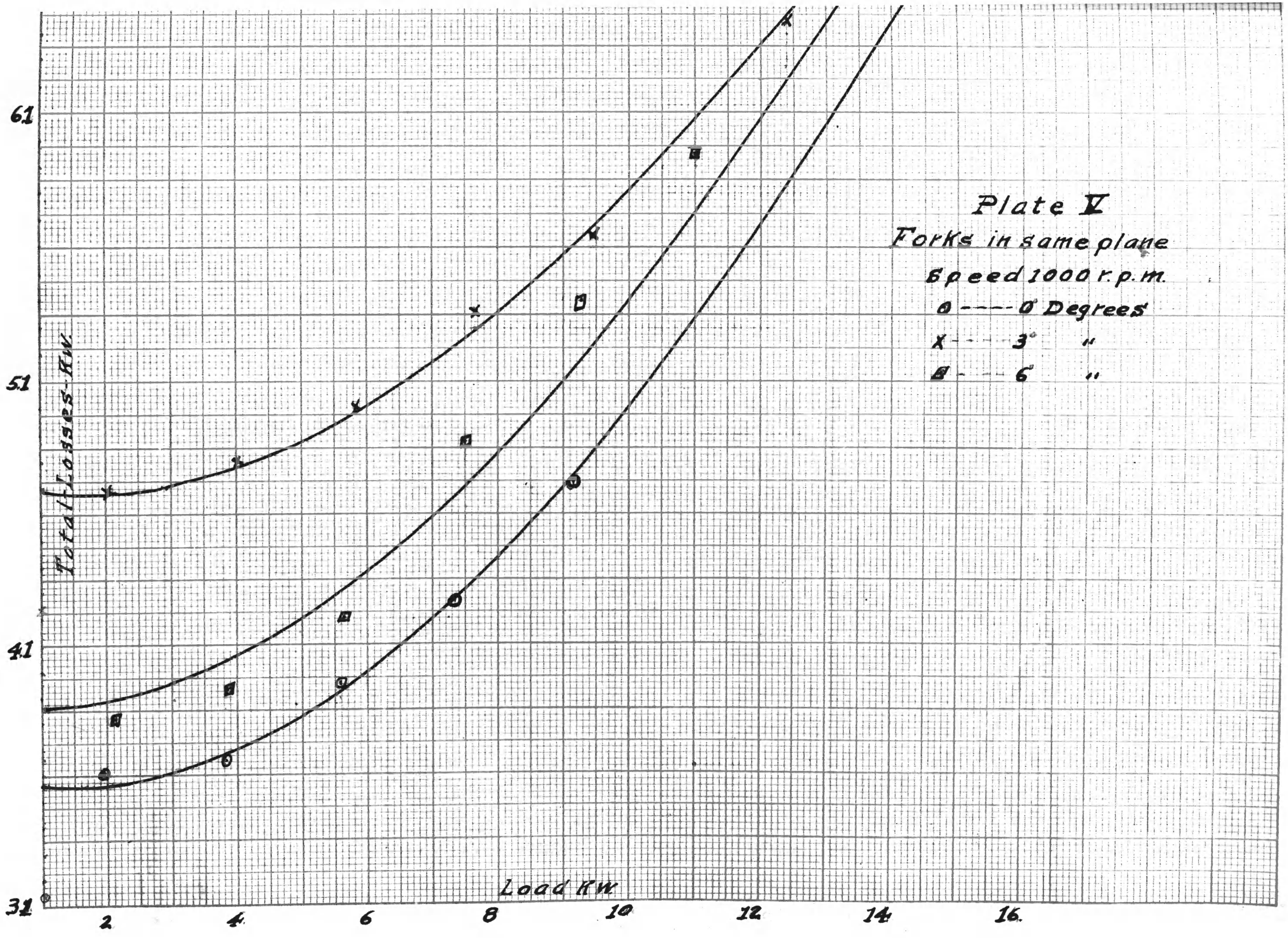


Plate V
Forks in same plane
Speed 1000 r.p.m.
0 Degrees
3 "
6 "
61
51
41
31
Total Losses-Kw
2
4
6
8
10
12
14
16
Load Kw

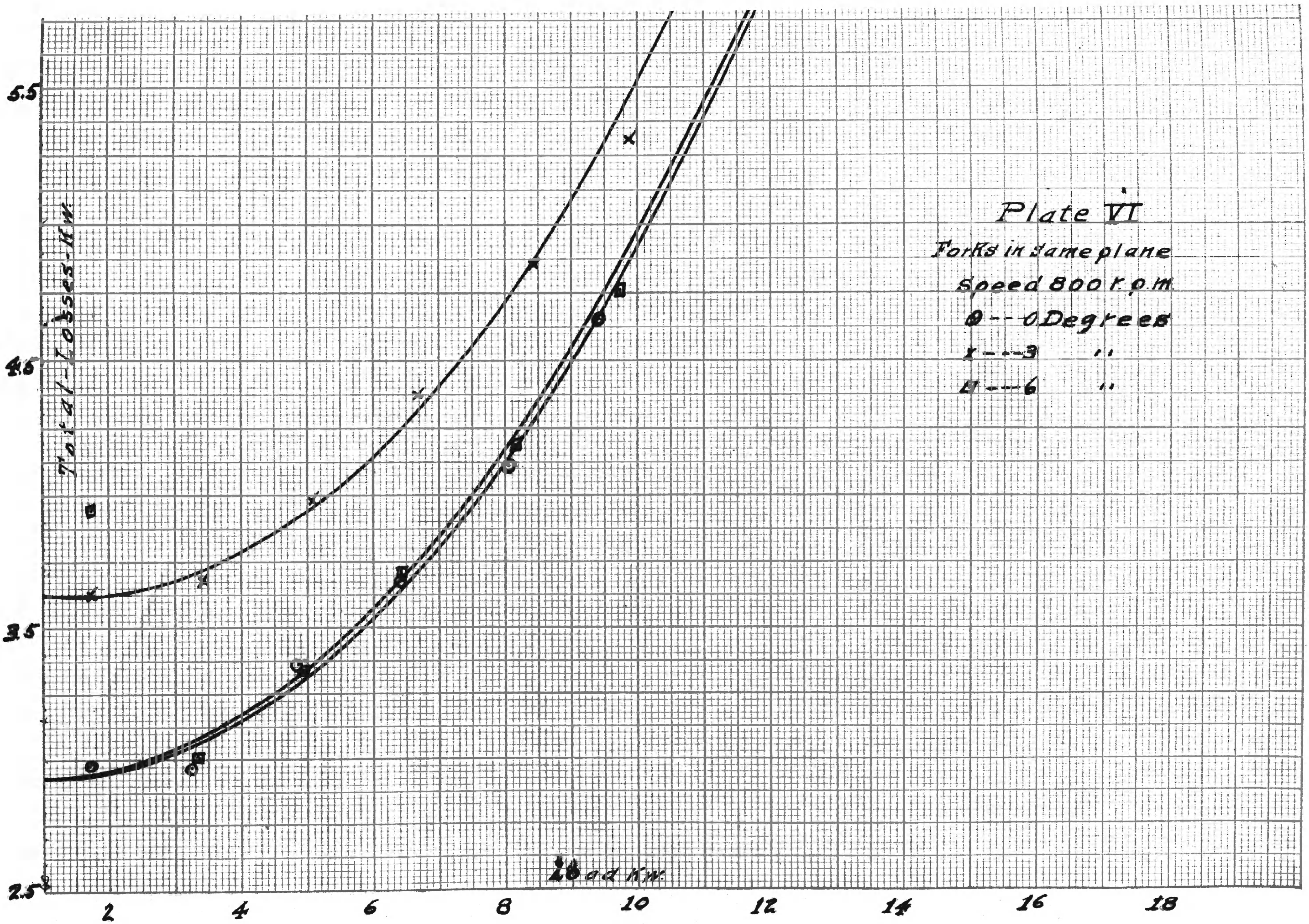


Plate VI
Forks in same plane
Speed 800 r.p.m.
0 --- 0 Degrees
x --- 3 ,,
□ --- 6 ,,
Total-Losses-Kw.
Load Kw.
5.5
4.5
3.5
2.5
2
4
6
8
10
12
14
16
18

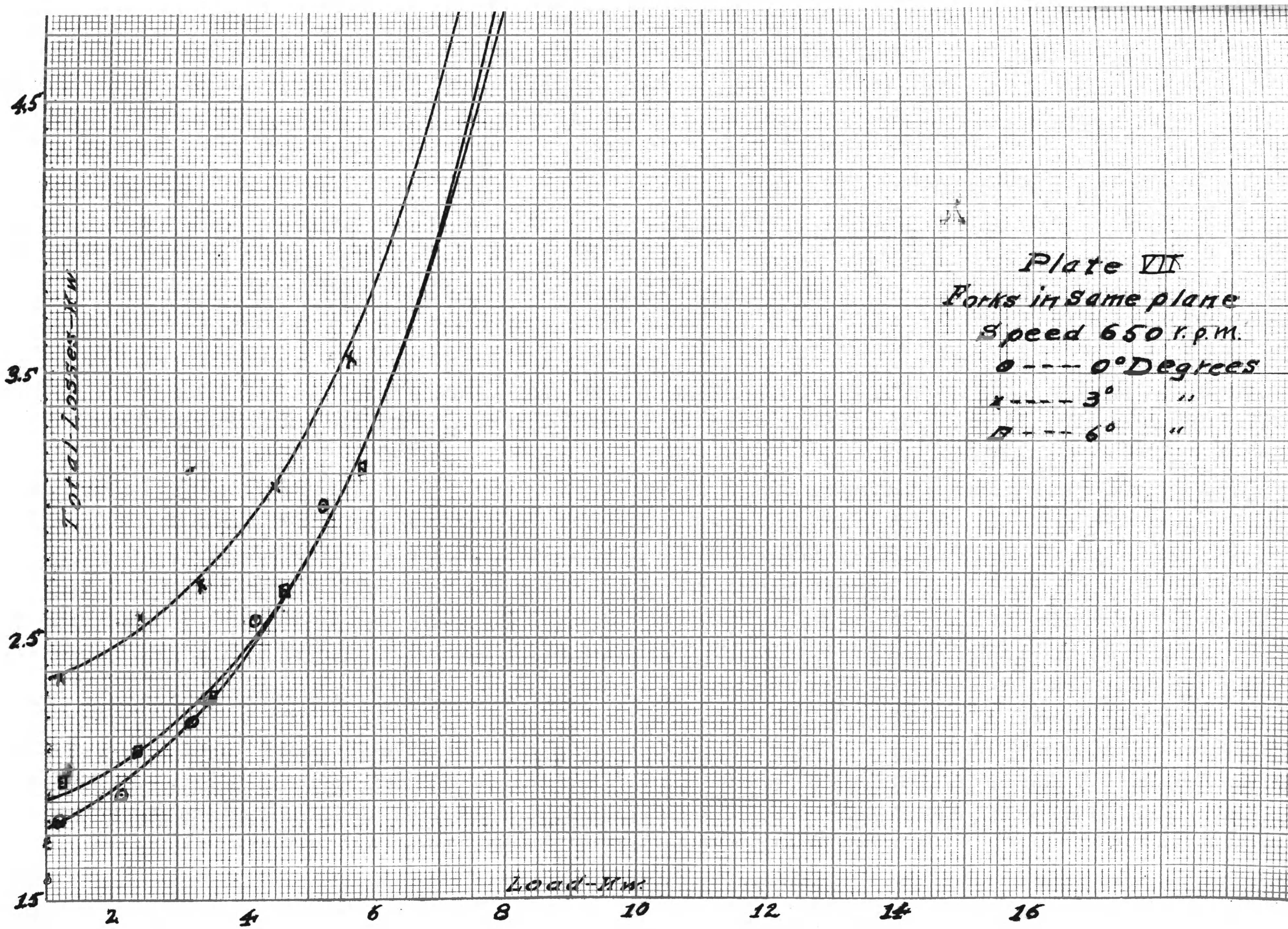


Plate VII
Forks in same plane
Speed 650 r.p.m.
o ---- 0° Degrees
x ---- 3° "
□ ---- 6° "
Total Losses-Kw
Load-Kw.
4.5
3.5
2.5
1.5
2
4
6
8
10
12
14
16

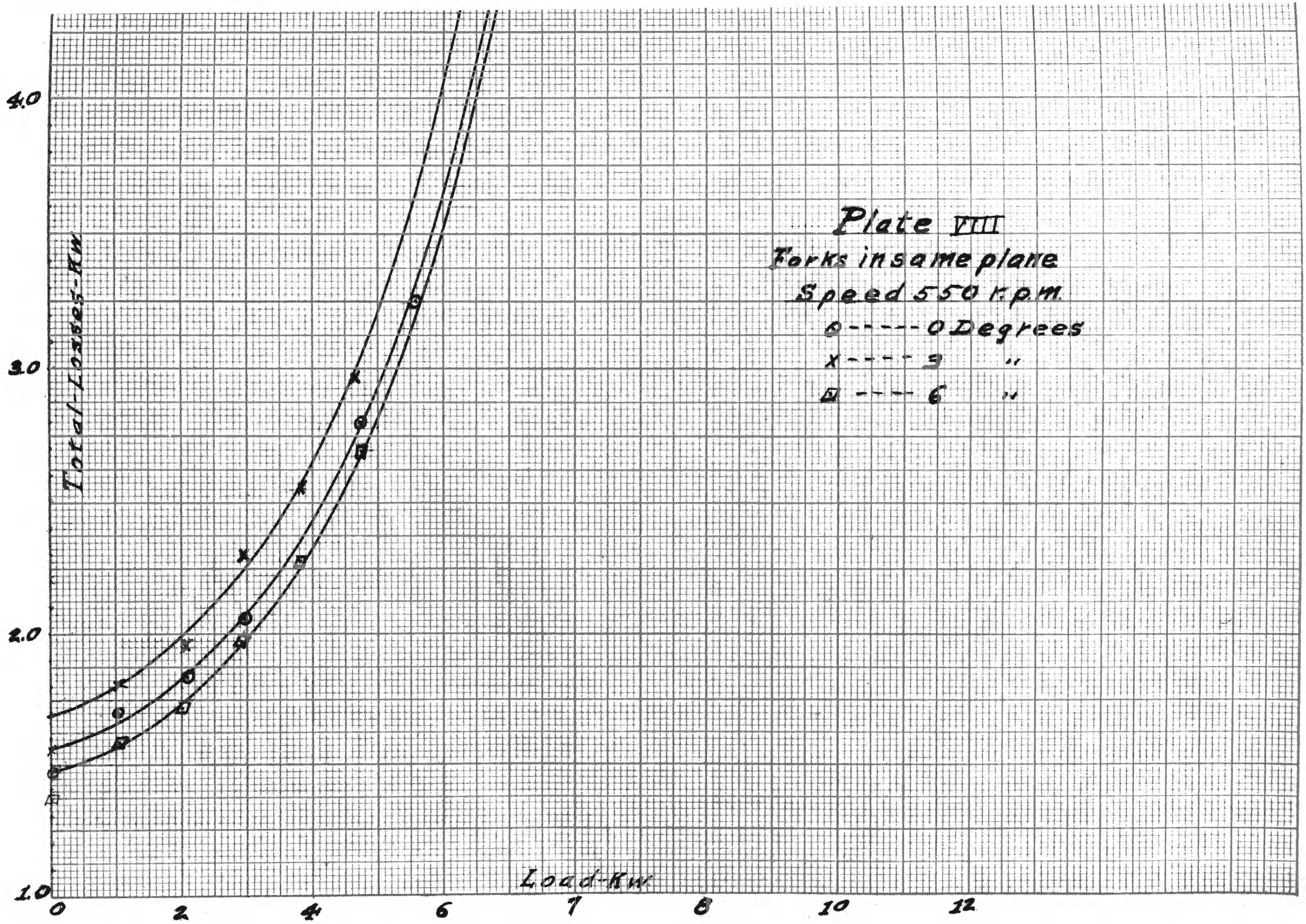


Plate VIII
Forks in same plane
Speed 550 r.p.m.
o ----- 0 Degrees
x ----- 3 "
□ ----- 6 "
Total-Losses-Kw
Load-Kw
4.0
3.0
2.0
1.0
0
2
4
6
7
8
10
12

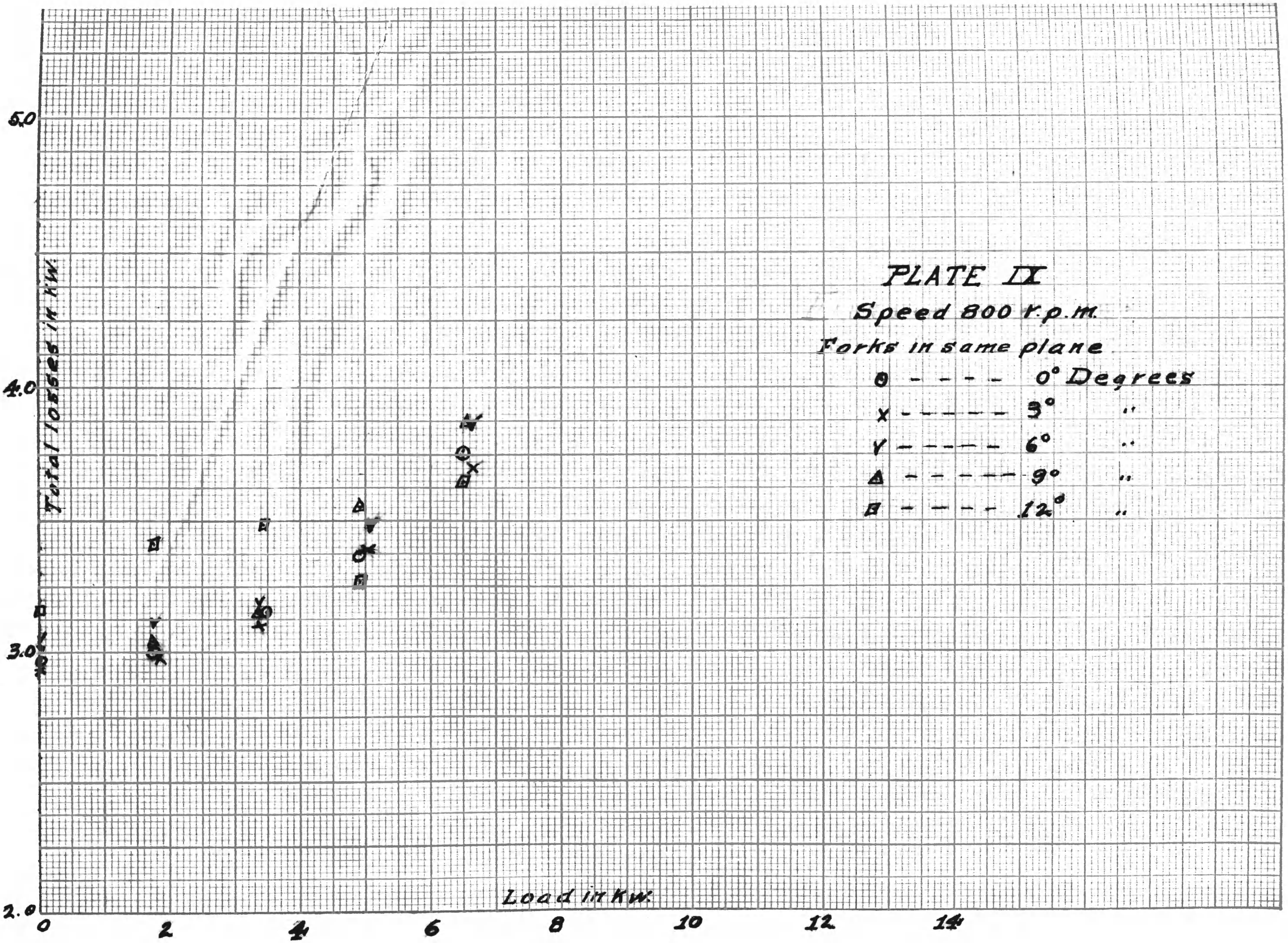


PLATE IX
Speed 800 r.p.m.
Forks in same plane
0° Degrees
3° ..
6° ..
9° ..
12° ..
Total losses in KW.
Load in KW.
5.0
4.0
3.0
2.0
0
2
4
6
8
10
12
14

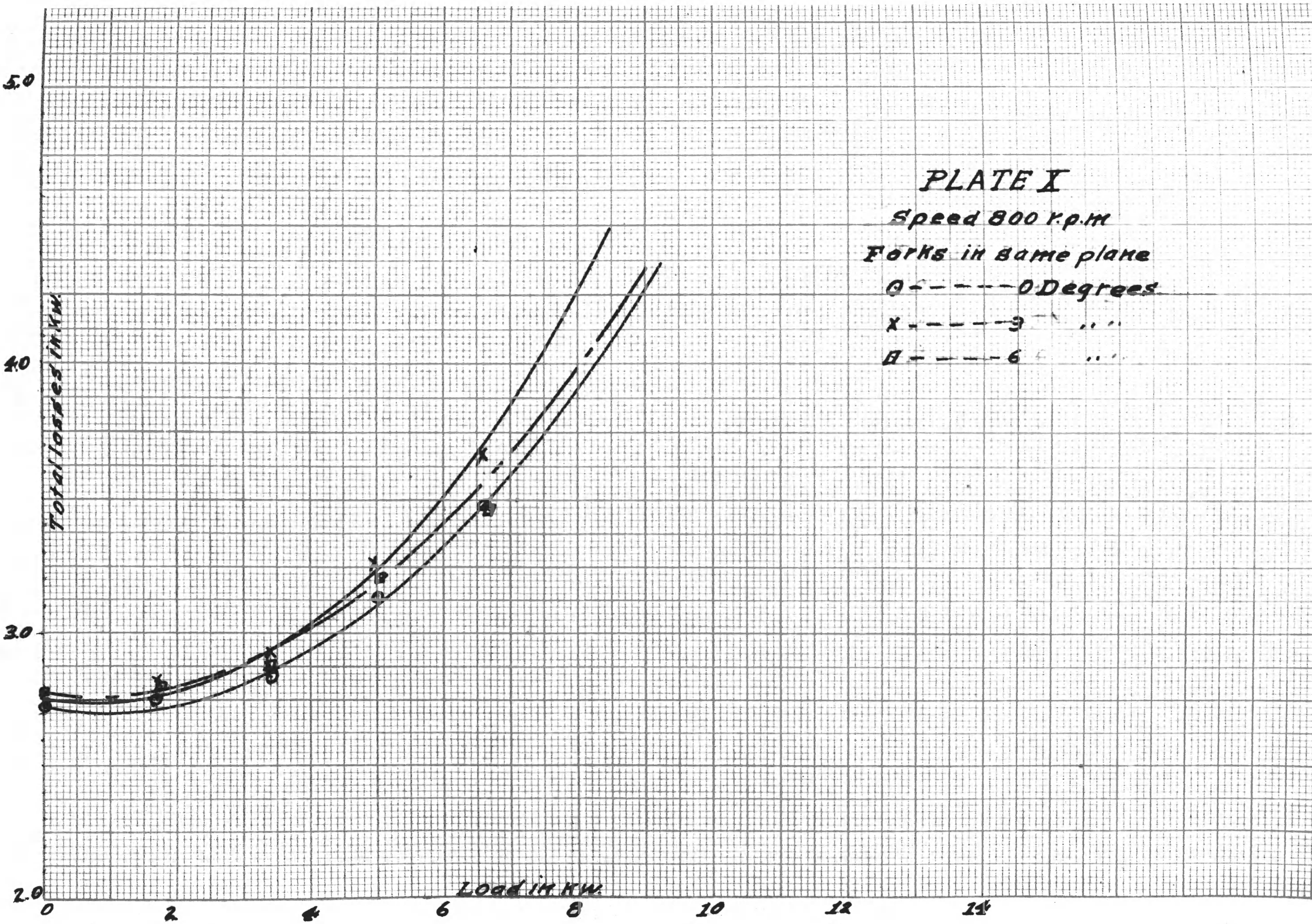


PLATE X
Speed 800 r.p.m
Forks in same plane
O------0 Degrees
X------3 " "
□------6 " "
Total losses in KW.
Load in KW.
5.0
4.0
3.0
2.0
0
2
4
6
8
10
12
14

TABLE II

(Forks on same plane)

Speed	Angle	M.F.	L.C.	Volts	Total Loss in Watts	Load in Amperes	Total load in Watts
1000	0	2.0	38.9	80.7	3145	0	0
			45.4	39.6	3618	25	1990
			47.7	76.5	3660	50	3822
			53.1	74.4	3961	75	5585
			58.2	73.4	4270	100	7345
			64.9	72.6	4722	125	9142
	3	2.2	51.0	83.2	4240	0	0
			57.7	81.4	4693	25	2038
			59.9	80.2	4808	50	4018
			65.3	78.4	5088	75	5863
			69.9	76.9	5379	100	7691
			74.9	75.8	5645	125	9471
			85.1	76.0	6460	150	11400
	6	2.2	44.9	81.9	3680	0	0
			47.5	80.3	3820	25	2010
			50/7	77.7	3940	50	3880
			56.0	75.6	4230	75	5660
			64.8	75.2	4870	100	7520
			72.1	74.9	5400	125	9360
			81.4	73.2	5960	150	11000
800	0	2.0	36.5	69.5	2535	0	0
			43.0	69.3	2981	25	1724
			45.9	64.9	2978	50	3243
			51.8	64.5	3378	75	4893
			57.4	64.1	3676	100	6410
			64.3	64.1	4116	125	8008
			73.9	62.8	4650	150	9425
	3	2.0	44.2	71.1	3146	0	0
			51.3	70.6	3630	25	1765
			53.0	68.9	3658	50	3448
			59.1	67.7	3996	75	5073
			65.4	66.9	4370	100	6698
			72.7	66.6	4851	125	8485
			81.6	66.2	5390	150	9903

TABLE II (CONT)

Speed	Angle	M.F.	L.C.	Volts	Total Loss in Watts	Load in Amperes	Total load in Watts
800	6	2.0	34.9	71.8	2510	0	0
			42.1	70.5	3965	25	1765
			44.9	67.2	3020	50	3360
			50.3	66.1	3325	75	4960
			56.7	64.5	3660	100	6450
			64.5	65.0	4190	125	8130
			73.6	64.8	4770	150	9740
650	0	1.9	33.2	47.9	1590	0	0
			38.6	46.8	1808	25	1169
			43.5	43.7	1901	50	2185
			51.3	42.8	2196	75	3212
			61.1	42.1	2570	100	4212
			72.4	41.8	3025	125	5240
	3	1.9	40.9	51.3	2094	0	0
			47.2	50.4	2380	25	1259
			52.6	49.5	2598	50	2474
			60.1	45.2	2719	75	3393
			68.1	45.2	3083	100	4523
			78.8	45.2	3565	125	5640
	6	1.9	33.0	52.1	1720	0	0
			38.4	50.7	1945	25	1268
			43.2	48.2	2075	50	2405
			49.4	47.8	2360	75	3590
			57.1	46.8	2680	100	4680
			67.5	46.6	3140	125	5830
550	0	1.9	33.6	44.3	1482	0	0
			39.5	43.4	1717	25	1084
			44.4	41.3	1835	50	2067
			51.7	39.9	2065	75	2990
						100	
			73.8	38.3	2824	125	4775
			87.1	37.3	3250	150	5595
	6	1.9	35.9	43.0	1543	0	0
			43.2	41.8	1810	25	1050
			49.1	40.2	1968	50	2014
			57.5	38.8	2306	75	2910
			67.1	38.2	2560	100	3820
			79.6	37.4	2975	125	4665

TABLE II (CONT)

Speed	Angle	M.F.	L.C.	Volts	Total Loss in Watts	Load in Amperes	Total Load in Watts
550	6	1.9	32.1	43.1	1380	0	0
			37.9	41.8	1590	25	1048
			43.1	40.0	1724	50	2000
			51.2	38.8	1984	75	2910
			59.3	38.5	2280	100	3850
			72.2	37.7	2720	125	4720

TABLE III

Speed	Angle	M.F.	L.C.	Volts	Total Loss in Watts	Load in Amperes	Total Load in Watts
800	0	2.2	42.4	70.2	2990	0	0
			43.5	69.1	3000	25	1725
			46.9	67.0	3140	50	3350
			51.3	66.2	3390	75	4960
			57.4	65.0	3760	100	6500
	3	2.2	41.5	70.5	2930	0	0
			42.5	69.8	2970	25	1745
			45.9	67.5	3100	50	3380
			51.4	66.4	3420	75	4980
			56.4	66.8	3780	100	6680
	6	2.2	43.0	70.6	3030	0	0
			44.1	70.1	3090	25	1750
			47.1	67.6	3180	50	3380
			52.0	67.0	3480	75	5030
			58.8	66.1	3880	100	6610
	9	2.2	42.7	70.6	3010	0	0
			43.4	69.6	3020	25	1740
			47.1	67.0	3150	50	3350
			53.4	66.5	3550	75	4980
			58.9	65.5	3860	100	6550
	12	2.2	44.1	71.3	3140	0	0
			47.8	70.3	3440	25	1760
			51.0	68.4	3490	50	3420
			49.4	66.2	3270	75	4960
			56.6	65.9	3730	100	6590

TABLE IV

Speed	Angle	M.F.	L.C.	Volts	Total Loss in K.W.	Load in Amperes	Loads in K.W.
800	0	2.2	37.6	72.0	2710	0	0
			38.9	70.7	2750	25	1770
			41.7	68.3	2850	50	3420
			47.0	66.7	3130	75	5000
			52.8	66.0	3490	100	6600
	3	2.2	38.4	70.8	2720	0	0
			40.6	69.5	2840	25	1740
			43.9	66.9	2940	50	3430
			49.2	66.4	3270	75	4980
			56.1	65.4	3670	100	6540
	6	2.2	38.7	71.9	2790	0	0
			39.0	71.5	2790	25	1790
			42.1	68.0	2860	50	3400
			47.4	67.3	3190	75	5050
			51.7	66.8	3460	100	6680

Group. III. Plate XI.

The curves of Plate XI were plotted from the data in table 5. The data in this table was obtained by taking one speed and one load and obtaining readings of the losses at the different degrees of offset at which the joints were run.

Obtaining readings in this manner necessitated stopping and making the change by shifting the generator every time, but the time it took was very slight so that no temperature changes were apt to enter into our results.

This manner of conducting the test was different from the way in which our former readings had been observed. Formerly to obtain anyone set of curves for any angle. The machines were set at the desired offset and kept in that position for all the different speeds at which the joints were tested.

The curves of plate XI bring out very clearly how the losses in the joints differ when the forks on the intermediate shaft are in the same plane, and also when they are at the ninety degree position. A similar set of readings were tried for at 150 amperes load and 800 rev. per minute, but turned out unsatisfactory, therefore are not given.

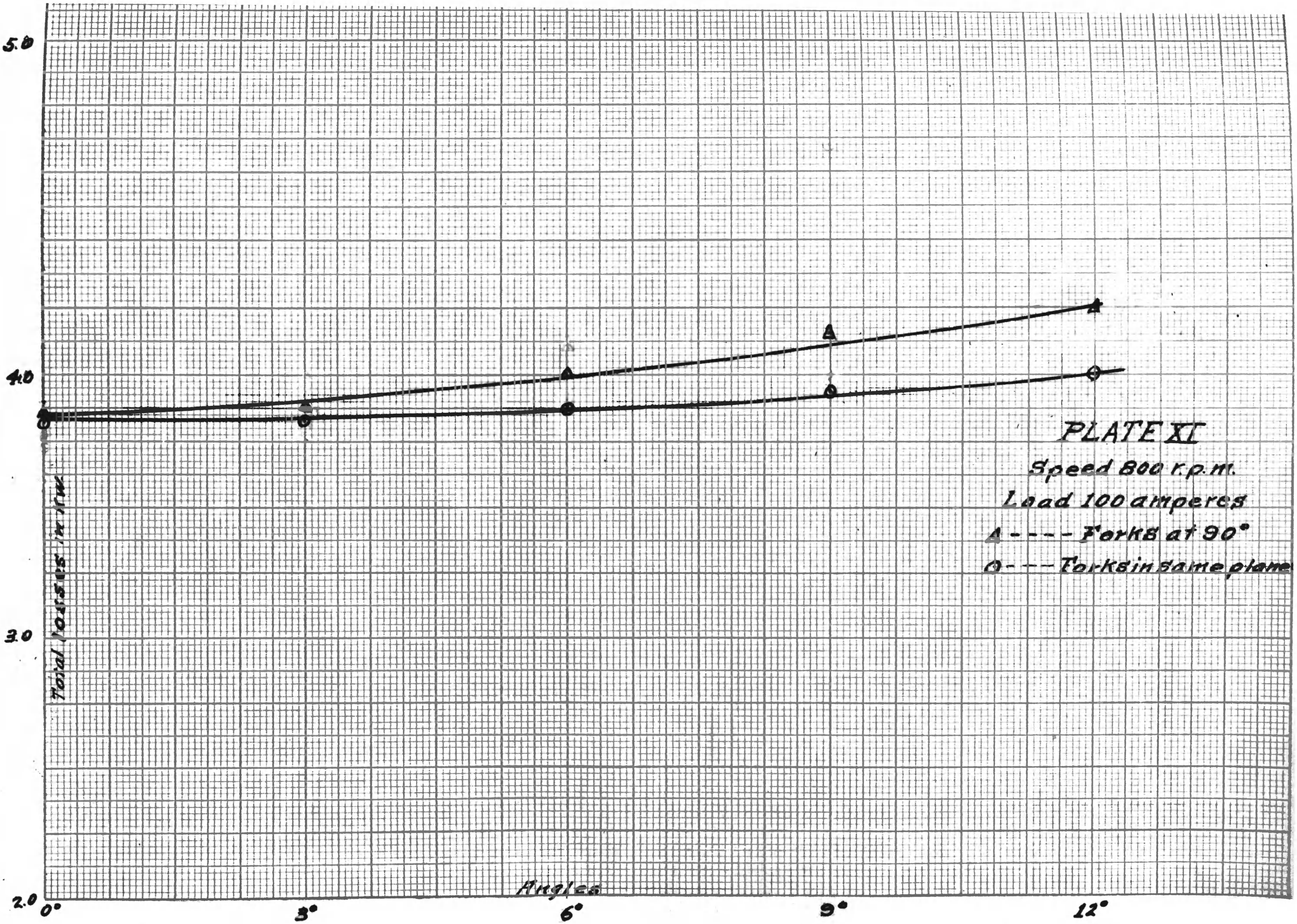


PLATE XI
Speed 800 r.p.m.
Load 100 amperes
Δ ---- Forks at 90°
O ---- Forks in same plane
Total losses in kw
Angles
5.0
4.0
3.0
2.0
0°
3°
6°
9°
12°

TABLE V

Speed	Angle	M.F.	L.C.	Volts	Total Loss in Watts	Load in Amperes	Loads in Watts
800	0	2.2	58.1	65.8	3820	100	6584
	3		58.1	65.9	3830	100	6590
	6		58.6	66.3	3880	100	6630
	9		59.6	66.0	3930	100	6600
	12		61.1	65.6	4000	100	6560
Fork at 90°							
	0	2.2	58.0	66.2	3835	100	6620
	3		58.3	66.7	3890	100	6670
	6		60.9	65.7	4000	100	6570
	9		63.4	65.1	4130	100	6510
	12		65.1	65.3	4250	100	6530

Group IV. Plates XII to XV inclusive.

The curves in this group are plotted from the data in table two and shows how the losses in the joints varied with the different angles of offset. The points for the curves of plate XV take a position that gives the curves a different shape from the other curves of this group. The probable reason for this is that we had considerable trouble in getting readings at this speed, on account of not being able to adjust our apparatus as accureately as on the other speeds. Therefore, we feel that no stress can be laid on the position taken by the curves of plate XV.

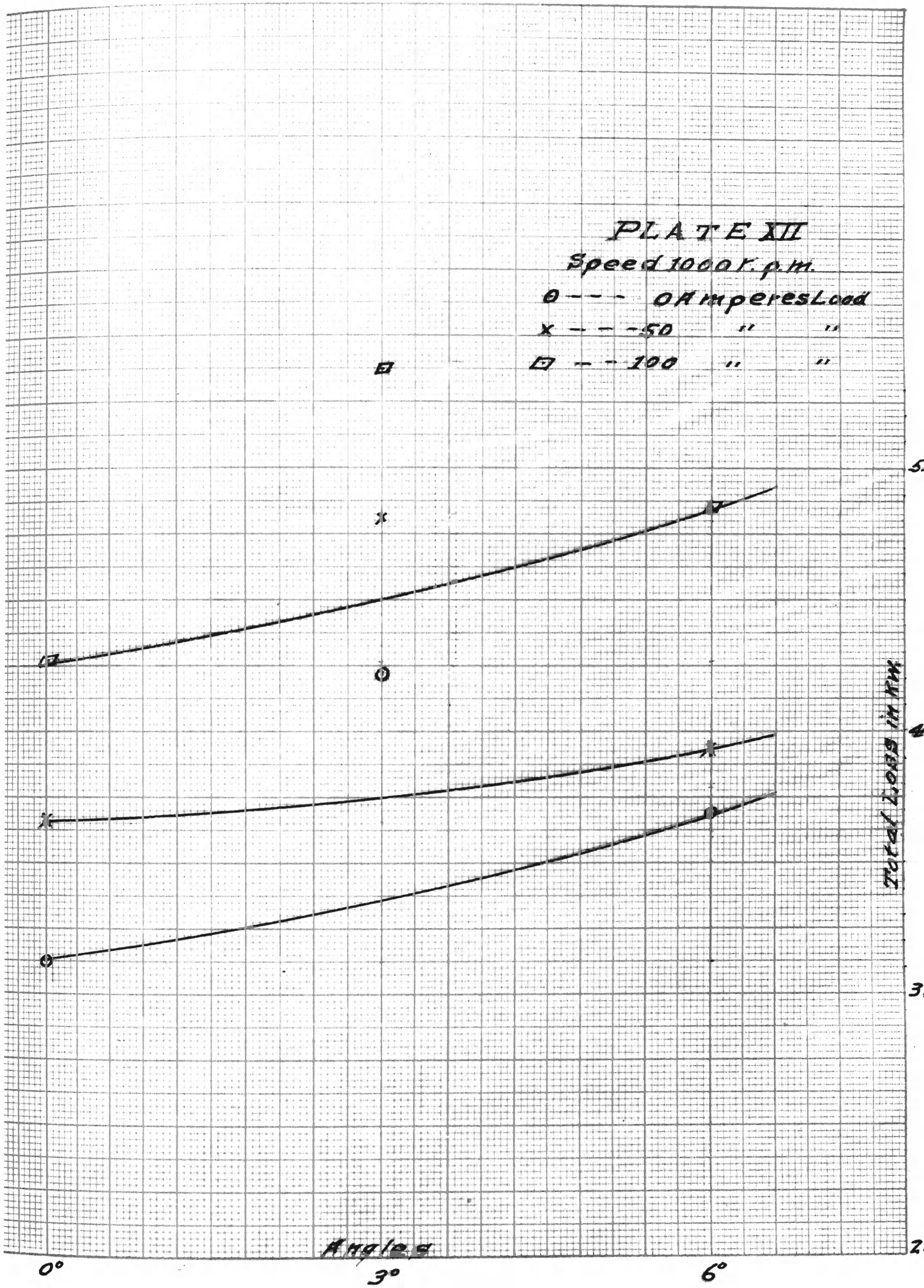
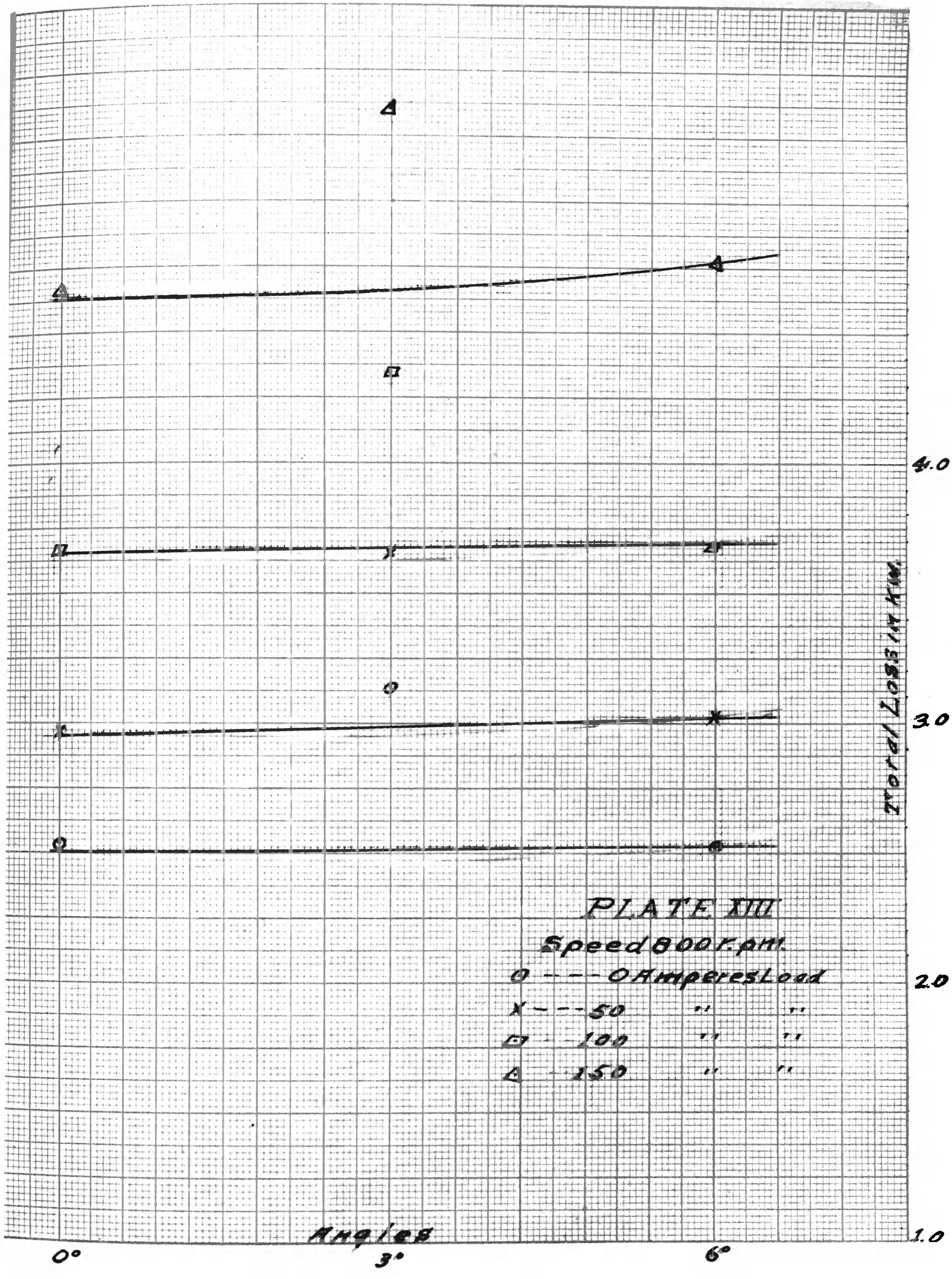


PLATE XII
Speed 1000 r.p.m.
O ---- O Amperes Load
x ---- 50 " "
□ ---- 100 " "
5.0
4.0
3.0
2.0
Total Loss in Kw.
Angles
0°
3°
6°



4.0
3.0
2.0
1.0
Total Loss in Kw.
PLATE XIII
Speed 800 r.p.m.
0 - - - 0 Amperes Load
X - - - 50 " "
□ - - 100 " "
△ - - 150 " "
Angles
0°
3°
6°

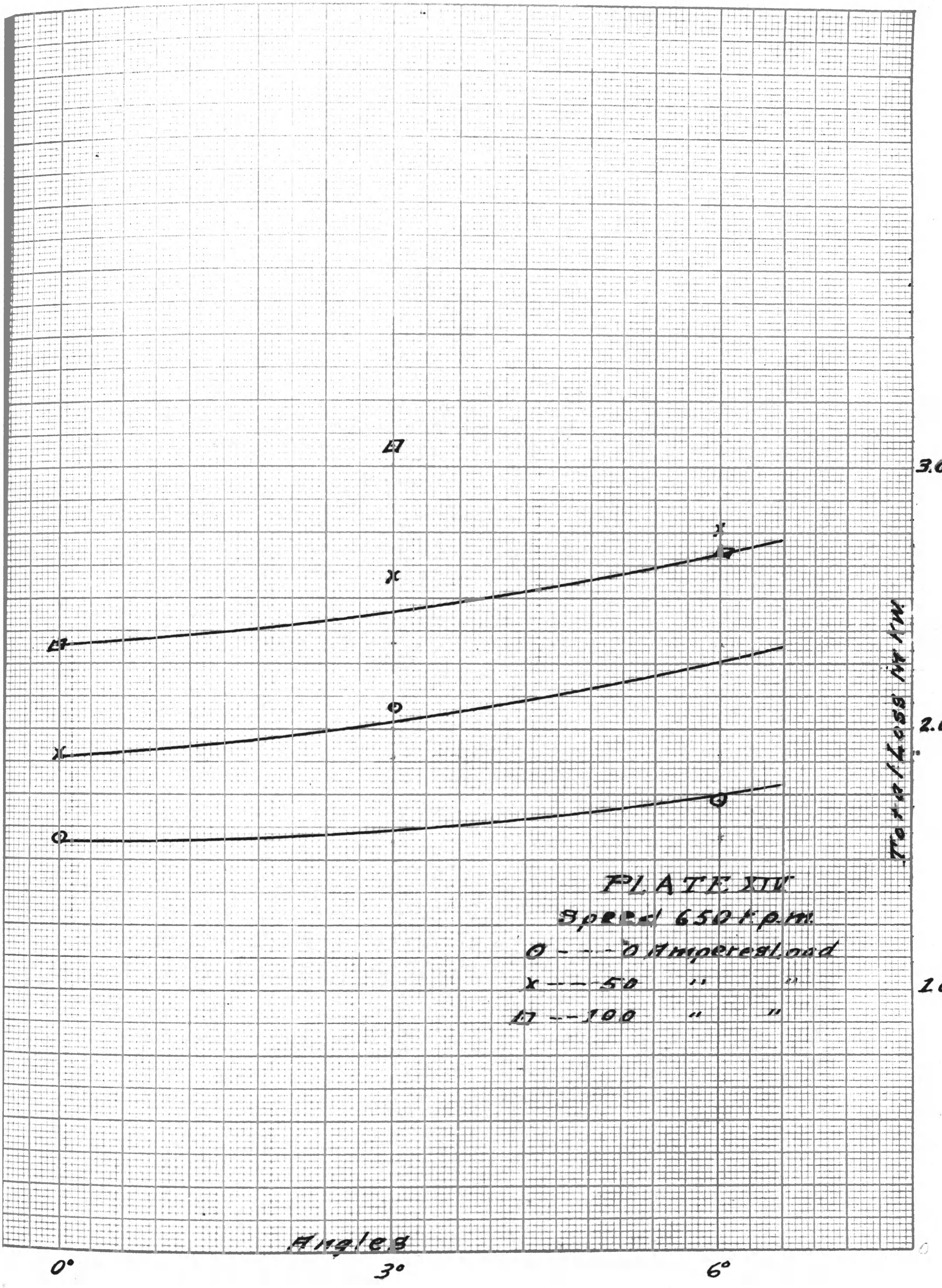


PLATE XIV
Speed 650 r.p.m.
O ---- 0 Amperes Load
x ---- 50 " "
▫ --- 100 " "
Total Loss in K.W.
3.0
2.0
1.0
0
Angles
0°
3°
6°

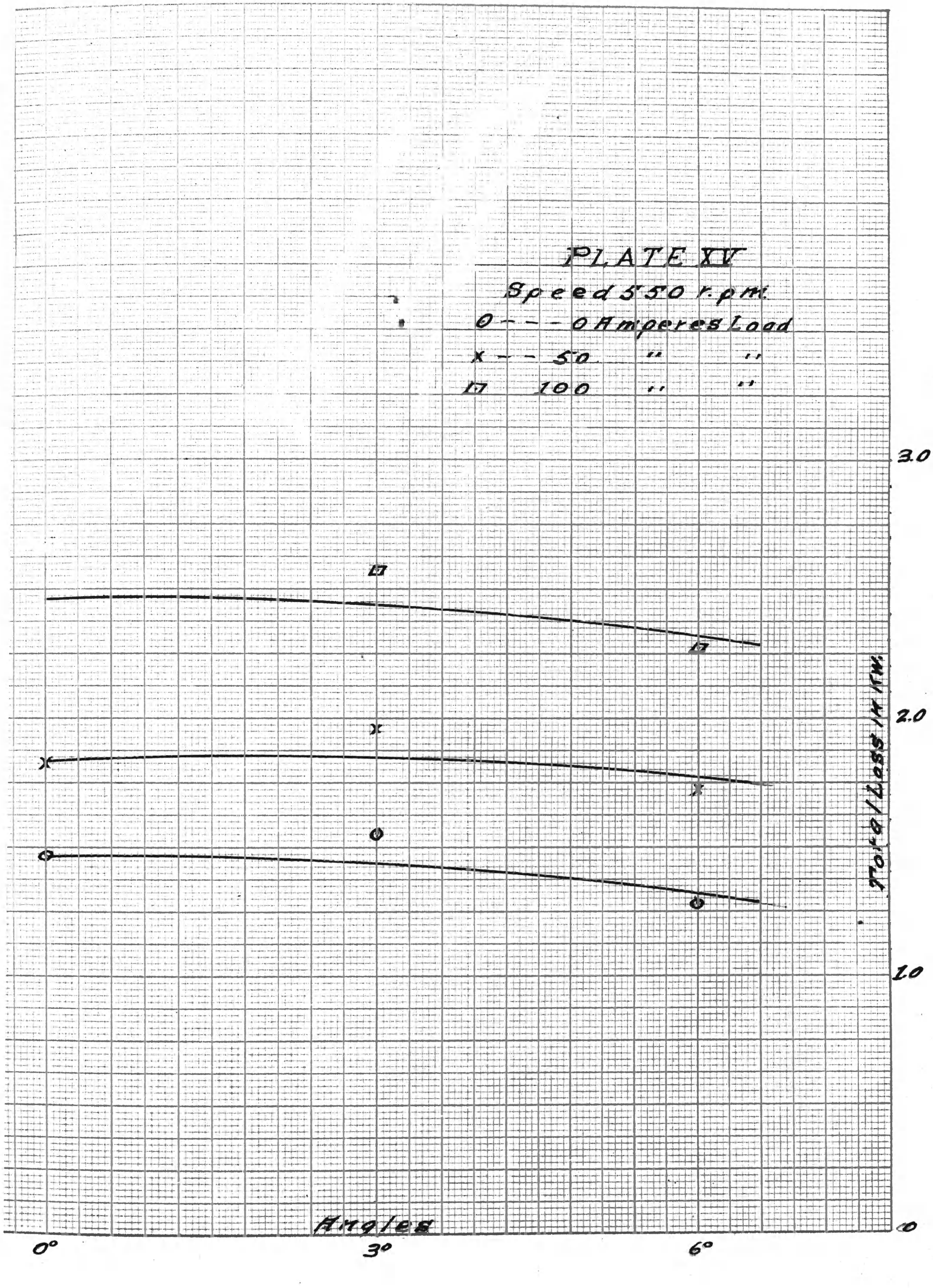


PLATE XV
Speed 550 r.p.m.
0 - - - 0 Amperes Load
x - - - 50 " "
□ 100 " "
3.0
2.0
1.0
0
Motor Loss in K.W.
Angles
0°
3°
6°

Group V. Plates XVI to XVIII inclusive.

The data for this group of curves was obtained from the curves in group IV. The actual loss in watts was obtained for each degree offset for the different loads, by drawing a straight horizontal line through the zero point on each curve then drawing a perpendicular to the curve at the different angles and reading the loss in watts on this vertical line, from where it crosses the horizontal line and the point at which it strikes the curve. These data are found in table six. These curves show the actual loss of the joints and how it varies with the different angles, loads and speeds. The data for this group of curves is found in table six.

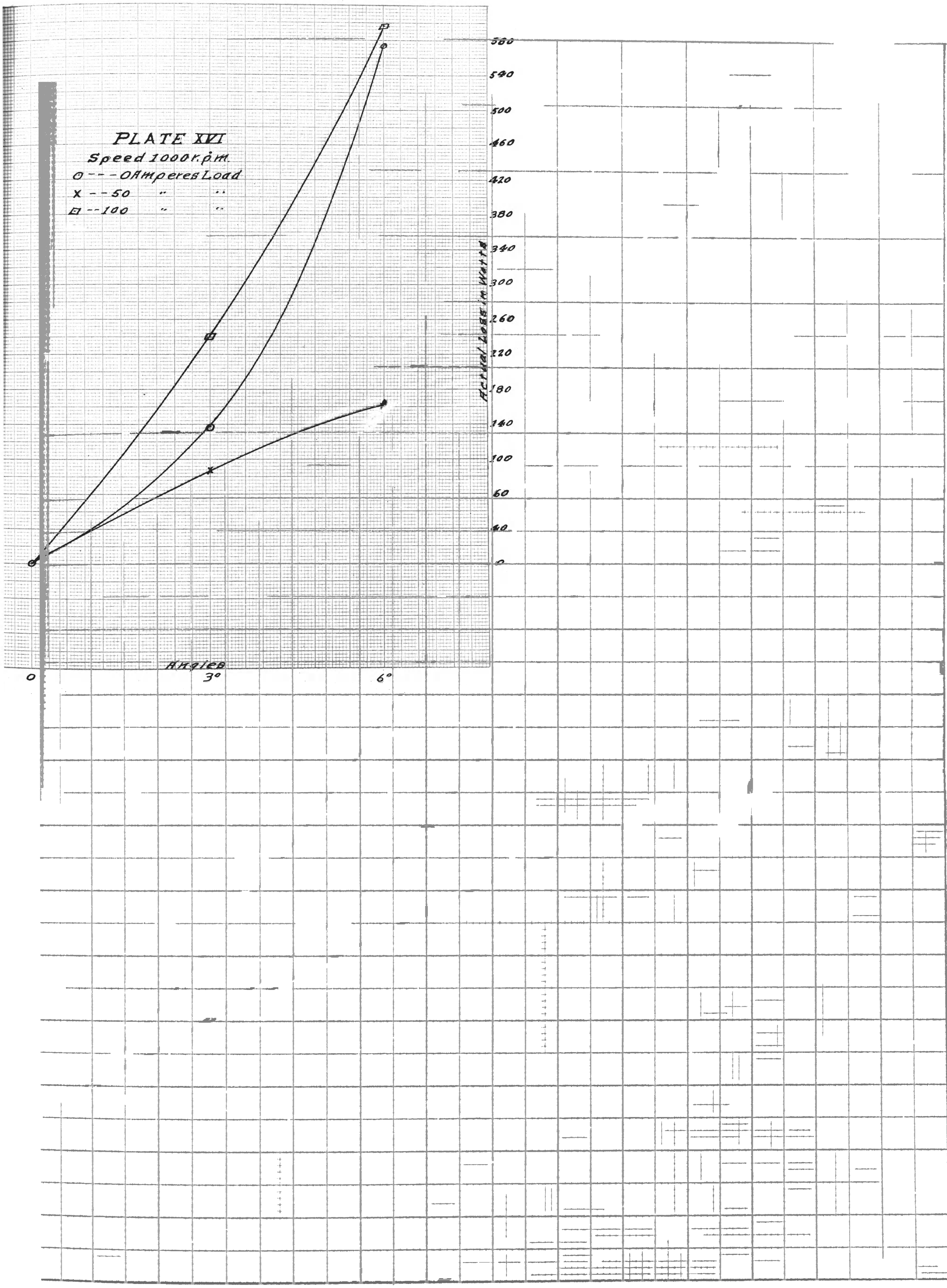


PLATE XVI
Speed 1000 r.p.m.
o---0 Amperes Load
x--50 " "
□--100 " "
Actual Loss in Watts
560
540
500
460
420
380
340
300
260
220
180
140
100
60
40
0
Angles
0
3°
6°

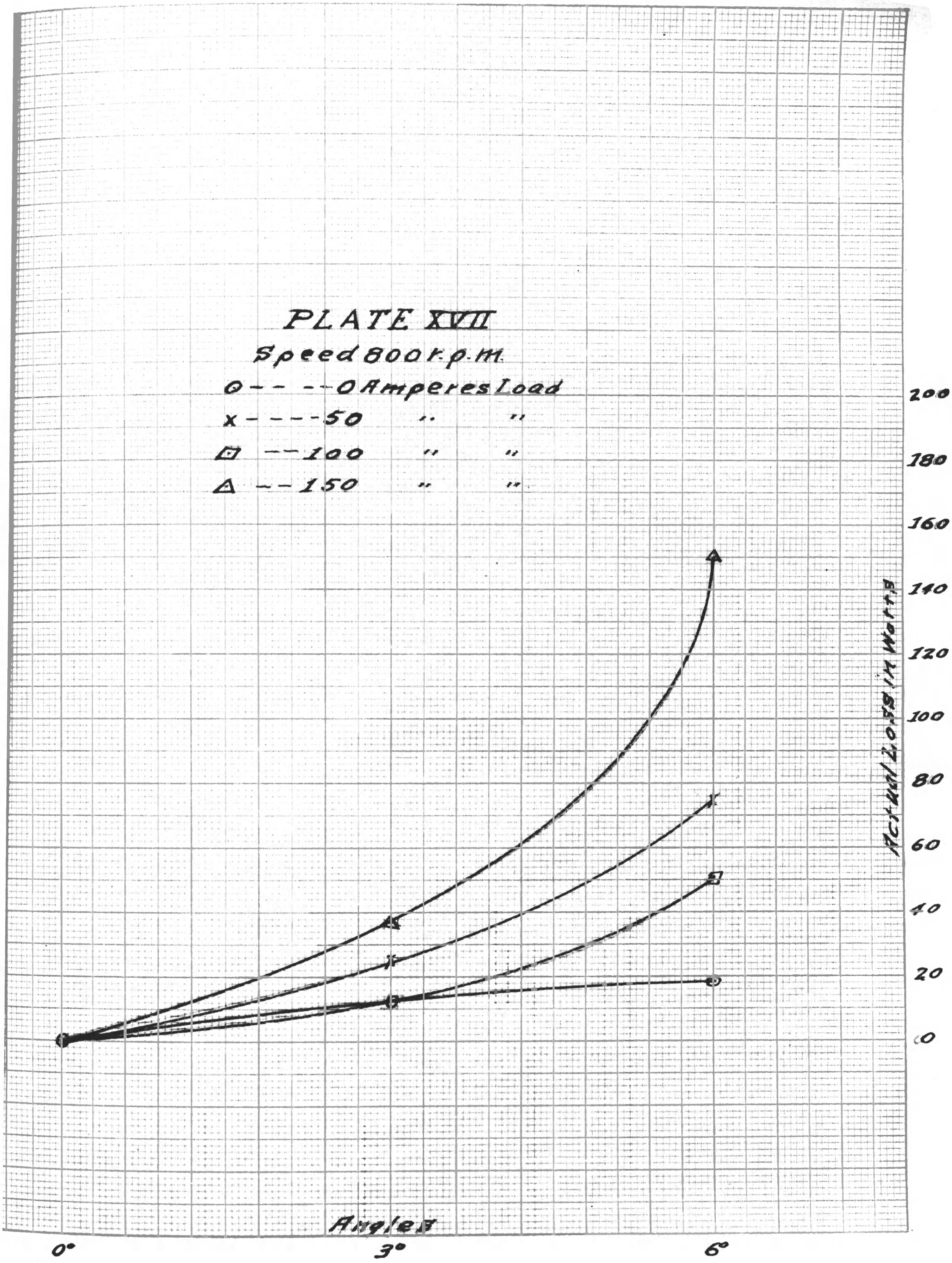


PLATE XVII
Speed 800 r.p.m.
O - - - - 0 Amperes Load
x - - - - 50 " "
□ - - 100 " "
△ - - 150 " "
200
180
160
140
120
100
80
60
40
20
0
Actual L 0.55 in Watts
Angles
0°
3°
6°

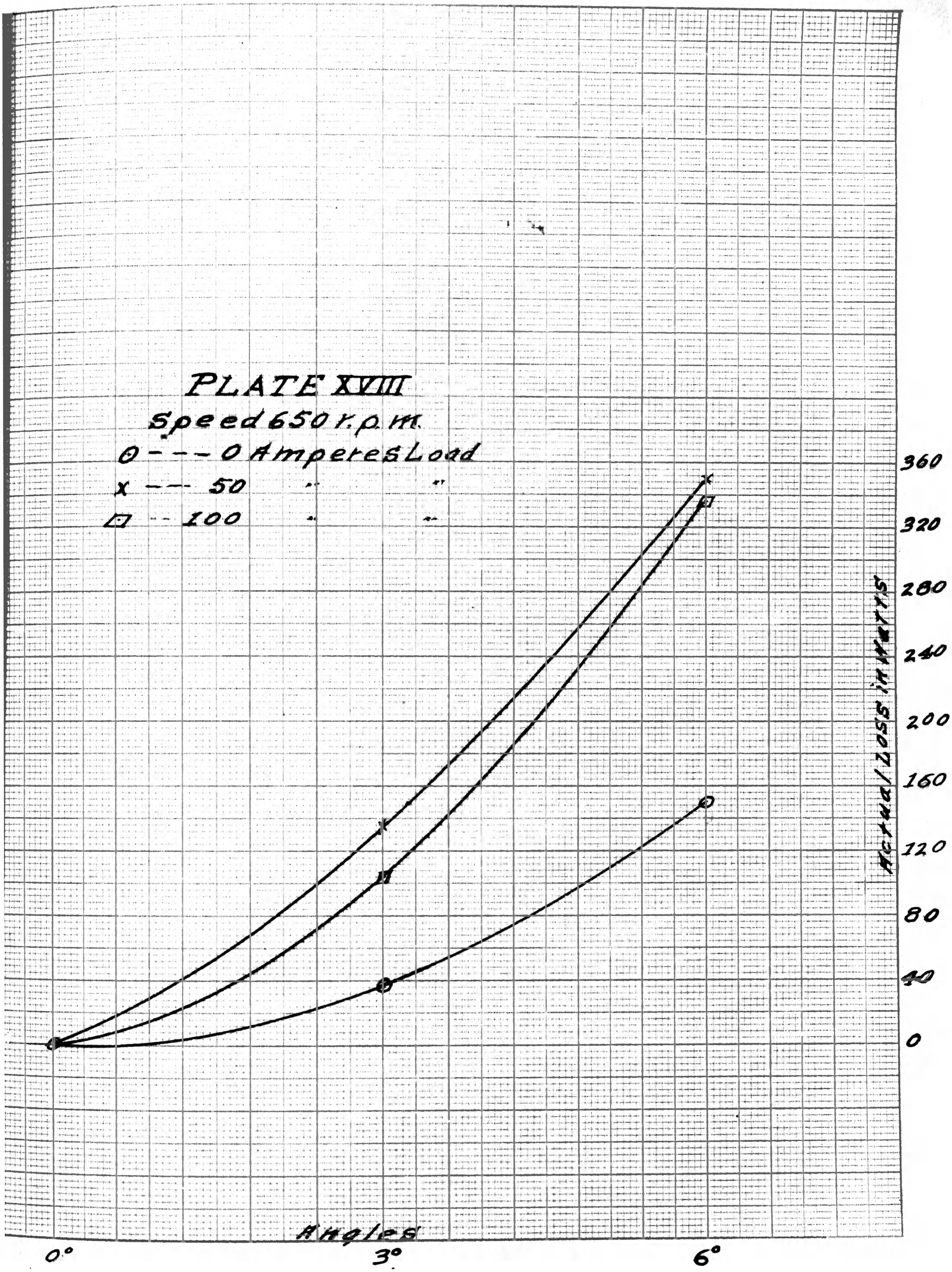


PLATE XVIII
Speed 650 r.p.m.
O --- 0 Amperes Load
x --- 50 " "
□ -- 100 " "
Actual Loss in Watts
360
320
280
240
200
160
120
80
40
0
Angles
0°
3°
6°

Group VI. Plates XIX and XX.

This group of curves was plotted from the data in table three and is shown so as to obtain some idea as to how the losses increase with a larger angle of offset.

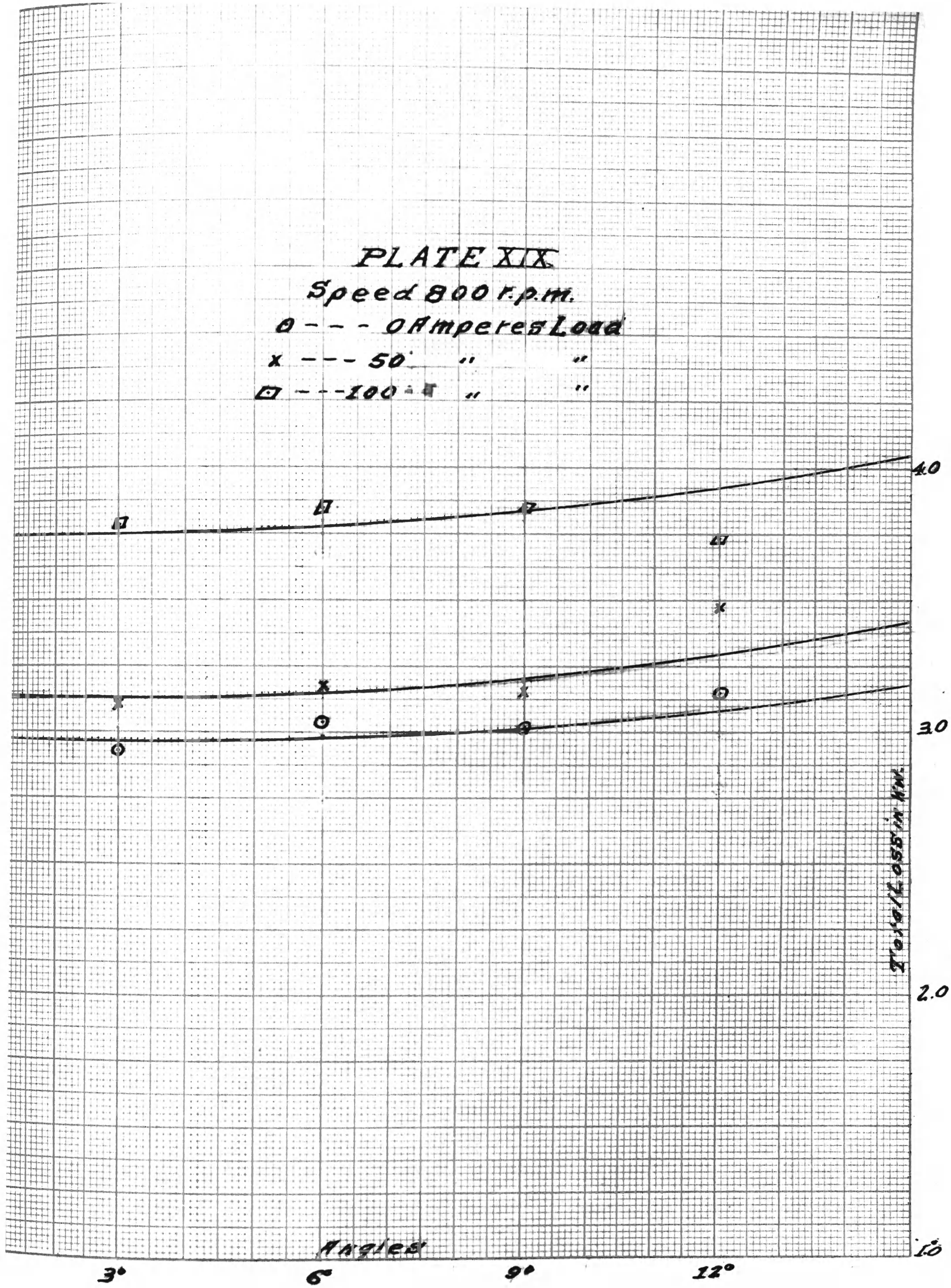


PLATE XIX
Speed 800 r.p.m.
o - - - 0 Amperes Load
x - - - 50 " "
□ - - - 100 " "
4.0
3.0
2.0
1.0
Total Loss in Kw.
Angles
3°
6°
9°
12°

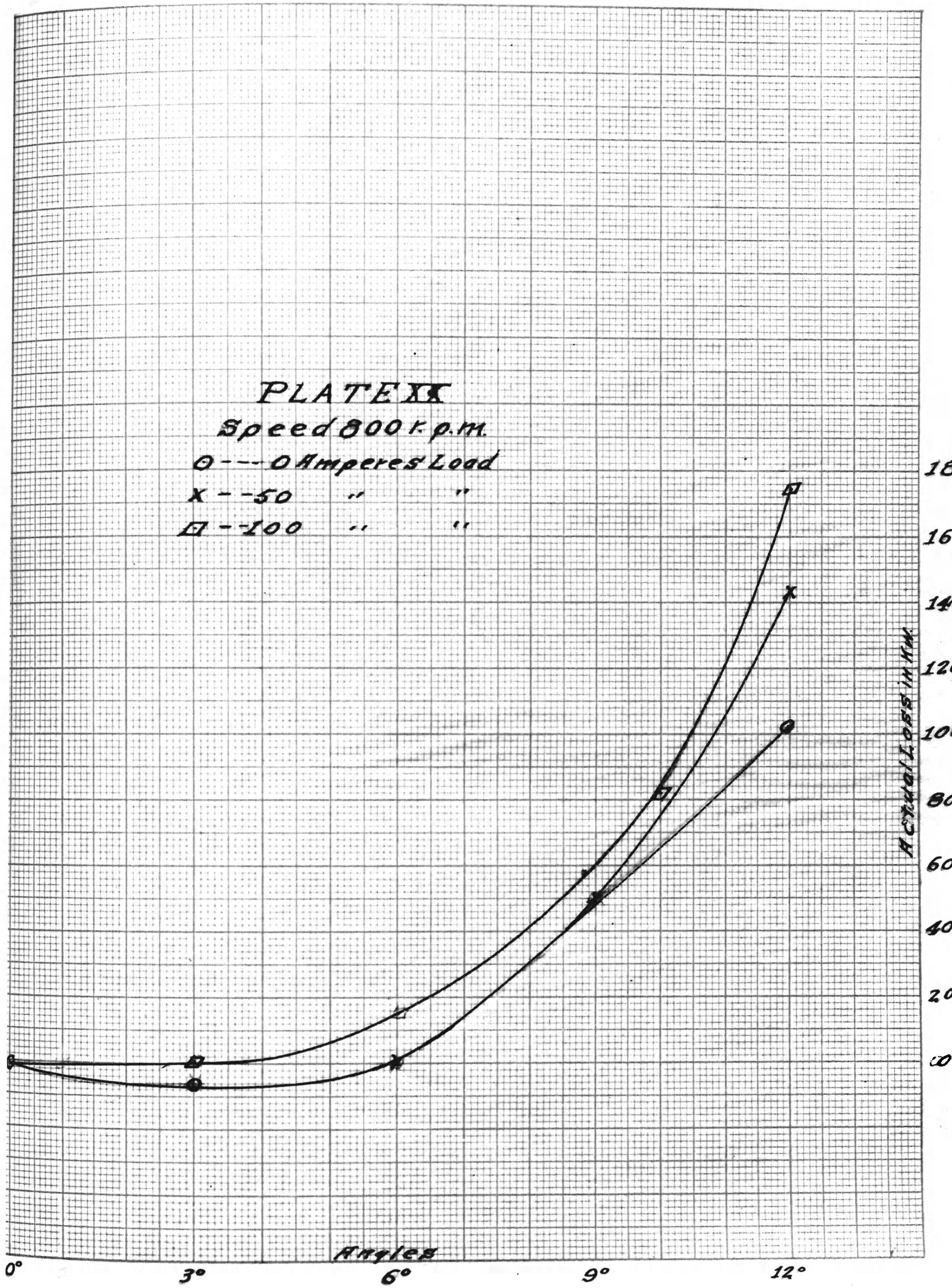


PLATE XX
Speed 800 r.p.m.
O---0 Amperes Load
X--50 " "
□--100 " "
180
160
140
120
100
80
60
40
20
00
Actual Loss in Kw.
Angles
0°
3°
6°
9°
12°

TABLE VI

Speed	Angle	Actual Loss in Watts	Load in Amperes
1000	0	0	
	3	137.5	
	6	572.5	
	0	0	50
	3	87.5	
	6	150	
	0	0	100
	3	250.0	
	6	597.5	
800	0	0	0
	3	12.5	
	6	18.6	
	0	0	50
	3	25.0	
	6	75.0	
	0	0	100
	3	18.6	
	6	50.0	
	0	0	150
	3	37.5	
	6	150.0	
650	0	0	0
	3	37.5	
	6	150.0	
	0	0	50
	3	137.5	
	6	350	
	0	0	100
	3	125.0	
	6	337.5	

CONCLUSIONS

Some of the conclusions arrived at are as follows:

1. The loss in the universal joints is small when operating at a small deflection.

2. With constant speed and deflection the losses increase as the load increases.

3. With constant speed and load the losses increase as the deflections increase.

4. With constant deflection and load the losses increase as the speed increases.

The same conlcusions would be arrived at whether the forks of the joints were in a ninety degree position or in the same plane. The only difference would be that the losses would be larger when the forks are at a ninety degree position than when in the same plane. This is shown very clearly by plate XI. Therefore no curves are shown with the forks at ninety degrees except those of group one and plate XI of group three.

A DISCUSSION OF THE RESULTS OF THE TEST.

A discussion of the results of the test on Blood Bros. Machine Company's universal joints will now be taken up.

The curves as plotted from the data obtained on these joints show up better in almost every respect This is due principally to the operators of the apparatus having learned where and how to guard against the various sources of error that influenced the previous groups of curves.

Group I. Plates I to III inclusive.

No curves are plotted here with the forks at the ninety degree position on account of not being able to obtain sufficient data with the forks of these joints at the ninety degree position. The effect set up by the variance in the velocity ratio kept us from obtaining any complete set of runs while working with the joints in this position.

Plates I to III inclusive show in a general way how the losses vary with the speed, angles and loads.

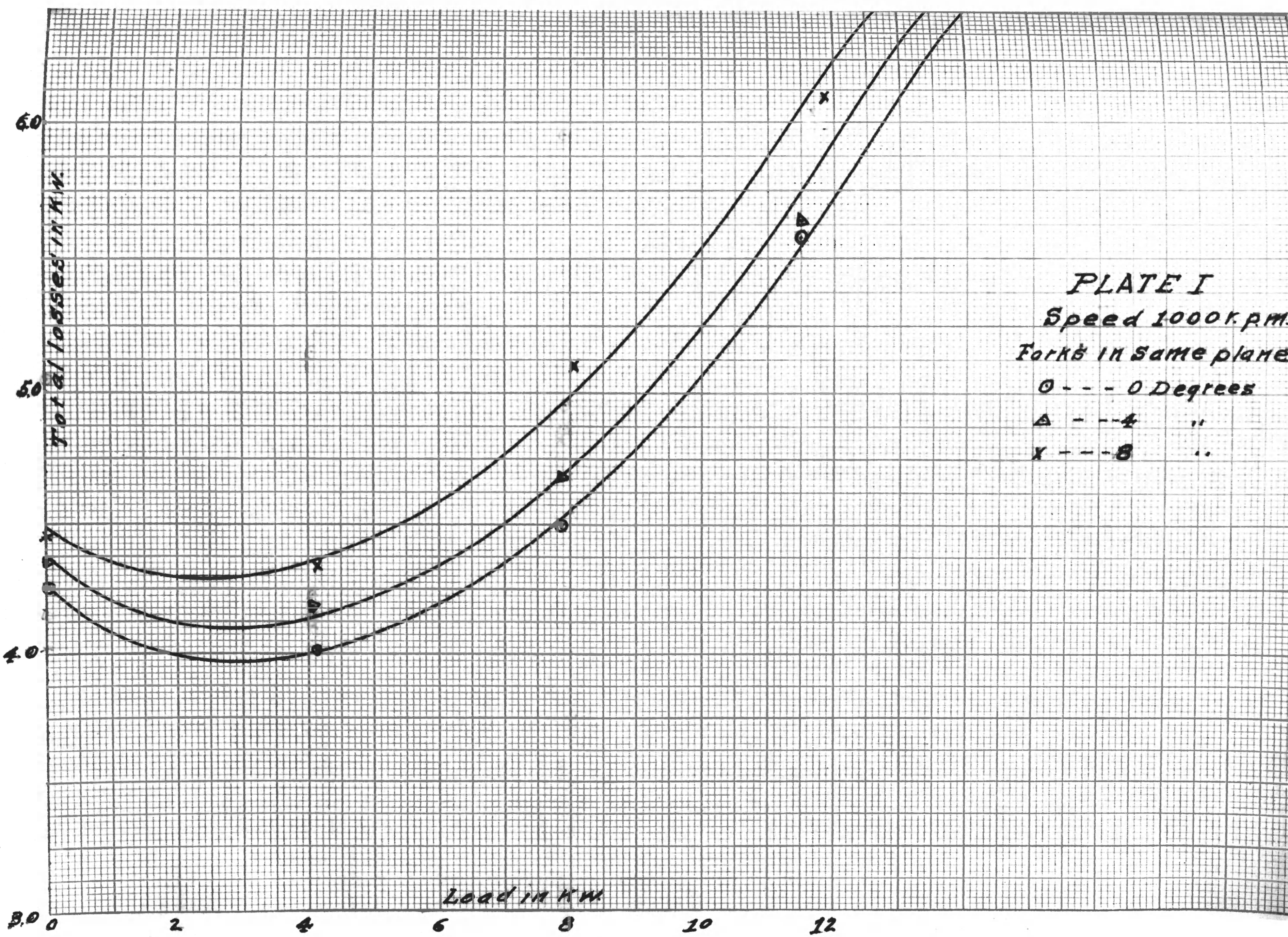


PLATE I
Speed 1000 r.p.m.
Forks in same plane
O - - - 0 Degrees
Δ - - - 4 "
x - - - 8 "
Total losses in K.W.
Load in K.W.
3.0
4.0
5.0
6.0
0
2
4
6
8
10
12

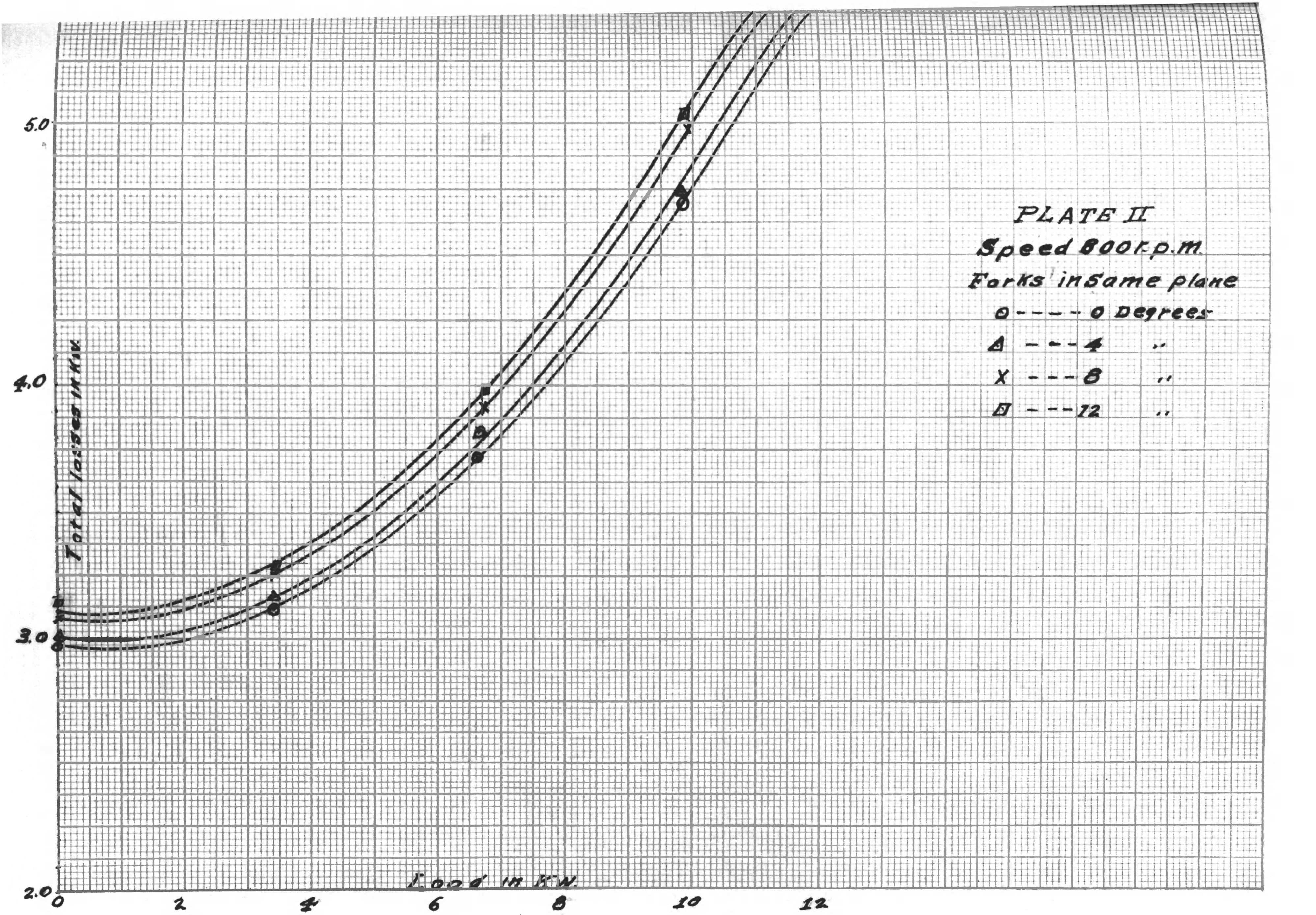


PLATE II
Speed 800 r.p.m.
Forks in same plane
O ---- 0 Degrees
Δ --- 4 "
X --- 8 "
□ --- 12 "
Total losses in K.W.
Load in K.W.
5.0
4.0
3.0
2.0
0
2
4
6
8
10
12

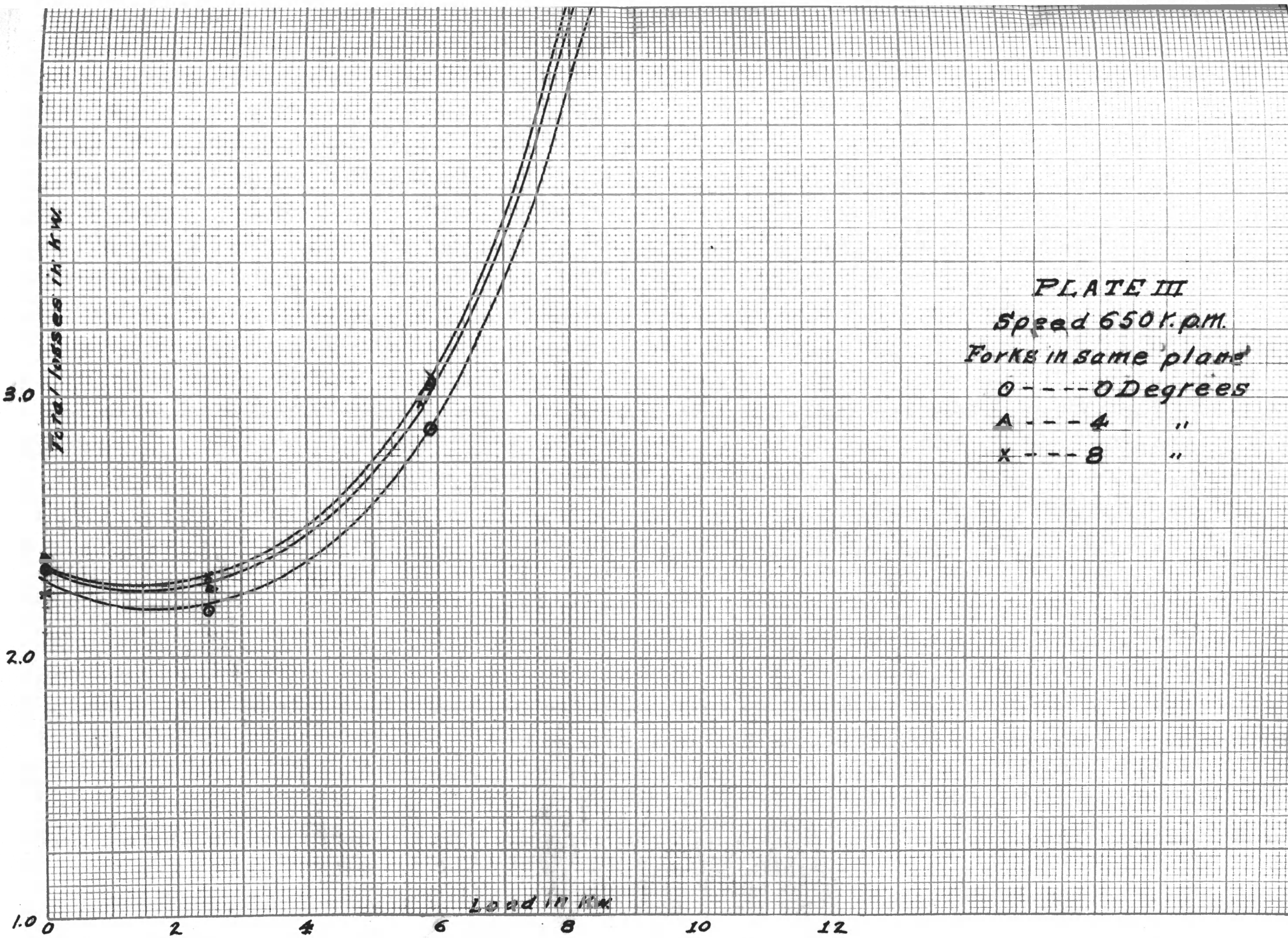


PLATE III
Speed 650 r.p.m.
Forks in same plane
O - - - - 0 Degrees
A - - - 4 "
X - - - 8 "
Total losses in kw.
Load in kw.
1.0
2.0
3.0
0
2
4
6
8
10
12

TABLE I

Speed	Angle	M.F.	L.C.	Volts	Total Loss in Watts	Load in Amperes	Total Loss in Watts.
1000	0	2.0	49.6	85.9	4260	0	0
			48.8	82.1	4010	50	4100
			58.6	78.8	4620	100	7880
			73.9	77.0	5690	150	11505
	4	2.0	51.3	85.1	4360	0	0
			52.2	81.2	4240	50	4060
			61.8	78.0	4820	100	7800
			74.3	76.8	5720	150	11503
	8	2.0	51.6	86.2	4440	0	0
			52.1	83.6	4350	50	4180
			63.3	80.5	5100	100	8050
			77.4	78.9	6110	150	11850
800	0	2.2	41.7	71.5	2980	0	0
			45.1	68.9	3110	50	3450
			56.3	66.2	3720	100	6620
			73.8	65.4	4830	150	9820
	4		42.6	70.6	3000	0	0
			46.3	68.5	3170	50	3430
			57.5	66.5	3820	100	6650
			74.1	65.3	4840	150	9800
	8		43.5	71.1	3090	0	0
			47.1	69.0	3250	50	3450
			58.3	67.0	3910	100	6700
			75.5	66.0	4980	150	9990
	12		44.1	71.3	3140	0	0
			47.1	69.6	3280	50	3480
			59.1	67.5	3950	100	6750
			76.4	65.7	5620	150	9850
650	0	1.9	43.0	54.0	2320	0	0
			43.6	50.0	2180	50	2500
			59.5	48.3	2870	100	4830
	4		43.4	54.4	2370	0	0
			45.2	50.0	2260	50	2500
			63.6	48.2	3060	100	4820
	8		41.3	53.6	2210	0	0
			45.5	50.0	2275	50	2500
			63.0	47.5	2990	100	4750

No reliable data at 550 rev. per minute.

Group II. Plates IV to VII inclusive.

These curves are taken from the data in table one but show how the losses vary with the angles. Plate IV shows a comparison of the losses with respect to the angles, with the joints in the ninety degree position and also when in the same plane. The data for this plate of curves are taken from table two.

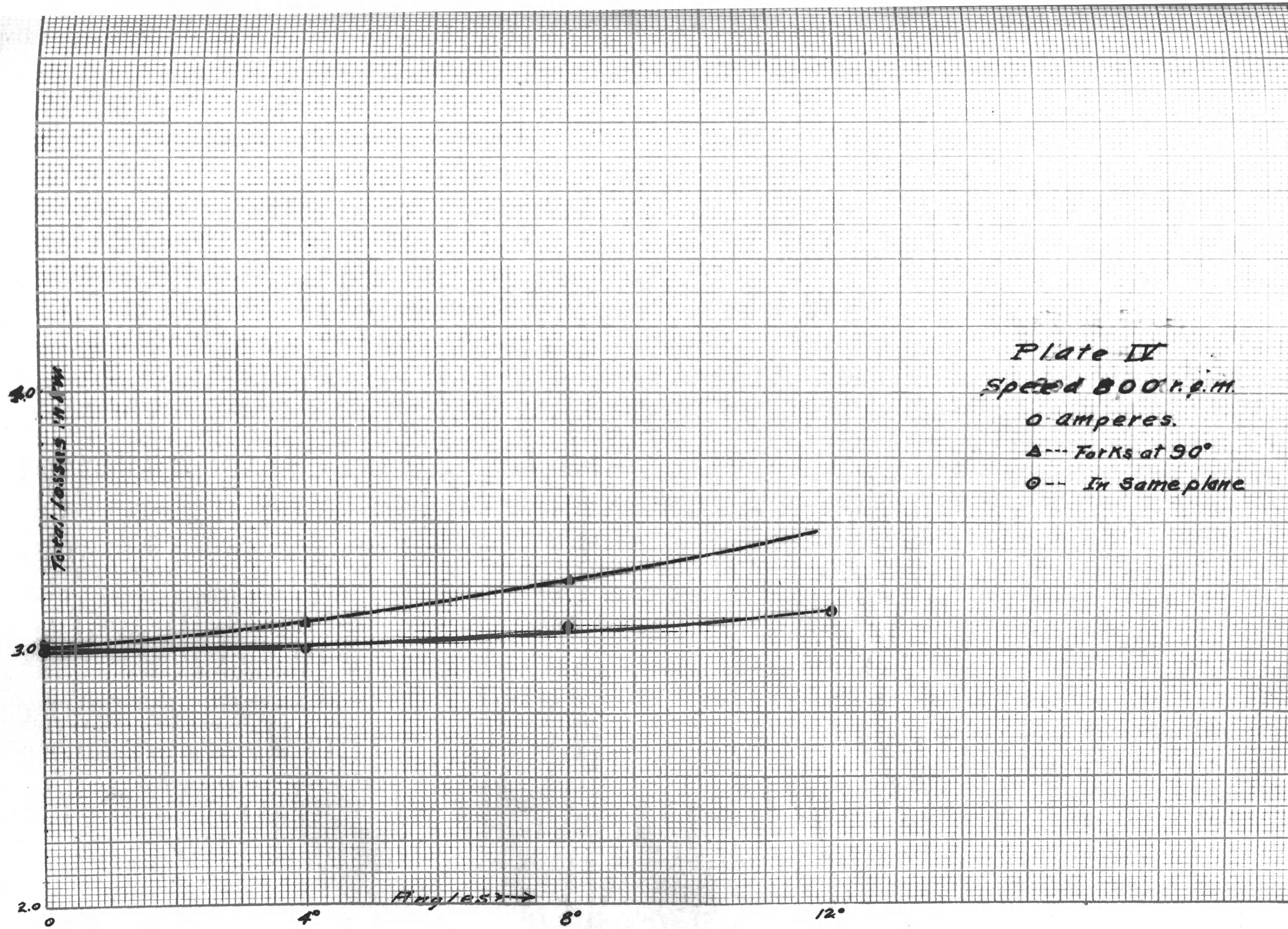


Plate IV
Speed 800 r.p.m.
0 amperes.
△--- Forks at 90°
⊙-- In Same plane
Total losses in KW
4.0
3.0
2.0
Angles →
0
4°
8°
12°

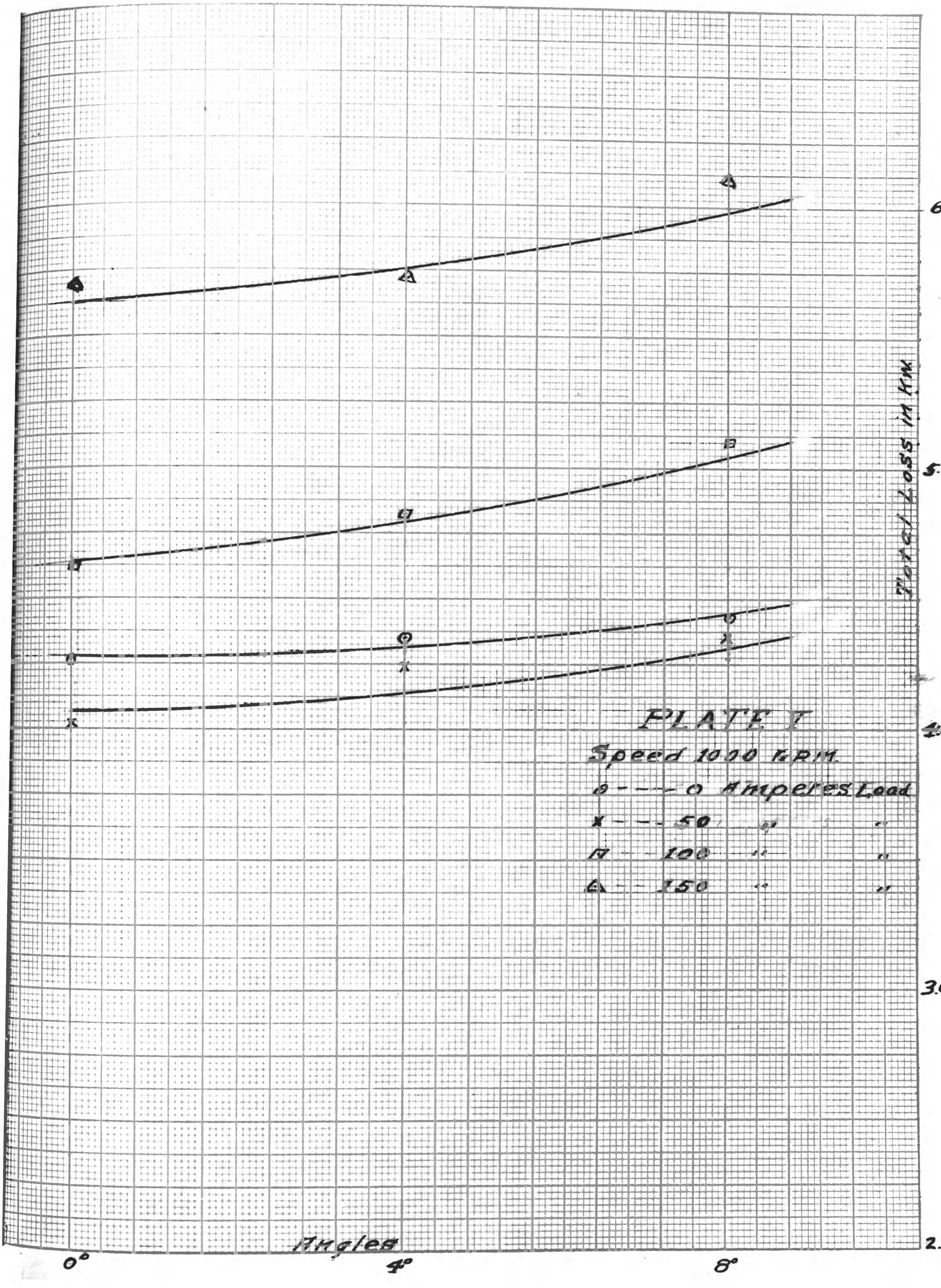


PLATE I
Speed 1000 RPM.
o --- 0 Amperes Load
x --- 50 " "
□ - 100 " "
△ - 150 " "
Total Loss in KW
6.0
5.0
4.0
3.0
2.0
Angles
0°
4°
8°

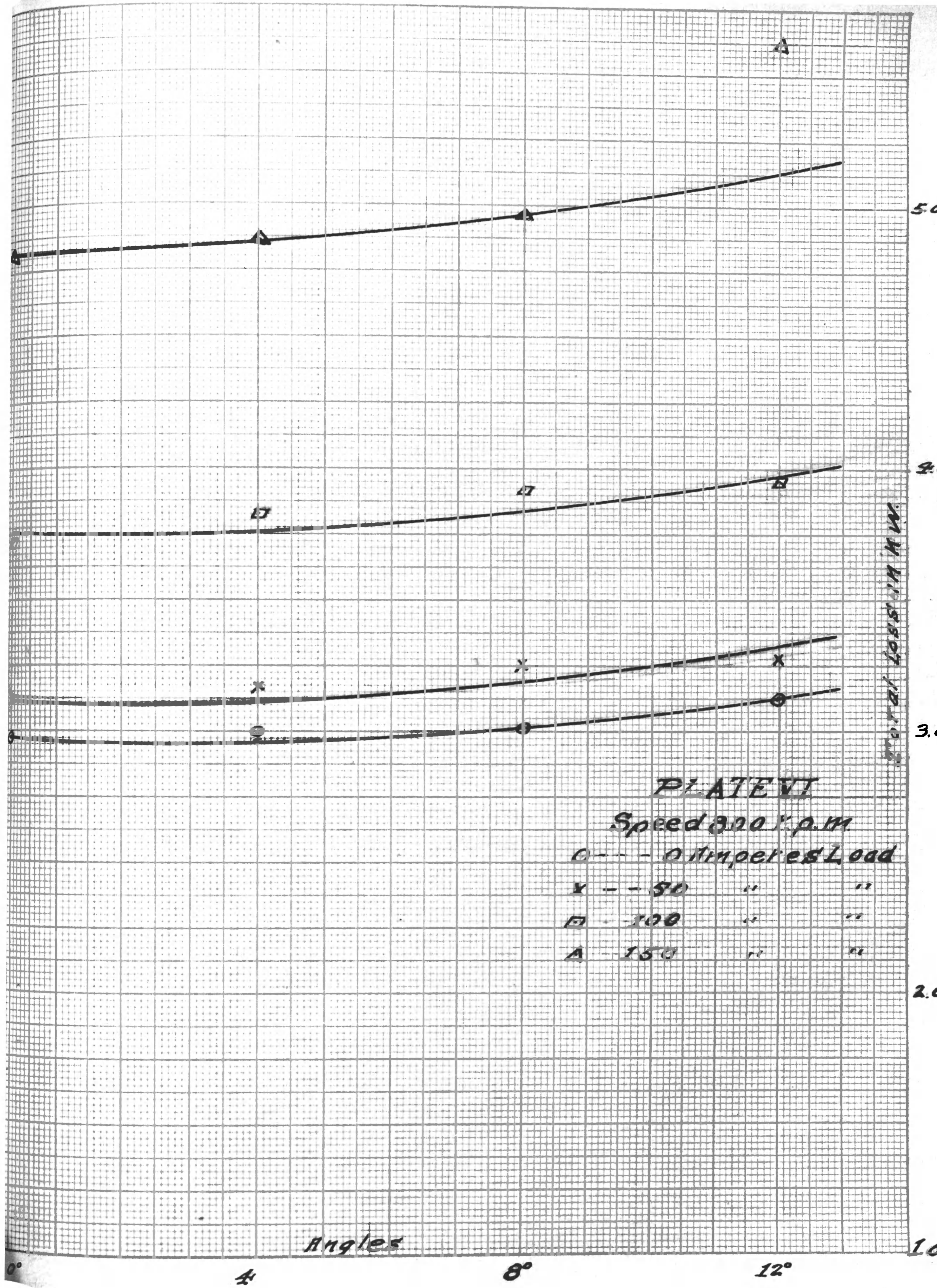


PLATE VI
Speed 800 r.p.m.
O - - - 0 Amperes Load
x - - 50 " "
□ - 100 " "
△ - 150 " "
Total Loss in K.W.
5.0
4.0
3.0
2.0
1.0
Angles
0°
4
8°
12°

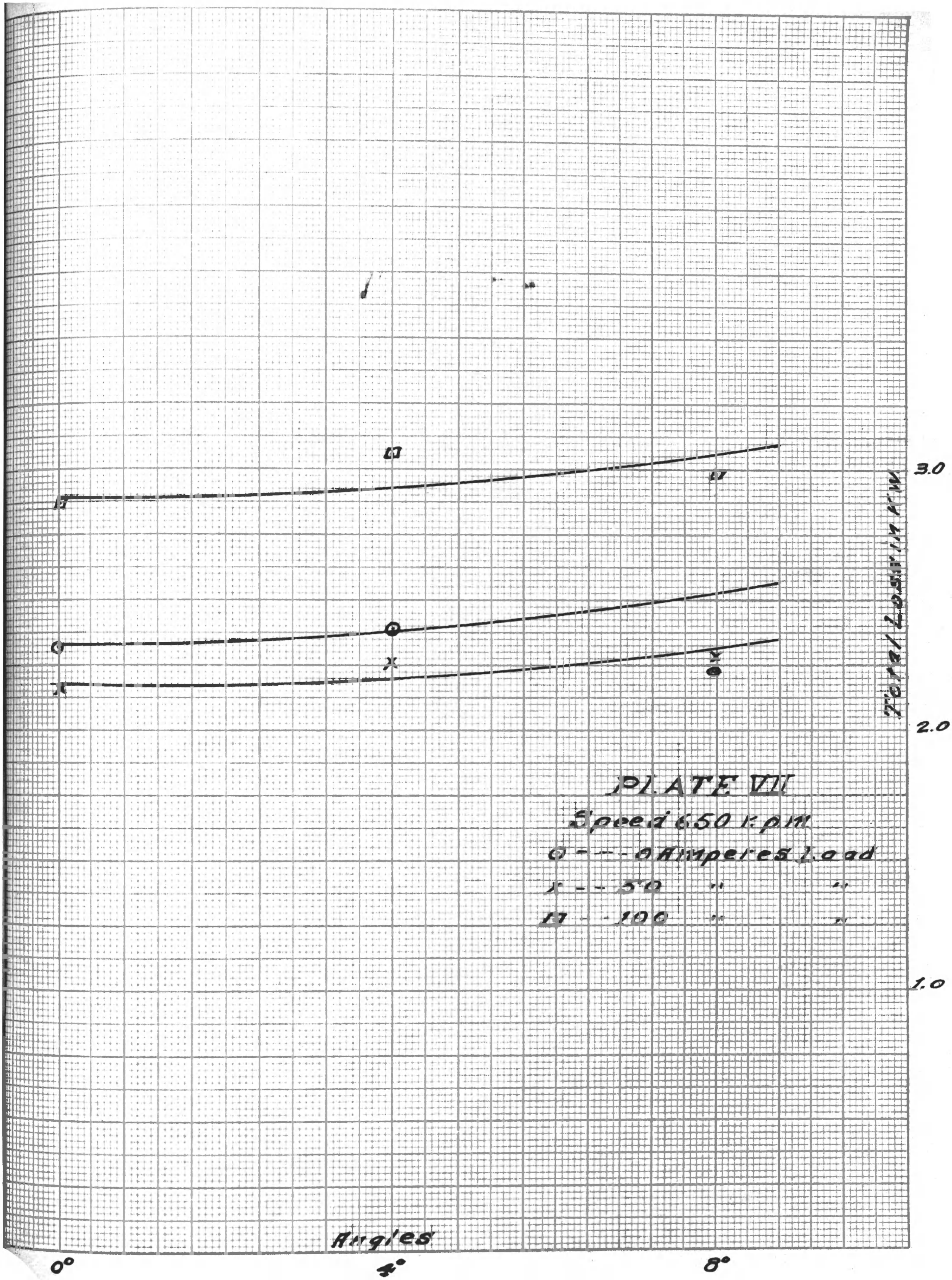


PLATE VII
Speed 650 r.p.m.
o --- 0 Amperes Load
x -- 50 " "
□ - 100 " "
Total Losses in K.W.
3.0
2.0
1.0
Angles
0°
4°
8°

TABLE II

Speed	Angle	M.F.	L.C.	Volts	Total Loss in Watts	Load in Amperes	Total Loss in Watts
800	0	2.2	41.7	71.5	2980	0	0
			45.1	68.9	3110	50	3450
			56.3	66.2	3720	100	6620
			73.8	65.4	4830	150	9820
	4		42.6	70.6	3000	0	0
			46.3	68.5	3170	50	3430
			57.5	66.5	3820	100	6650
			74.1	65.3	4840	150	9800
	8		43.5	71.1	3090	0	0
			47.1	69.0	3250	50	3450
			58.3	67.0	3910	100	6700
			75.5	66.0	4980	150	9990
	12		44.1	71.3	3140	0	0
			47.1	69.6	3280	50	3480
			59.1	67.5	3950	100	6750
			76.4	65.7	5620	150	9850
Forks at 90°							
	0	2.2	42.3	70.4	2980	0	0
			45.1	67.6	3050	50	3380
			55.6	65.0	3610	100	6500
			73.4	64.4	4730	150	9650
	4		43.1	71.9	3100	0	0
			45.4	69.7	3160	50	3480
			57.2	67.0	3830	100	6700
			76.0	65.5	4980	150	9830
	8		45.5	72.1	3280	0	0
			47.1	69.7	3280	50	3480
			58.5	66.3	3880	100	6630

Group III. Plates VIII to X inclusive.

The curves on these plates show how the actual losses vary in the joints at different loads and angles of offset. The data for these are taken from the curves of plates V to VII inclusive. The actual loss in watts is found for each angle by drawing a horizontal line through the zero degree position of the curve of each load and speed then at the other angles draw a vertical line through the curve and the horizontal line. The loss is then determined by reading it from the distance on the vertical line between the curve and the horizontal line. These data will be found collected in table three.

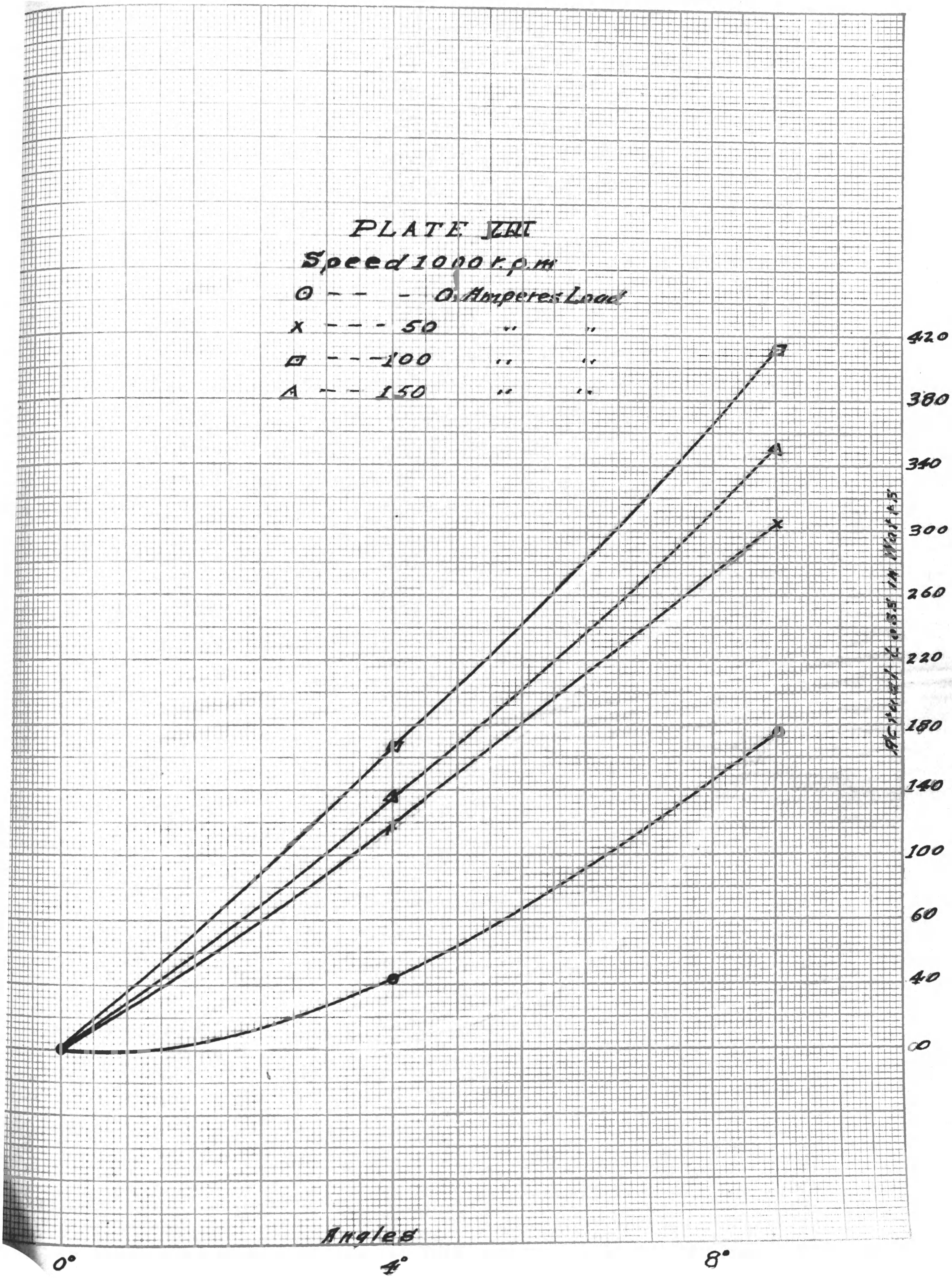


PLATE XIII
Speed 1000 r.p.m
O - - - 0 Amperes Load
x - - - 50 " "
□ - - - 100 " "
A - - 150 " "
Actual Loss in Watts
420
380
340
300
260
220
180
140
100
60
40
00
Angles
0°
4°
8°

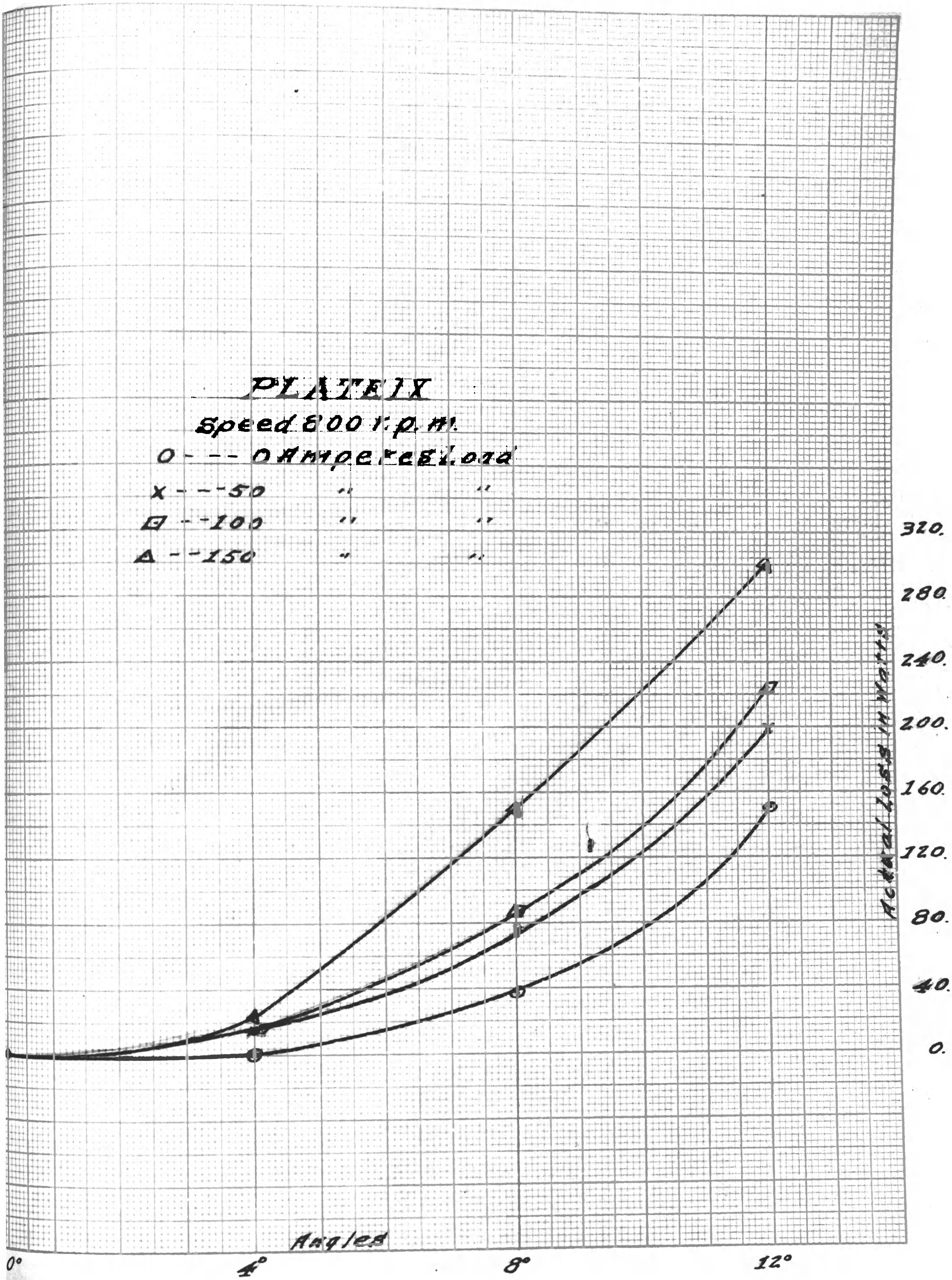


PLATE IX
Speed 800 r.p.m.
O - - - 0 Amperes Load
X - - - 50 " "
□ - - 100 " "
Δ - - 150 " "
Actual Loss in Watts
0.
40.
80.
120.
160.
200.
240.
280.
320.
Angles
0°
4°
8°
12°

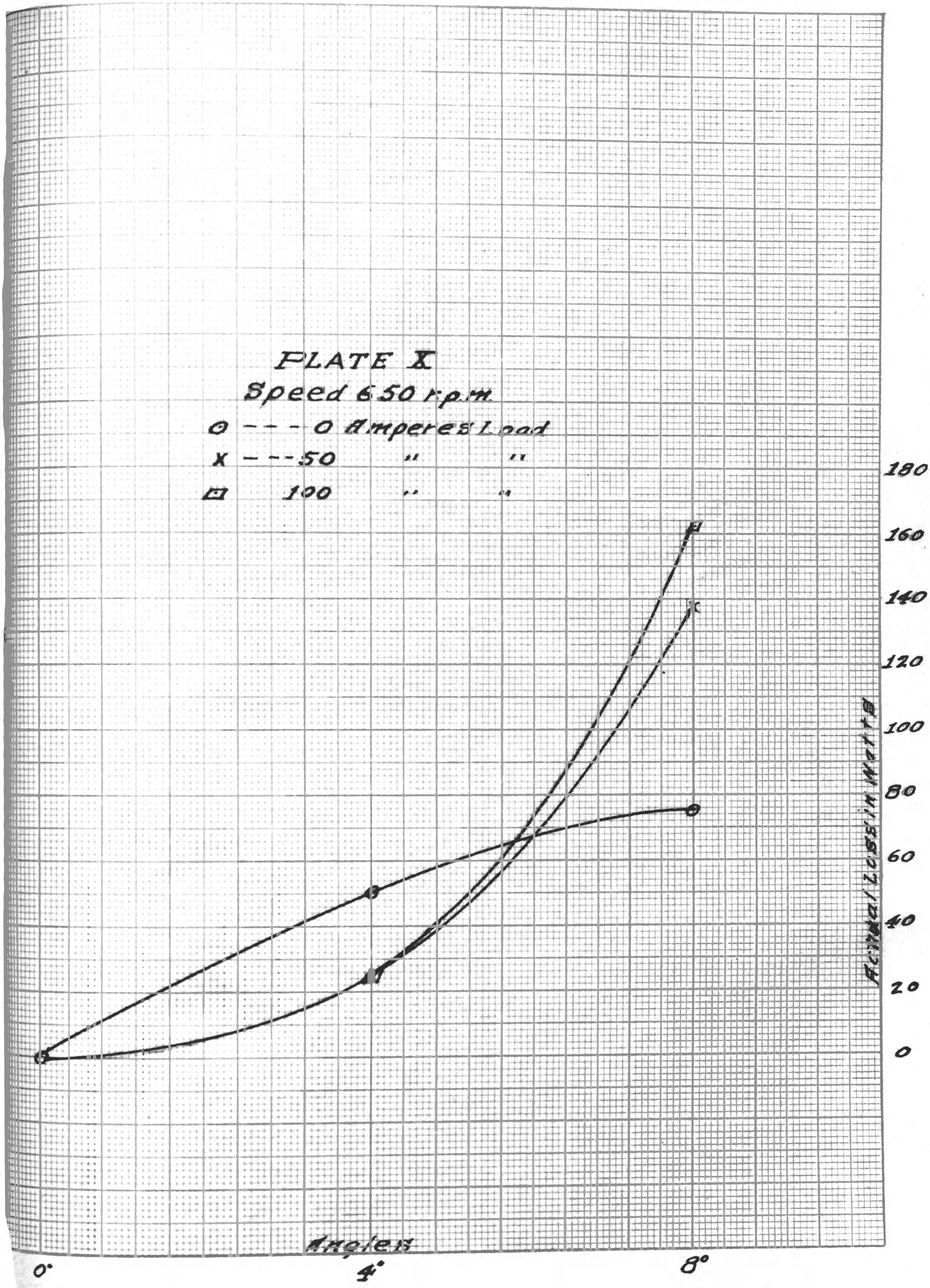


PLATE X
Speed 650 r.p.m.
O - - - - 0 Amperes Load
X - - - 50 " "
☐ 100 " "
180
160
140
120
100
80
60
40
20
0
Actual Loss in Watts
Angles
0°
4°
8°

TABLE III

Speed	Angles	Actual Loss in Watts	Load in Amperes
1000	0	0	0
	4	43.6	0
	8	175.0	0
	0	0	50
	4	118.6	50
	8	306.2	50
	0	0	100
	4	168.6	100
	8	412.5	100
	0	0	150
	4	137.5	150
	8	350.0	150
800	0	0	0
	4	0	0
	8	37.5	0
	12	15.0	0
	0	0	50
	4	12.5	50
	8	75.0	50
	12	200.0	50
	0	0	100
	4	12.5	100
	8	87.5	100
	12	225.0	100
	0	0	150
	4	25.0	150
	8	150.0	150
	12	300.0	150
650	0	0	0
	4	50.0	0
	8	75.0	0
	0	0	50
	4	25.0	50
	8	137.5	50
	0	0	100
	4	25.0	100
	8	162.5	100

Group IV. Plates XI and XII are worked up to show the efficiency of the two joints. The data for these curves are found in tables four and five. The data for table four is taken from the curves of group two on the Spicer joint,. and the data for table 5 is taken from group one, on the Blood Bros. joints. A load of 4000 watts was taken and the total losses read off for each angle of offset. The total loss at the zero angle curve being taken as the normal condition. On plate XI no points were obtained for the three degree offset on account of the position taken by the three degree curve on plates V to VIII inclusive of group two on the Spicer joints.

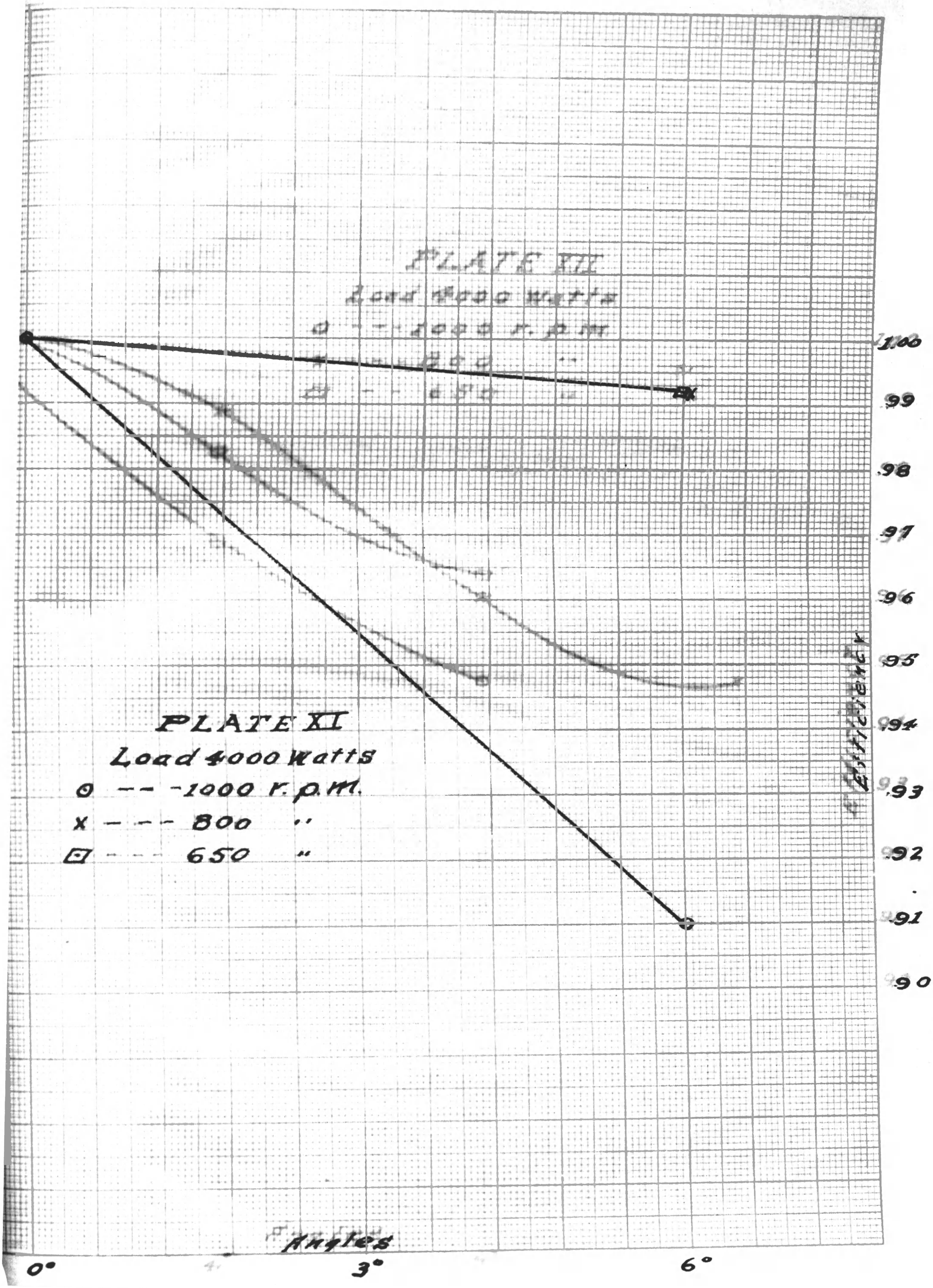


PLATE XI
Load 4000 Watts
o --- 1000 r.p.m.
x --- 800 "
⊡ --- 650 "
1.00
.99
.98
.97
.96
.95
.94
.93
.92
.91
.90
Efficiency
Angles
0°
3°
6°

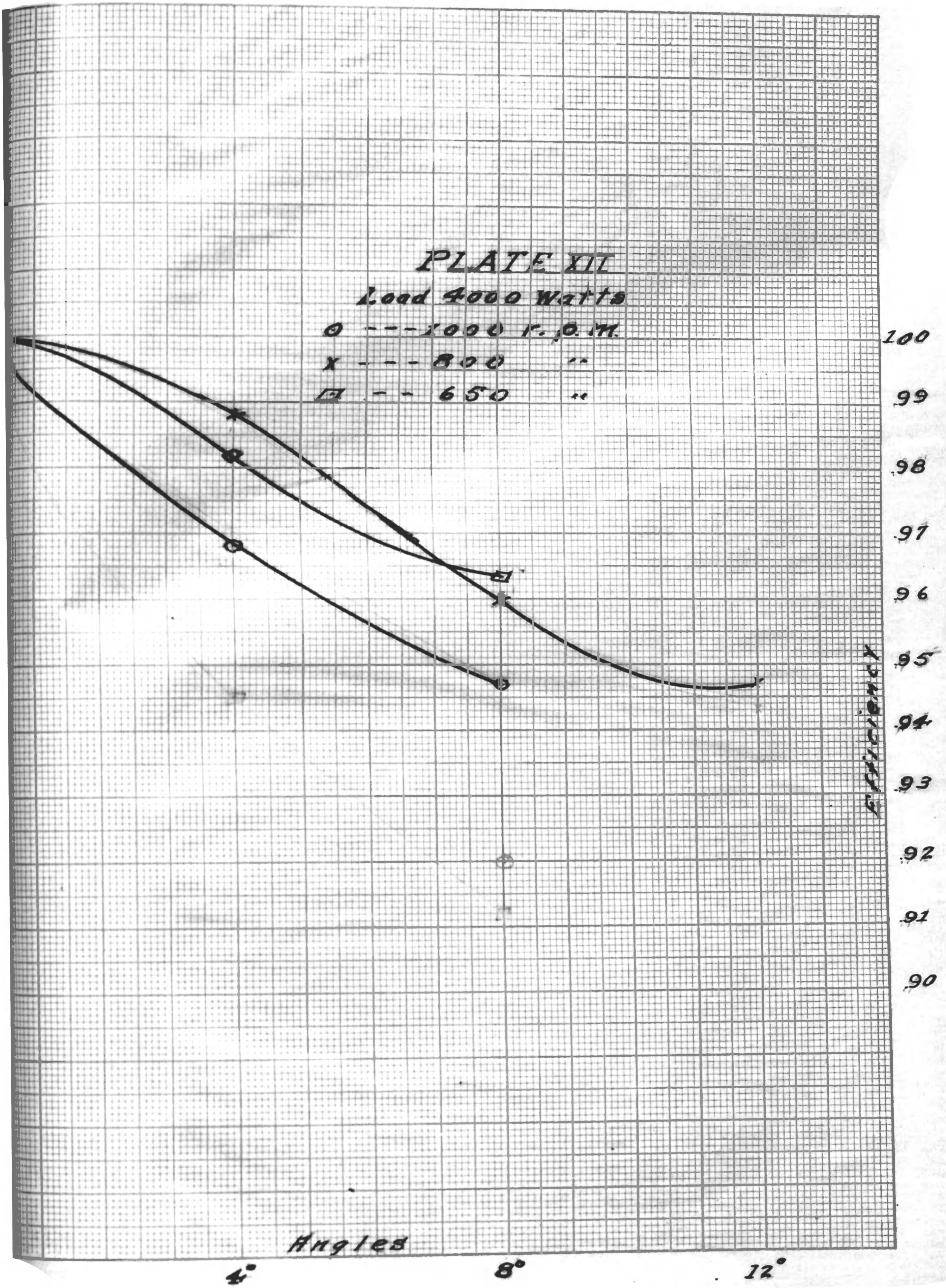


PLATE XII
Load 4000 Watts
o ---1000 r.p.m.
x --- 800 "
□ -- 650 "
100
99
98
97
96
95
94
93
92
91
90
Efficiency
Angles
4°
8°
12°

TABLE IV

Speed	Angle	Loss in Watts	Efficiency	Load in Watts
1000	0	3600	0	4000
	3			4000
	6	3956	.91	4000
800	0	3650	0	4000
	3			4000
	6	3675	.992	4000
650	0	2400	0	4000
	3			4000
	6	2425	.992	4000

TABLE V

Speed	Angle	Loss in Watts	Efficiency	Load in Watts
1000	0	4000	100	4000
	4	4131	.968	4000
	8	4350	.92	4000
800	0	3200	100	4000
	4	3243	.988	4000
	8	3337	.96	4000
	12	3381	.947	4000
650	0	3375	100	4000
	4	3475	.972	4000
	8	3506	.963	4000

RECAPITULATION

In attempting to make this report as full and complete as possible, and show the thoroughness with which the test was carried on, the author has shown some results that would be very apt to be misleading to the reader. It is hoped then by the following to correct any erroneous impressions that may have been obtained from what has gone before and leave with the reader, a lucid, brief but definite understanding of the results and conclusions arrived at in the report.

The time spent on the previous test of the Spicer joints by Mr. Rush and myself, was mostly taken up in getting our testing equipment in proper working order, our object being to get our apparatus so adjusted that a fairly wide range of speeds could be obtained with the different loads at which it was desired to test the joints. After Mr. Rush and myself had gotten our apparatus adjusted as we desired, very little time was left to make a thorough study of the losses in the joints and what data we did obtain was of little value. All the data that were obtained, were taken with the joints in the ninety degree positions, and the method of conducting the test was such, that errors were introduced, which made our results of little scientific value. These facts were brought to light by Mr. Malcolmson and myself in obtaining data for the test covered by this report.

Most of the work and data enclosed in this report, for the part on the Spicer joints, will have to be considered as only a preliminary for the other work. As it was while working with the Spicer joints, that the operators learned how to conduct the test, so that the losses in the joints at different degrees of offset were obtained with the highest degree of accuracy that was possible to obtain with the machines and instruments used in the test.

The data for curves on plates I to VIII were completed by Nov. 8, 1913; such data being taken by the same method as Mr. Rush and I had used on the former test. This method consisted of setting the generator end of the joints at a certain offset and then running through all the different speeds with all the different loads before changing to a new offset.

The curves of plates V to VIII caused an investigation to be made in this method of conducting the test. It was decided to see what results would be obtained by taking one speed and running through a larger range of offsets, varying the loads from zero to 150 amperes. The data for plate IX was obtained Dec. 13, 1913, by using just one speed and running through a large range of off-sets without making any definite stop in the test till the data for the last offset had been obtained. While obtaining the data for plate IX, the fact of cleaning the brushes at definite intervals was presented to us very clearly. Then on Dec. 16, 1913, a test was made using every precaution possible, cleaning the brushes before every reading, and all the data being obtained on that day for the different offsets. Plate X shows these data plotted and curves drawn in. These curves seemed to come out fairly satisfactory, but not as well as should be expected. It was then decided to take the one speed and just one load at any one time and run through the entire range of offsets. This was tried with a zero load, 100 ampere load, and 150 ampere load, and on Jan. 10, 1914, the data for plate XI was obtained. The data for the zero and the 150 ampere loads turned out very unsatisfactory. The instruments used were very sensitive and thus recorded any very slight change that was apt to occur in the speed, line current and voltage, this fact in all probability accounting for our difficulty in obtaining good results at all times. The curves of plate XI showed that we were getting data that was of real value to us.

Plates XII to XV on the Spicer joints are developed from the same data as the curves on plates V to VIII, but show more nearly what is wanted to be shown than the curves on plates V to VIII. The curves as plotted on plates I to VIII amount to more of a comparison of curves for armature reaction and regulation, or simply an electrical test on the machine, the parabolic shape taken by the curves thus being due to armature reaction.

The curves of plates XVI to XVIII are getting at what is wanted and would be of some scientific value, if the data for the curves from which they have been constructed had been taken in the right manner.

The authority for plotting the curves on plates XII to XV, as plotted on these plates, is taken from the curves on plate XIX and also from plate XI.

Thus of all the data tabulated and plotted on the Spicer joints, and a lot that was thrown aside as being entirely worthless, the data from which the curves on plates XI are plotted, are all that can be said to have any real scientific value. After obtaining the data for the curves on plate XI, it was decided to continue the test with Blood Bros. joints, as more time had been consumed with the Spicer joints by far, than had been planned on.

In connecting up Blood Bros. joints, it was noticed that the forks on the intermediate shift did not lie in the same plane, nor in a ninety degree position, but at an angle of about 15 degrees from being in the same plane. No good reason could be advanced for this fact, so it was decided to make a new intermediate shaft, making it possible to connect up the joints either in the same plane, or in a ninety degree position, meanwhile writing to Blood Bros. asking them what position they intended their joints to work in. An answer was received in due time, stating that the forks should be in the same plane as they thought the efficiency of the joints would be affected if this was not the case. The explanation for the forks on the intermediate shaft being in the position as we found them, was due to a misunderstanding of the shop force of Blood Bros.

After running these joints considerable to get them in proper working order, the first useful data was obtained Jan. 17, 1914, which is shown plotted on plate IV. Similar data were tried for with different loads, but it was soon found that these joints would not permit working within the ninety degree position only with a zero load, even then, not at a large offset.

On Jan. 24, Feb. 5, Feb. 7, and Feb. 14, 1914, data were collected for plates I to III, and plates V to VII. These data were all taken by taking one speed and running through all the different offsets and loads while on that particular speed. This method of conducting the test, made it possible to obtain data for the different offsets at which the joints were tested. Under these conditions, a constant set of conditions are maintained, while the data are being taken, as can be accomplished with the equipment used.

The data for the plates VIII to X is obtained from the curves on the plates V to VII, the zero offset reading on the curves of plates V to VII, being taken as the true or perfect condition everytime, then subtracting the readings of total losses at this position from the reading of total losses at the other offsets. These readings were taken directly off the curves, disregarding the points from which the curves were plotted. The curves on plates V to VII were averaged among the points plotted. Subtracting data in this way to get the actual losses, gives a very close determination of what the true losses really are in the joints, and the curves for actual losses as plotted, show that the data thus obtained, approach very closely the actual losses in the joints. By comparing the curves of plates VIII to X on Blood Bros. joints, it is plainly evident that those on Blood Bros. joints show more uniformity than do those on the Spicer joints. The position taken by all the curves shown on Blood Bros., with one or two exceptions, approach conditions that would be expected of the curves, if a correct method of obtaining data for them could be discovered, as was accomplished.

Thus, as has been stated before, all the data taken on the Spicer joints were of no real value with the exception of one plate, plate XI, but the other data served as a guide, so that some general conclusions could be drawn off,and enabled us to strike at the very center of our problem when taking up the test on Blood Bros. joints. If time had permitted, as good results could have been obtained with the Spicer joints as with Blood Bros. joints.

By making a careful study of the curves as plotted on Blood Bros. joints, it can be seen that the losses in the joints are small when operating at a small deflection or offset. With the speed held constant, and deflection likewise, the losses increase as the load increases. Holding the speed constant and also the load on the joints, the losses increase as the deflections increase. Then finally with constant load and constant deflection, the losses increase as the speed increases. These are the same conclusions arrived at on the Spicer joints, even with the poor data obtained on the Spicer joints.

The losses as shown for the Spicer joints are larger than the losses in Blood Bros. joints, with the exception, that at the 800 rev. per minute, the losses are larger for the Blood Bros. joints. But since the losses as shown for the Spicer joints cannot be taken as reliable, it cannot be stated definitely, that the losses in the Spicer joints are larger than those in Blood Bros., but the general trend of the data in the two different makes of joints would seem to give authority enough to say that the losses are larger in the Spicer joints than in Blood Bros. joints.

The Spicer joints can be operated with the forks in the ninety degree position without any serious difficulty, while it is impossible to do so with Blood Bros. joints. The Spicer joints will permit working at larger offsets than Blood Bros. joints, from the nature of their construction.

The problem of obtaining data for an efficiency curve is a very perplexing one in this case. It is impossible to take the loads as expressed in amperes and compare them with the losses expressed in watts or kilowatts, as this would be using two different units, and if the loads are expressed in watts, we never have the same value for any load at any two different times, on account of the voltage varying. Therefore, to express the efficiency of the joints with tabulated data and plotted curves, data will have to be obtained from the curves plotted with the load expressed in watts, and the losses expressed in the same manner. This was the method used, and is explained on page 31 of this report.