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Civil and Environmental Engineering

1995

Hydraulic model study of the powerwheel, July 1995, 62p

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HYDRAULIC MODEL STUDY OF THE POWERWHEEL

by

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July, 1995

Imbt Hydraulics Laboratory Report IHL-143-95

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HYDRAULIC MODEL STUDY OF THE POWERWHEEL

Introduction

The PowerWheel is an advanced overshot water wheel, designed to generate electric power at drop structures on canals or on overflow spillways. Unlike the wheels of the 18^{th} and 19^{th} century which were designed to have maximum efficiency at a single flow rate, the current applications demand a wheel that can operate efficiently over a wide range of flows. The prototype PowerWheel will have a width to diameter ratio of 3 or more, in contrast to the wheels of the 19^{th} century, which had large diameters and narrow widths.

A model PowerWheel was built of plexiglass and delivered for testing to the Imbt Hydraulics Laboratory at Lehigh University. The wheel has a diameter of 3.5 ft and is 16 in wide. The wheel contains 20 buckets and the bucket depth can be varied from a shallow depth of 4 in to a mid depth of 7 in to 10 in for the deep bucket. The blades have a rather simple geometry with a 4 in radius quarter circle at the outside of the wheel and then straight to the bottom of the bucket. The flume in which the wheel was tested has a width of 18 in. The test setup is shown in Figure 1a. A hole was cut in the headbox of the flume and a delivery chute was connected to the head box, Figure 1b. The position of the chute can readily be moved up or down in relation to the wheel; for a fixed position of the chute on the head box, the slope of the chute can be changed because the chute was attached to the head box with a piano hinge. The location of the chute bottom in relation to the wheel top is noted in subsequent tables in this report. The laboratory flow system can deliver flow up to 6 cfs through a calibrated Venturi meter. The PowerWheel was subjected to flows ranging from 0.3 to 3.5 cfs.

An attempt was made to impart kinetic energy of the flow in the chute to the wheel. Thus, the end of the chute is located slightly upstream of the vertical bisector of the wheel and below the top of the wheel. A few tests were run to assess the effect of both the chute slope and the position of the chute in relation to the wheel.

Separate tests were conducted for each of the 3 different bucket depths: shallow, mid, and deep buckets.

A significant innovation in waterwheel technology that was tested was the use of a shroud, Figure 1(a). The shroud fits closely around the lower downstream quadrant of the wheel and prevents water from spilling until a bucket has reached the bottom of the wheel. Table 1 is a summary of all the tests performed.

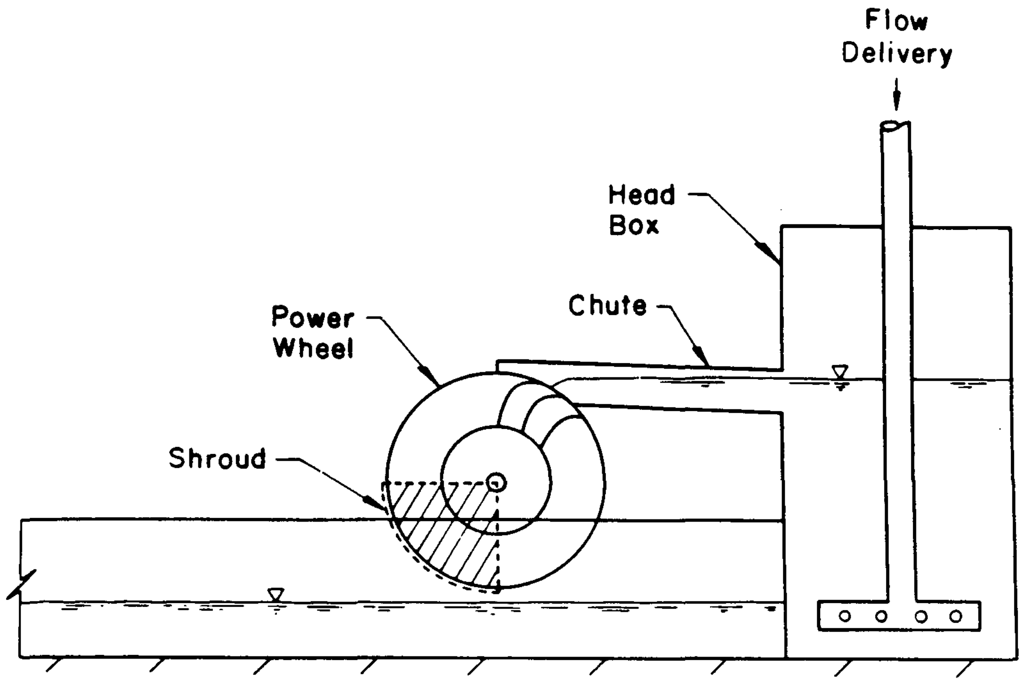


Figure 1(a). Sketch of PowerWheel and the Experimental Setup in Laboratory Flume

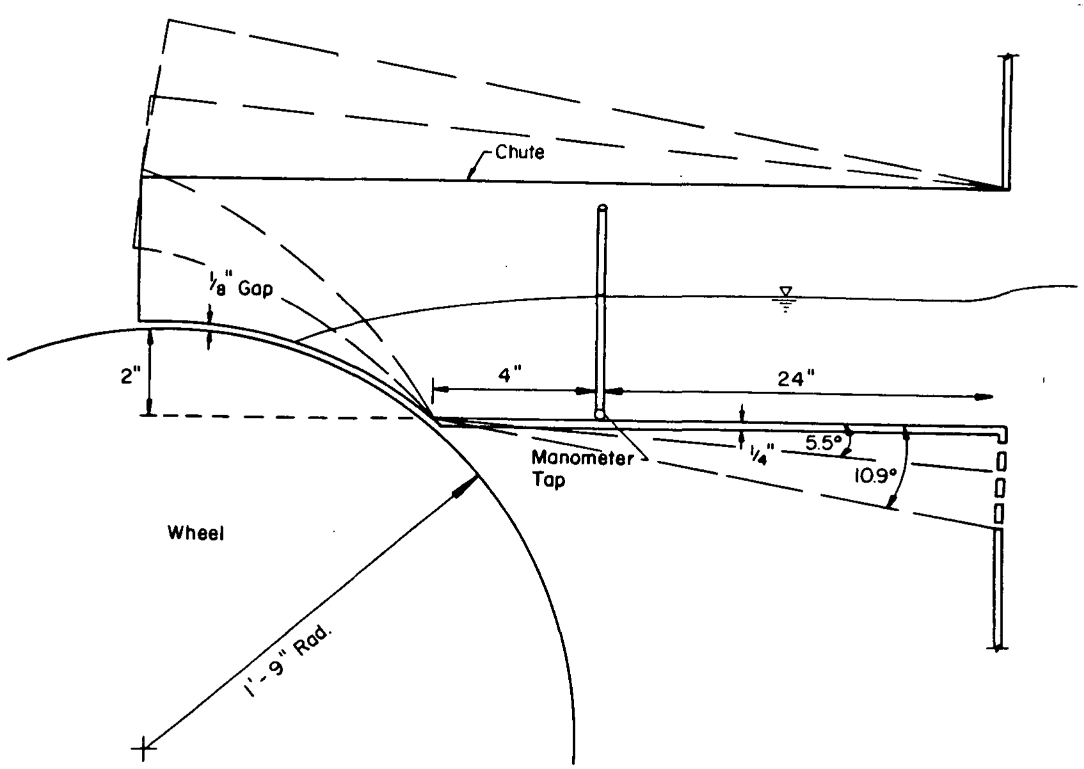


Figure 1(b). Sketch of Chute Dimensions and its Location with respect to the Wheel.

The PowerWheel was connected to a 240 V, 1750 rpm DC motor used as a generator. The connection between the wheel and the generator was through a 2-stage, belt-driven, pulley-wheel speed increasing system with a 90:1 ratio. The generator was connected to a variable load comprised of a bank of electric light bulbs. Various combinations of bulbs could be switched on and off to vary the demand and the speed of the wheel, Figure 2.

In summary, the major variables tested include: (1) the depth of the wheel buckets; (2) geometry of the chute; (3) effect of the shroud, and (4) effect of a wide range of flow rates supplied to the wheel.

The testing of a particular chute configuration with a given bucket depth followed a set procedure. A low flow rate was set and measured with the Venturi meter. The water level in the chute was noted. For the given flow rate, the elective load was then varied in increments. There are 11 sets of light bulbs that can be switched on. Typically, 7 to 9 data points were taken, including generator output voltage and current. The last variable to be measured was the rate of rotation of the wheel. This was accomplished by counting revolutions over a specified time period. The process was repeated for the next flow rate. Table 1 indicates the flow rate increments used. A complete set of data for all 4 tests can be found in Appendix A. Other variables measured or noted during testing include: bucket depth, chute angle and position.

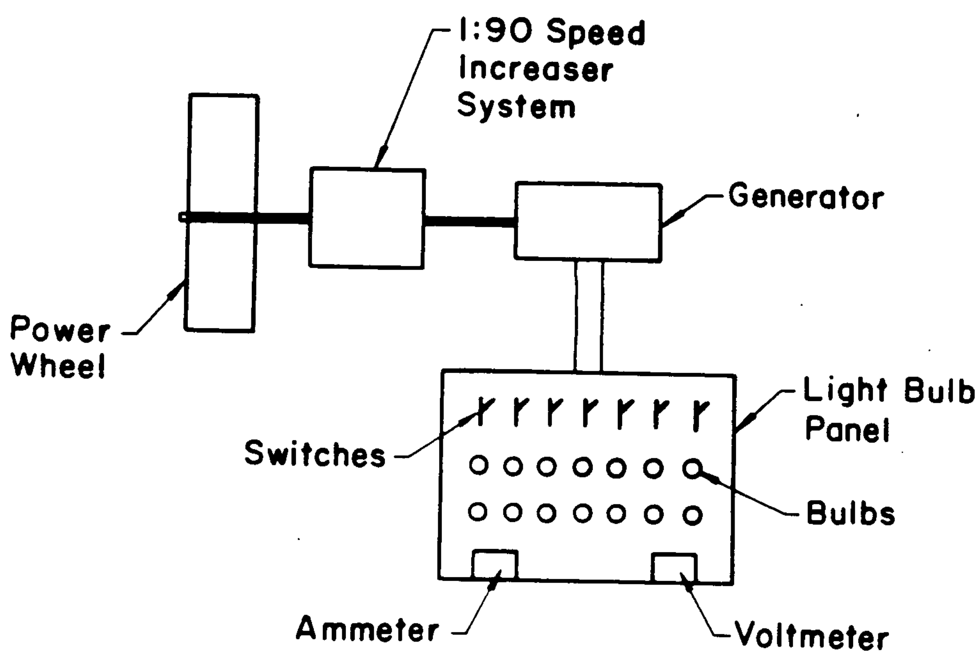


Figure 2. Schematic of PowerWheel, Speed Increaser, Generator, and Load Panel

Table 1: Summary of Tests Conducted with Model PowerWheel

Test	Chute Position	Bucket Depth	Flow Rates (cfs)	Shroud
1	Horizontal, 2 inches below top of wheel	Shallow	0.50, 0.75, 1.00, 1.25, 1.50, 1.75	No
		Mid	0.50, 0.75, 1.00 1.25, 1.50, 1.75	No
		Deep	0.50, 0.75, 1.00, 1.75, 1.50, 1.75	No
2	Slope = 5.5° 1-7/8 inches below top of wheel	Shallow	0.30, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00	No
		Mid	0.30, 0.50, 0.75 1.00, 1.25, 1.50 1.75, 2.00	No
		Deep	0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.25, 2.50, 3.00	No
3	Slope = 10.9° 2 inches below top of wheel	Deep	0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.30	No
4	Slope = 10.9° 2 inches below top of wheel	Deep	0.50, 1.00, 1.50, 2.00	Yes

Results

The data reduction involved calculating rate of rotation of the wheel in rpm and the power output, P_o, of the system (watts = volts x amps). The water power input, P_I, to the system can be calculated using the equation:

$$P_I = Q\gamma H/550$$

where Q is flow rate (cfs), γ is the specific weight of water (62.4 lb/ft^3), and H is the head of the water in the chute relative to the wheel bottom (ft), and P_I is the power in horsepower. The power units are easily converted to kilowatts. The efficiency of the whole system (wheel plus generator) can be assessed by comparing power output to power input. However, a separate test of the motor (generator) characteristics was conducted to assess the efficiency of the generator, which varies with load and rate of rotation (see Appendix B). The effect of motor efficiency on the overall system efficiency is discussed later.

Table 2 shows a typical set of results for Test 4 and a flow rate of 1.5 cfs. As more light bulbs are turned on and the load increases, the rate of rotation of the wheel decreases. The power output increases to a maximum of 203.8 watts and then decreases. This general pattern is typical of other tests.

Table 2: Results for Test 4 and Flow Rate = 1.5 cfs, P_I = 466 watts

Lights On	Volts	Amps	W (rpm)	P_O (watts)
2	187.0	0.75	24.0	140.3
and 1	175.0	0.88	22.9	154.0
and 3	155.2	1.20	21.4	186.2
and 11	148.0	1.34	20.9	198.3
and 4	128.2	1.59	19.7	203.8
and 5	112.5	1.80	19.0	202.5
and 6,7	87.6	2.18	18.5	191.0
and 8,9,10	73.8	2.60	18.6	191.9

Table 3 shows a comparison of results for Tests 1-4. For a flow rate of 1.5 cfs, the data in the table indicates that the power output for the shallow buckets is much less than the mid and deep buckets; the mid and deep buckets yield similar results. Test 4, with the shroud attached to the wheel, yields the largest value of power output and the highest value of total efficiency.

Table 3: Representative Results of Model PowerWheel Tests for Conditions of Maximum Power Output and Efficiency for a Flow Rate = 1.5 cfs

Test	Bucket Depth	P_I (watts)	Maximum P_O (watts)	W (rpm)	e_T %
1	Shallow	456	89.7	17.4	19.7
	Mid	455	157.2	19.4	34.5
	Deep	455	155.0	17.7	34.0
2	Shallow	469	88.7	17.1	18.9
	Mid	469	154.0	17.6	32.8
	Deep	470	160.9	17.4	34.2
3	Deep	469	149.4	17.4	31.9
4	Deep	466	203.8	19.7	43.7

Figure 3 and 4 show graphs of rate of rotation (rpm) on the ordinate and power (watts) output of the system, P_O, on the abscissa for Test 3 and 4, respectively, with flow rate as the third parameter.

Figures 3 and 4 show that power output, P_o, increases with increasing flow rate. Also, for the higher flows, the wheel rate of rotation is around 18 to 20 rpm. A comparison of the two sets of results for deep buckets, with and without the shroud, shows that the shroud causes an increase in power output for all flow rates except the smallest.

Note that efficiency of the whole system is the product of the generator, wheel, and speed increaser efficiencies.

$$e_T = e_G \times e_W \times e_s \qquad (1)$$

From the data, it is obvious that efficiency is very low for shallow buckets compared to mid and deep buckets. For deep buckets, efficiency is highest for flow rates around 2.00 cfs. At higher flows, some of the flow is not effectively captured by the buckets. Note, also, that the tests with the shroud result in the highest total efficiencies.

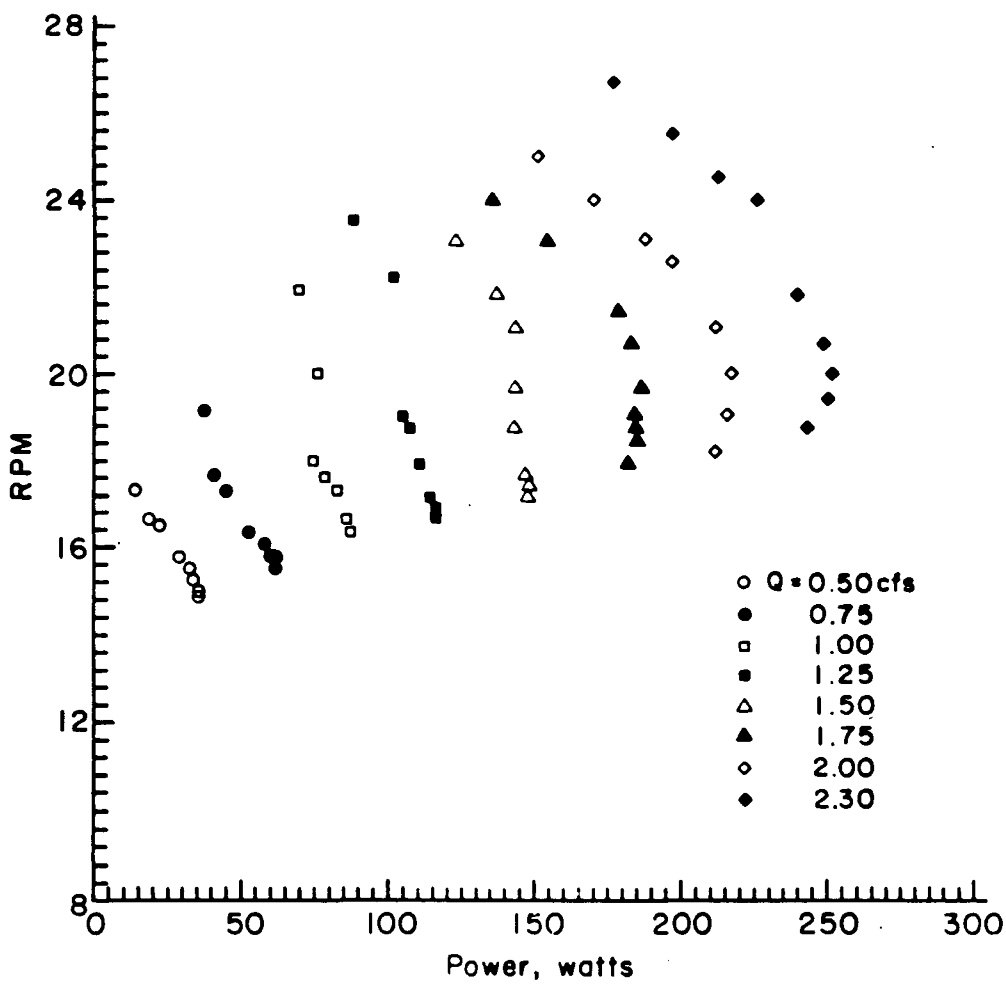


Figure 3. Power Output vs. Rate of Rotation and Flow Rate for Test 3, Deep Buckets and Chute at 10.9°, No Shroud

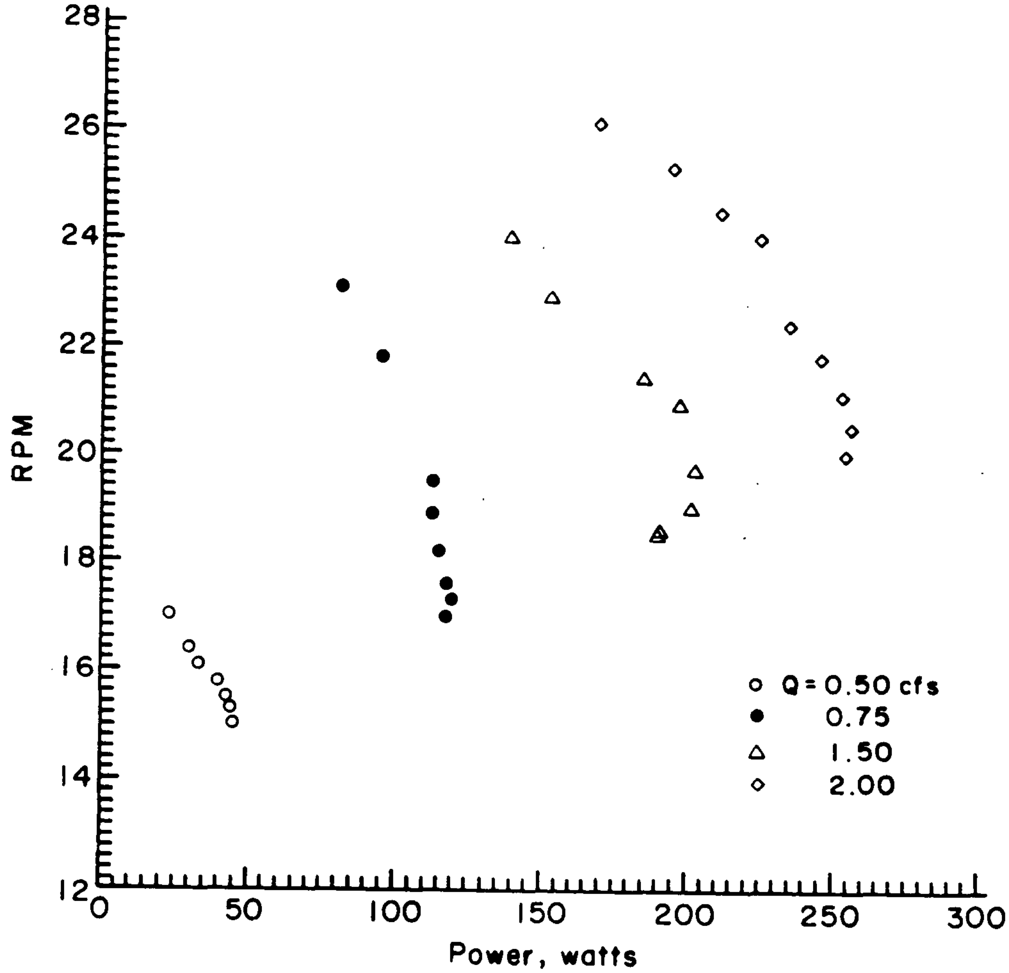


Figure 4. Power Output vs. Rate of Rotation and Flow Rate for Test 3, Deep Buckets and Chute at 10.9°, Shroud Attached

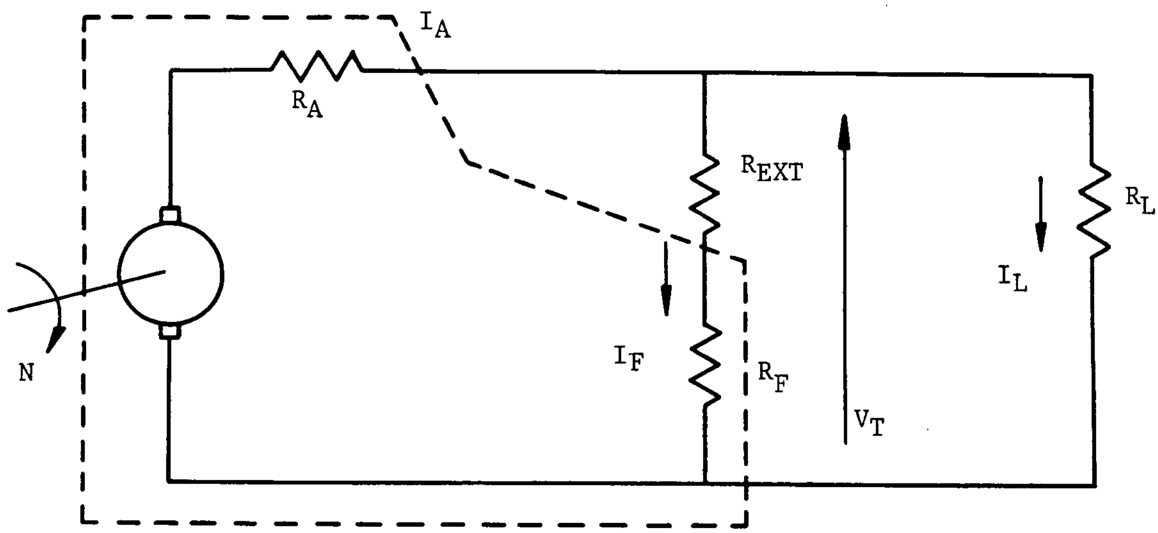
The efficiency of the DC Motor (Generator) was tested in the Electrical Engineering Department of Lehigh University by Professor Donald L. Talhelm.

The test was conducted in the following manner. A three-phase AC induction motor with speed control was used as a motor to drive the DC machine that was used as a generator in the PowerWheel tests. Characteristics of the machine that was tested are as follows:

<u>DC Motor (Generator) Characteristics</u>

Manufacturer	General Electric
Model	5CD14E10A 341610E
Serial Number	ML8-84
Horsepower	1.5
Rated speed	1750 RPM
Rated volts	240
Rated amps - armature	5.4
Rated amps - field	0.33

A diagram showing the circuit used for testing the generator efficiency is shown in Figure 5. Test speeds varied from 1150 to 2150 RPM with armature currents that varied from 0 to 5 amps. The test data are presented in Appendix B.



I_A	=	armature amps	V_T	=	terminal volts
I_F	=	field amps	$V_T I_A$	=	generator power
I_L	=	load amps = $I_A - I_F$	$V_T I_L$	=	load power

Figure 5: Setup for testing the generator efficiency.

The plots of generator efficiency, e_G, vs power (see Appendix B) for a given rate-of-rotation can be used to obtain e_G in Equation (1). The following procedure was used: (i) For a particular value of e_T, note the value of power, P_o; (ii) Using the appropriate graphs in Appendix B of e_G vs P_o, obtain a value of e_G that corresponds to the value of P_o. Interpolation is required in this procedure since the plots in Appendix B show results for generator speeds of 1150, 1250...2350, 2450 rpm. Using a ratio of 90:1 for speeds of generator to PowerWheel, a wheel rate-of-rotation of 23 rpm corresponds to a generator speed of 2070 rpm. Thus, efficiencies could be interpolated from the plots for 2050 and 2150 rpm. Since the 2070 rpm speed required is close to 2050 rpm for which a graph is available, values were obtained from the graph with 2050 rpm. Similarly, for the 20 rpm wheel speed (1800 rpm generator speed), the graph for 1750 rpm was used.

Knowing the total system efficiency, e_T, from the hydraulic tests and assuming the speed increaser efficiency, e_s, is 0.9, the PowerWheel efficiency, e_W, can be calculated from Equation (1). In Table (4), the results of calculation of the PowerWheel efficiency for Tests 3 and 4 with flow rates of 1.0, 1.5, and 2.0 cfs, and rates-of-rotation of 20 and 23 rpm are shown. The data for total system efficiency, e_T, are obtained from the tables in Appendix A. Some estimation is required to obtain a value of e_T that corresponds to the given rate-of-rotation, W. That is, for a given flow rate, the data set may not contain a rate of rotation exactly equal to 20.0 or 23.0 rpm; however, the value of e_T for a value of W within a few tenths of either 20.0 or 23.0 was used. For example, Table 4(b), for W = 23 rpm, shows e_T = 26.4 for a flow rate of Q = 1.5 cfs. In Appendix A, Test 3, the total efficiency for Q = 1.5 cfs is 26.4% when W = 23.08. Hence, the table shows e_T = 26.4% for W = 23 rpm. For the same data point in Appendix A, Test 3, the power out, P_O, is 124.0 watts. Using this value of power and a rate of rotation of 23x90 or 2070 rpm, a value of 68% for generator efficiency is obtained from the figure in Appendix B for W = 2050 rpm.

Table (4) shows the values of wheel efficiency from Equation (1). The highest wheel efficiency is around 80%.

	No Shroud (Test 3)			With Shroud (Test 4)		
Q (cfs)	e_T	e_G	e_W	e_T	e_G	e_W
1.0	25.2	40.0	70.0	36.0	50.0	80.0
1.5	30.9	55.0	62.4	43.5	65.0	74.3
2.0	34.2	68.0	55.9	40.1	70.0	63.6

(a)

	No Shroud			With Shroud		
Q (cfs)	e_T	e_G	e_W	e_T	e_G	e_W
1.0	-	-	-	27.1	59.0	51.1
1.5	26.4	68.0	43.1	33.0	71.0	51.7
2.0	29.6	78.0	42.2	36.5	79.0	51.3

(b)

Table 4: Efficiency of the PowerWheel at various flow rates and rotation rates for Tests 3 and 4 with (a) W = 20 rpm and (b) W = 23 rpm.

Conclusions

- The deepest bucket size provides the maximum power output for all flow rates tested, although the mid size bucket is almost as efficient.

- An upward approach angle of the chute of approximately 5% can increase power output by up to 10% over a horizontal chute at flow rates larger than 1.5 cfs. For smaller flows, there is no discernable difference in power or efficiency between the sloped and horizontal chutes.

- Power output increases with an increase in flow rate from less than 0.5 ft^3/sec to 3.0 ft^3/sec.

- For flows over approximately 2.0 ft^3/sec, the wheel buckets can no longer contain all the flow, and water cascades over the perimeter of the wheel.

- The shroud significantly enhances (18-40%) the power output of the wheel as well as the system efficiency at all but the lowest flow rates tested.

- Over the range of flow rates tested, the maximum power is produced with a rate of rotation of around 20 rpm.

- The test PowerWheel attained efficiencies up to 80% with the shroud.

Acknowledgement

This study was funded by Voith Hydro Inc. of York, PA and was commissioned by PowerWheel Corporation. The technical direction for the testing was provided by Kenneth R. Broome, P.E., Howard A. Mayo, Jr., P.E., and Robert A. Dickie, P.E.

NOTATION

e_G - generator efficiency
e_s - speed increaser efficiency
e_w - wheel efficiency
e_T - total system efficiency

H - head of water, measured from wheel bottom to surface of water in the chute at manometer tap.

P_I - water power input to the wheel
P_o - power output of the system
Q - flow rate
W - rate of rotation of the wheel
γ - specific weight of water

APPENDIX A

TEST DATA

Notation used in the data tables:

DC = depth of water in the chute

e_T = efficiency of the whole system
= P_o/PI

H = total head measured from the wheel bottom to the surface of water in the chute.

P_o = power output of the system

PI = water power to the wheel

Q = flow rate

W = rate of rotation of the wheel

TEST 1: Chute Horizontal and intersects wheel 2 inches below top of wheel with 1/8 inch gap

BUCKETS SHALLOW

Test Data	Lights	Volts	Amps	W(rpm)	P_o(watts)	e_T(%)
Q = 0.5 cfs	1	98.9	0.26	17.9	25.7	17.5
DC = 1-9/16 inch	11	88.6	0.36	17.4	31.9	21.7
H = 3.48 ft	9	69	0.56	16.4	38.6	26.3
PI = 147 watts	10	64	0.64	16	41	27.9
	8	53	0.81	15.8	43	29.3
	7	45.5	0.94	15.6	42.8	29.1
Q = 0.75 cfs	1	129.5	0.32	21.4	41.4	18.6
DC = 1-7/8 inch	11	115	0.42	20	48.3	21.7
H = 3.51 ft	9	89	0.64	18.8	57	25.6
PI = 223 watts	10	81.7	0.73	17.4	59.6	26.7
	8	68	0.92	16.9	62.6	28.1
	7	58.3	1.09	16.4	63.5	28.5
	6	51	1.25	16	63.8	28.6
	5	45.7	1.41	15.8	64.4	28.9
	4,3,2	34.5	1.82	15.2	62.8	28.2
Q = 1 cfs	1	151	0.36	23.5	54.4	18.2
DC = 2-3/16 inch	11	133.8	0.48	21.1	64.2	21.5
H = 3.536 ft	9	102.5	0.72	19	73.8	24.7
PI = 299 watts	10	92.5	0.8	18.2	74	24.7
	8	94.5	0.98	17.1	73	24.4
	7	63.5	1.15	16.4	73	24.4
	6	55.5	1.29	16.2	71.6	23.9
	5,4,3	41.5	1.75	16.2	72.6	24.3
Q = 1.25 cfs	1	165.3	0.38	24	62.8	16.7
DC = 2-1/2 inch	11	146.1	0.5	22.2	73.1	19.4
H = 3.56 ft	9	109.4	0.74	19.4	81.0	21.5
PI = 377 watts	10	99.8	0.83	18.8	82.8	22.0
	8	79.6	1.03	17.6	82.0	21.7
	7	68.2	1.17	17.1	79.8	21.2
	6	58.8	1.34	16.7	78.8	20.9
	5	53.1	1.51	16.6	80.2	21.3
	2,3,4	40.7	1.93	16.6	78.6	20.8

Q = 1.5 cfs	1	177.7	0.41	25	72.9	16.0
DC = 2-7/8 inch	11	153.8	0.53	22.642	81.5	17.9
H = 3.594 ft	9	113.9	0.76	19.672	86.6	19.0
PI = 456 watts	10	103.8	0.85	19.05	88.2	19.3
	8	84.8	1.04	17.91	88.2	19.3
	7	73.5	1.22	17.39	89.7	19.7
	6	63.6	1.38	16.9	87.8	19.2
	5	56.3	1.55	16.67	87.3	19.1
	2,3,4	43.6	2	16.67	87.2	19.1
Q = 1.75 cfs	1	191.4	0.43	26.09	82.3	15.4
DC = 3-1/8 inch	11	163.4	0.55	23.53	89.9	16.8
H = 3.615 ft	9	119.8	0.79	20	94.6	17.7
PI = 535 watts	10	108.9	0.87	19.35	94.7	17.7
	8	87.8	1.06	19.05	93.1	17.4
	7	73.6	1.24	17.39	91.3	17.1
	5,6	57.3	1.57	16.9	90.0	16.8

BUCKETS MID

Q = 0.5 cfs	1	96	0.27	16.9	25.9	17.6
DC = 1-9/16 inch	11	88.3	0.37	16.4	32.7	22.2
H = 3.484 ft	9	69.5	0.58	15.8	40.4	27.5
PI = 147 watts	10	64.2	0.65	15.4	41.7	28.4
	8	53.2	0.82	15.2	43.6	29.7
	7	45.7	0.98	15	44.8	30.5
	6	40.1	1.12	15	44.9	30.5
Q = 0.75 cfs	1	125.8	0.34	20.7	42.8	19.3
DC = 1-13/16 inch	11	112.2	0.44	19.7	49.4	22.3
H = 3.505 ft	9	92.1	0.7	18.2	64.5	29.1
PI = 222 watts	10	86.5	0.78	17.6	67.5	30.4
	8	74	1	16.4	74	33.3
	7	64.5	1.18	16.4	76.1	34.3
	6	56.9	1.34	16.2	76.2	34.3
	5	50.9	1.5	16	76.4	34.4
Q = 1 cfs	1	170.1	0.42	24	71.4	23.9
DC = 2-1/8 inch	11	146.8	0.53	21.8	77.8	26.0
H = 3.531 ft	9	112.6	0.79	19.4	88.9	29.7
PI = 299 watts	10	104.6	0.88	18.8	92	30.8
	8	88.4	1.1	17.9	97.2	32.5
	7	76.5	1.3	17.1	99.5	33.3
	6	68.6	1.48	16.9	101.5	33.9
	5	61.2	1.65	16.7	101	33.8

Q = 1.25 cfs	1	188.7	0.45	25.5	101.6	26.9
DC = 2-1/2 inch	11	175.6	0.6	24	105.4	28.0
H = 3.563 ft	9	134.1	0.88	21.1	118	31.3
PI = 377 watts	10	124	0.97	20	120.3	31.9
	8	103.8	1.2	19	124.6	33.1
	7	89	1.41	18.2	125.5	33.3
	6	79.2	1.6	17.6	126.7	33.6
	5	71.3	1.78	17.4	126.9	33.7
	4	65	1.95	16.9	126.7	33.6

Q = 1.5 cfs	1	200.8	0.47	26.7	94.4	20.7
DC = 2-13/16 inch	11	188.5	0.63	25.5	118.8	26.1
H = 3.589 ft	9	157.4	0.96	23.1	151.1	33.2
PI = 455 watts	10	143.3	1.07	21.8	153.3	33.7
	8	119	1.31	20.3	155.9	34.3
	7	103.4	1.52	19.4	157.2	34.5
	6	90.2	1.73	18.5	156	34.3
	5	80.6	1.93	18.2	155.6	34.2

Q = 1.75 cfs	1	214	0.49	27.9	104.9	19.6
DC = 3-1/8 inch	11	199.7	0.64	26.7	127.8	23.9
H = 3.615 ft	9	170.3	1.01	24	171.7	32.1
PI = 535 watts	10	158	1.12	23.1	176.9	33.1
	8	130.4	1.37	21.1	178.6	33.4
	7	111.1	1.6	20	177.8	33.2
	6	97.2	1.8	19	175	32.7
	5	86.8	2	18.5	173.6	32.4
	4	78	2.15	17.9	167.7	31.3
	3	71.3	2.34	17.6	166.8	31.2

BUCKETS DEEP

Q = 0.5 cfs	1	78.8	0.21	16.2	16.5	11.2
DC = 1-9/16 inch	11	73.3	0.29	15.8	21.3	14.5
H = 3.484 ft	10	67.4	0.36	15.6	24.3	16.5
PI = 147 watts	9	54.4	0.58	15.2	31.6	21.5
	8	45.8	0.75	14.8	34.4	23.4
	7	39.3	0.89	14.6	35	23.8
	6	34.5	1.03	14.6	35.5	24.1

Q = 0.75 cfs	1	126	0.33	20.3	41.6	18.7
DC = 1-7/8 inch	11	103	0.41	18.2	42.2	18.9
H = 3.510 ft	10	90.7	0.49	17.4	44.4	19.9
PI = 223 watts	9	76	0.72	16.7	54.7	24.5
	8	66.4	0.92	16.2	61.1	27.4
	7	58.1	1.09	15.8	63.3	28.4
	6	51.7	1.25	15.6	64.6	29.0
	5	46.5	1.4	15.4	65.1	29.2

Q = 1 cfs	1	167.6	0.4	23.1	67	22.4
DC = 2-1/4 inch	11	145.4	0.52	21.1	75.6	25.3
H = 3.542 ft	10	123.2	0.59	19.7	72.7	24.3
PI = 299 watts	9	94.4	0.8	17.6	75.5	25.3
	8	80.8	1.02	17.1	82.4	27.6
	7	71.3	1.21	16.4	86.3	28.9
	6	63.5	1.42	16	90.2	30.2
	5	57.5	1.59	15.7	91.4	30.6
	4	52.5	1.73	15.7	90.8	30.4
	3	48.4	1.89	15.7	91.5	30.6
Q = 1.25 cfs	1	186.2	0.44	24.5	81.9	21.7
DC = 2-9/16 inch	11	173.2	0.58	23.5	100.5	26.7
H = 3.568 ft	10	157	0.71	22.2	111.5	29.6
PI = 377 watts	9	119.6	0.94	19.4	112.4	29.8
	10	98.5	1.16	18.2	114.3	30.3
	9	86.5	1.37	17.4	118.5	31.4
	8	77.3	1.57	16.9	121.4	32.2
	7	69.5	1.75	16.9	121.6	32.3
Q = 1.5 cfs	1	199	0.45	25.5	89.6	19.7
DC = 2-13/16 inch	11	187.6	0.62	24.5	115.9	25.5
H = 3.589 ft	10	177.3	0.76	23.5	134.7	29.6
PI = 455 watts	9	144.8	1.05	21.1	152	33.4
	8	118.2	1.29	19.7	152.5	33.5
	7	101.5	1.52	18.8	154.3	33.9
	6	90.3	1.7	17.9	153.5	33.7
	5	81.5	1.9	17.7	154.9	34.0
Q = 1.75 cfs	1	213.2	0.49	26.7	104.5	19.5
DC = 3-3/16 inch	11	200.3	0.67	25.5	134.2	25.0
H = 3.620 ft	10	190	0.81	24.5	153.9	28.7
PI = 536 watts	9	164.5	1.15	23.1	189.2	35.3
	8	137.4	1.42	20	195.1	36.4
	7	118	1.65	19.7	194.7	36.3
	6	104.5	1.86	18.8	194.4	36.3
	5	94	2.07	18.5	194.6	36.3

TEST 2: Chute on 5.5 degree slope and intersects wheel
1-7/8 inches below top of wheel with 1/8 inch gap

BUCKETS SHALLOW

Test Data	Lights	Volts	Amps	W(rpm)	P_o (watts)	e_T(%)
Q = 0.3 cfs	1	54.5	0.17	14.9	9.3	10.7
DC = 2-1/4 inch	11	48.8	0.24	14.8	11.7	13.4
H = 3.453 ft	9	37.8	0.4	14.3	15.1	17.4
PI = 87 watts	10	34.5	0.45	14.2	15.5	17.8
	8	28.2	0.58	13.8	16.4	18.9
	7	23.8	0.71	13.6	16.9	19.4
	6	20	0.82	13.5	16.4	18.9
	5	17.8	0.94	13.2	16.7	19.2
Q = 0.5 cfs	1	97	0.29	18.2	28.1	19.0
DC = 2-15/16 inch	11	86.5	0.38	17.1	32.9	22.2
H = 3.510 ft	9	68.2	0.58	16.4	39.6	26.8
PI = 148 watts	10	63.2	0.65	16.1	41.1	27.8
	8	53	0.82	15.8	43.5	29.4
	7	45.7	0.97	15.5	44.3	29.9
	6	40	1.12	15.3	44.8	30.3
	5	35.5	1.25	15.3	44.4	30.0
Q = 0.75 cfs	1	128.5	0.36	19.7	46.3	20.5
DC = 3-9/16 inch	11	114.5	0.46	18.5	52.7	23.3
H = 3.563 ft	9	89	0.68	17.1	60.5	26.8
PI = 226 watts	10	82	0.76	16.7	62.3	27.6
	8	68.2	0.95	16.4	64.8	28.7
	7	59	1.12	16.1	66.1	29.2
	6	51.8	1.27	15.8	65.8	29.1
	5	46.5	1.43	15.8	66.5	29.4
	2,3,4	35.2	1.85	15.8	65.1	28.8
Q = 1 cfs	1	145	0.4	20.7	58	19.0
DC = 4-1/16 inch	11	128	0.5	19	64	21.0
H = 3.604 ft	9	98.4	0.73	17.6	71.8	23.5
PI = 305 watts	10	90.8	0.81	17.1	73.5	24.1
	8	76.2	1.01	16.7	76.9	25.2
	7	64.7	1.18	16.4	76.3	25.0
	6	56.7	1.34	16.1	76	24.9
	5	50.5	1.49	16.1	75.2	24.7
	2,3,4	38.5	1.92	15.8	73.9	24.2

Q = 1.25 cfs	1	156.5	0.43	20.7	67.3	17.4
DC = 4-5/8 inch	11	137	0.53	20	72.6	18.8
H = 3.651 ft	9	103.8	0.75	17.9	77.9	20.2
PI = 386 watts	10	95.2	0.83	17.4	79	20.5
	8	79	1.03	17.1	81.4	21.1
	7	67	1.2	16.4	80.4	20.8
	6	59	1.37	16.4	80.8	20.9
	5,4	48	1.67	16.1	80.2	20.8
	3,2	40.3	1.95	16.1	78.6	20.4
Q = 1.5 cfs	1	169.5	0.45	22.6	76.3	16.3
DC = 5-3/16 inch	11	148.5	0.56	21.1	83.2	17.7
H = 3.698 ft	9	111.5	0.79	18.8	88.1	18.8
PI = 469 watts	10	101.7	0.87	18.2	88.5	18.9
	8	83.5	1.06	17.5	88.5	18.9
	7	71.5	1.24	17.1	88.7	18.9
	6	62.6	1.41	16.9	88.3	18.8
	5,4	51.3	1.73	16.7	88.7	18.9
	3,2	42.8	2.01	16.5	86	18.3
Q = 1.75 cfs	1	177.5	0.47	23.1	83.4	15.1
DC = 5-5/8 inch	11	154	0.58	21.1	89.3	16.1
H = 3.734 ft	9	113.5	0.8	18.5	90.8	16.4
PI = 553 watts	10	102	0.88	18	89.8	16.2
	8	84.8	1.08	17.6	91.6	16.6
	7	71.8	1.25	17.1	89.8	16.2
	6	63.3	1.42	16.8	89.9	16.3
	5,4	51.5	1.73	16.7	89.1	16.1
	3,2	43.5	2.02	16.7	87.9	15.9
Q = 2 cfs	1	186.5	0.48	23.8	89.5	14.1
DC = 6 inch	11	158	0.59	21.4	93.2	14.6
H = 3.766 ft	9	115.3	0.81	18.8	93.4	14.7
PI = 637 watts	10	105	0.89	18.2	93.5	14.7
	8	87.5	1.09	17.9	95.4	15.0
	7	74	1.27	17.1	94	14.8
	6	64.3	1.42	16.9	91.3	14.3
	5,4	53	1.77	17.1	93.8	14.7
	3,2	43	2.02	16.5	86.9	13.6

BUCKETS MID

Q = 0.3 cfs	1	50.3	0.16	15	8	9.1
DC = 2-5/16 inch	11	44.9	0.22	14.5	9.9	11.3
H = 3.458 ft	9	33.2	0.37	14.1	12.3	14.0
PI = 88 watts	10	31.4	0.42	13.8	13.2	15.0
	8	26	0.55	13.6	14.3	16.3
	7	22.2	0.68	13.4	15.1	17.2
	6,5	17.1	0.91	13.1	15.6	17.7
	4,3	13.8	1.12	12.9	15.5	17.6

Q = 0.5 cfs	1	97.3	0.28	17.6	27.2	22.2
DC = 2-15/16 inch	11	89	0.37	17.1	32.9	29.4
H = 3.510 ft	9	72.5	0.6	16.4	43.5	30.2
PI = 148 watts	10	67.7	0.66	16.1	44.7	31.2
	8	56.4	0.82	15.8	46.2	32.7
	7	48.4	1	15.5	48.4	32.7
	6,5	37.8	1.28	15.5	48.4	31.8
	4,3	30.8	1.53	15.1	47.1	0.0

Q = 0.75 cfs	1	129.5	0.36	19.7	46.6	20.6
DC = 3-9/16 inch	11	116.5	0.47	18.8	54.8	24.2
H = 3.563 ft	9	94.3	0.7	17.4	66	29.2
PI = 226 watts	10	88.5	0.79	17.1	69.9	30.9
	8	75.5	0.99	16.7	74.7	33.1
	7	65.7	1.17	16.4	76.9	34.0
	6	58.3	1.33	16.1	77.5	34.3
	5,4	47.3	1.64	15.9	77.6	34.3
	3,2	40.2	1.94	15.8	77.9	34.5

Q = 1 cfs	1	167.8	0.44	22.2	73.8	24.2
DC = 4-1/8 inch	11	145	0.54	20.3	78.3	25.7
H = 3.609 ft	9	115	0.79	18.5	90.9	29.8
PI = 305 watts	10	106.5	0.89	17.9	94.8	31.1
	8	90.5	1.1	17.4	99.6	32.7
	7	79.5	1.3	17	103.4	33.9
	6,5	63	1.65	16.7	104	34.1
	4,3,2	48.8	2.13	16.4	103.9	34.1

Q = 1.25 cfs	1	184.5	0.47	23.5	86.7	22.5
DC = 4-5/8 inch	11	170.5	0.61	22.2	104	26.9
H = 3.651 ft	9	134.5	0.88	19.7	118.4	30.7
PI = 386 watts	10	124.5	0.98	19.2	122	31.6
	8	105.5	1.2	18.5	126.6	32.8
	7	92	1.41	17.8	129.7	33.6
	6	81.7	1.61	17.4	131.5	34.1
	5,4	67	1.96	17.3	131.3	34.0
	3,2	57	2.28	17	129.9	33.7

Q = 1.5 cfs	1	196.8	0.5	24.5	98.4	21.0
DC = 5-1/8 inch	11	185.5	0.65	23.5	120.6	25.7
H = 3.693 ft	9	151.8	0.95	20.9	144.2	30.7
PI = 469 watts	10	139.5	1.05	20	146.5	31.2
	8	117.5	1.28	19	150.4	32.1
	7	102	1.5	18.5	153	32.6
	6	90.3	1.7	17.9	153.5	32.7
	5,4	74	2.08	17.6	153.9	32.8
	3,2	63	2.42	16.7	152.5	32.5
Q = 1.75 cfs	1	209	0.52	25.5	108.7	19.6
DC = 5-3/4 inch	11	195.5	0.67	24.5	130.9	23.6
H = 3.745 ft	10	183	0.8	23.4	146.4	26.4
PI = 554 watts	9	150.5	1.1	21.1	165.6	29.9
	8	125.5	1.33	19.7	166.9	30.1
	7	108.3	1.54	18.9	166.8	30.1
	6,5	86.5	1.96	18.4	169.5	30.6
	4,3,2	66.7	2.48	17.9	165.4	29.9
Q = 2 cfs	1	222	0.53	26.7	117.7	18.5
DC = 5-7/8 inch	11	204.5	0.68	25.5	139.1	21.9
H = 3.755 ft	9	174.5	1.03	22.9	179.7	28.3
PI = 635 watts	8	160.5	1.14	21.8	182.9	28.8
	7	133.5	1.38	20	184.2	29.0
	6,5	101	1.81	19	182.8	28.8
	4,3	81.3	2.18	18.2	177.2	27.9
	3,2	69.7	2.55	18.2	177.7	28.0

BUCKETS DEEP

Q = 0.5 cfs	1	88.3	0.25	16.9	22.2	14.9
DC = 3 inch	11	81.8	0.35	16.4	28.6	19.2
H = 3.516 ft	9	66	0.57	15.9	37.6	25.2
PI = 149 watts	8	55.3	0.74	15.5	40.9	27.4
	10	52.5	0.79	15.4	41.5	27.9
	7,6	39.5	1.09	15.2	43	28.9
Q = 0.75 cfs	1	121.5	0.33	18.8	40.1	17.7
DC = 3-1/2 inch	11	103.8	0.41	17.6	42.6	18.8
H = 3.557 ft	9	85.7	0.65	16.8	55.7	24.6
PI = 226 watts	10	80.9	0.74	16.7	59.9	26.5
	8	69	0.93	16.2	64.2	28.4
	7,6	53.2	1.26	16.1	67	29.6
	5,4	43.6	1.57	15.6	68.5	30.3
	3,2	36.9	1.85	15.5	68.3	30.2

Q = 1 cfs	1	162.6	0.42	21.8	68.3	22.4
DC = 4-1/16 inch	11	137.8	0.52	19.7	71.7	23.5
H = 3.604 ft	9	106.2	0.75	17.9	79.7	26.1
PI = 305 watts	10	99.5	0.85	17.5	84.6	27.7
	8	85	1.06	17.1	90.1	29.5
	7	75	1.26	16.7	94.5	31.0
	6	66.6	1.44	16.4	95.9	31.4
	5,4	54.5	1.78	16.4	97	31.8
	3,2	46.3	2.07	16.2	95.8	31.4
Q = 1.25 cfs	1	183.5	0.47	23.5	86.2	22.3
DC = 4-5/8 inch	11	168.4	0.6	22	101	26.2
H = 3.651 ft	9	128.1	0.85	19	108.9	28.2
PI = 386 watts	10	118.3	0.95	18.6	112.4	29.1
	8	100	1.17	17.9	117	30.3
	7,6	78.3	1.59	17.8	124.5	32.3
	5,4	64.8	1.96	16.8	127	32.9
	3,2	55.5	2.28	16.7	126.5	32.8
Q = 1.5 cfs	1	201.5	0.51	25	102.7	21.9
DC = 5-1/4 inch	11	185.7	0.65	23.5	120.7	25.7
H = 3.703 ft	9	151.7	0.96	20.7	145.6	31.0
PI = 470 watts	10	140.5	1.06	20	148.9	31.7
	8	118	1.31	18.9	154.6	32.9
	7,6	92	1.74	17.9	160.1	34.1
	5,4	76.3	2.11	17.4	160.9	34.2
	3,2	64.9	2.48	17.4	160.9	34.2
Q = 1.75 cfs	1	215	0.55	26.1	118.3	21.4
DC = 5-9/16 inch	11	198.7	0.76	24.7	151	27.4
H = 3.729 ft	9	172.4	1.14	22.9	196.5	35.6
PI = 552 watts	10	159	1.32	21.8	210	38.0
	8	133.8	1.6	20.3	214.1	38.8
	7,6	103.5	1.82	19	188.4	34.1
	5,4	85.2	2.24	18.4	190.8	34.6
	3,2	69.7	2.55	18.4	177.7	32.2
Q = 2 cfs	1	231.7	0.55	27.3	127.4	20.0
DC = 5-15/16 inch	11	214	0.72	26.1	154.1	24.2
H = 3.760 ft	9	185.7	1.08	23.5	200.6	31.5
PI = 636 watts	10	175.8	1.22	22.9	214.5	33.7
	7,8	131.5	1.74	20	228.8	36.0
	6	116.5	1.97	19.4	229.5	36.1
	5,4	96.8	2.4	18.6	232.3	36.5
	3,2	82.4	2.77	18.2	228.2	35.9

Q = 2.25 cfs	1	248.5	0.59	28.6	146.6	20.4
DC = 6-1/8 inch	11	228.5	0.75	26.9	171.4	23.8
H = 3.776 ft	9	197	1.11	24.2	218.7	30.4
PI = 719 watts	10	186	1.26	23.5	234.4	32.6
	8	161	1.56	21.8	251.2	34.9
	7	141	1.81	20.5	255.2	35.5
	6	124.3	2.04	19.7	253.6	35.3
	5,4	101.3	2.46	19	249.2	34.7
	3,2	85.2	2.83	18.6	241.1	33.5
Q = 2.5 cfs	2	237	0.86	27.9	203.8	25.2
DC = 6-3/4 inch	1	219.5	1	26.7	219.5	27.1
H = 3.828 ft	11	207	1.14	25.5	236	29.1
PI = 810 watts	10	197	1.31	24.5	258.1	31.9
	9	172	1.62	22.6	278.6	34.4
	8	149.8	1.89	21.2	283.1	35.0
	7,6	114	2.3	19.7	262.2	32.4
	5,4	95	2.7	19	256.5	31.7
	3	85.5	2.85	18.5	243.7	30.1
Q = 3 cfs	2	249	0.91	29.3	226.6	22.8
DC = 7-3/4 inch	1	233	1.04	27.6	242.3	24.4
H = 3.911 ft	10,11	201	1.32	25	265.3	26.7
PI = 993 watts	9	175	1.64	23.1	287	28.9
	8	153	1.9	21.6	290.7	29.3
	7	132	2.1	20.3	277.2	27.9
	6,5	101	2.48	19.4	250.5	25.2
	4,3	85	2.84	18.8	241.4	24.3

TEST 3: Chute on 10.9 degree slope and intersects wheel
2 inches below top of wheel with 1/8 inch gap

BUCKETS DEEP

Test Data	Lights	Volts	Amps	W(rpm)	P_o (watts)	e_T(%)
Q = 0.5 cfs	1	67.3	0.21	17.31	14.1	9.5
DC = 3-7/16 inch	11	63.8	0.3	16.67	19.1	12.9
H = 3.50 ft	10	60.3	0.38	16.51	22.9	15.5
PI = 148 watts	9	51.8	0.57	15.79	29.5	20.0
	8	44.7	0.74	15.52	33.1	22.4
	7	39.1	0.88	15.25	34.4	23.2
	6	34.8	1.04	15	36.2	24.5
	5	31	1.17	14.88	36.3	24.5
Q = 0.75 cfs	1	115.5	0.33	19.15	38.1	16.9
DC = 4-1/8 inch	11	100.2	0.41	17.65	41.1	18.2
H = 3.557 ft	10	90.8	0.5	17.31	45.4	20.1
PI = 226 watts	9	75	0.71	16.36	53.3	23.6
	8	64.9	0.9	16.07	58.4	25.8
	7	56.7	1.07	15.79	60.7	26.8
	6,5	44.9	1.39	15.79	62.4	27.6
	4,3	37.3	1.66	15.52	61.9	27.4
Q = 1 cfs	1	163.8	0.43	21.95	70.4	23.1
DC = 4-3/4 inch	11	142.5	0.54	20	77.0	25.2
H = 3.609 ft	9	101.3	0.74	18	75.0	24.6
PI = 305 watts	10	94.7	0.83	17.65	78.6	25.8
	8	80.6	1.03	17.31	83.0	27.2
	7	70.6	1.22	16.67	86.1	28.2
	6,5	56.8	1.55	16.36	88.0	28.9
	4,3,2	43.3	2.02	16.67	87.5	28.7
Q = 1.25 cfs	1	185.9	0.48	23.53	89.2	23.1
DC = 5-1/4 inch	11	168.4	0.61	22.22	102.7	26.6
H = 3.651 ft	9	125.5	0.84	19.05	105.4	27.3
PI = 386 watts	10	116	0.93	18.75	107.9	27.9
	8	96.7	1.15	17.91	111.2	28.8
	7,6	75	1.53	17.14	114.8	29.7
	5,4	62	1.89	16.9	117.2	30.4
	3,2	52.7	2.22	16.67	117.0	30.3
Q = 1.5 cfs	2	174.6	0.71	23.08	124.0	26.4
DC = 5-3/4 inch	1	162.5	0.85	21.82	138.1	29.5
H = 3.693 ft	11	151	0.96	21.05	145.0	30.9
PI = 469 watts	3	121.5	1.19	19.67	144.6	30.8
	10	114.5	1.26	18.75	144.3	30.8
	9	99.2	1.49	17.65	147.8	31.5
	9	87.7	1.69	17.65	148.2	31.6
	7,6	72.5	2.06	17.39	149.4	31.8
	5,4	61.7	2.41	17.14	148.7	31.7

Q = 1.75 cfs	2	187.5	0.73	24	136.9	24.8
DC = 6-1/4 inch	1	176.5	0.88	23.08	155.3	28.1
H = 3.734 ft	3	151	1.19	21.43	179.7	32.5
PI = 553 watts	11	143	1.29	20.69	184.5	33.4
	4	122	1.54	19.67	187.9	34.0
	10	114.5	1.62	19.05	185.5	33.5
	9	101	1.84	18.75	185.8	33.6
	8,7	84	2.22	18.46	186.5	33.7
	6,5	71	2.58	17.91	183.2	33.1
Q = 2 cfs	2	201	0.76	25	152.8	23.9
DC = 6-3/4 inch	1	188.7	0.91	24	171.7	26.9
H = 3.776 ft	11	180	1.05	23.08	189.0	29.6
PI = 639 watts	10	168	1.18	22.6	198.2	31.0
	9	146	1.46	21.05	213.2	33.4
	8	127	1.72	20	218.4	34.2
	7,6	101	2.15	19.05	217.2	34.0
	5,4,3	79	2.69	18.2	212.5	33.3
Q = 2.3 cfs	2	218	0.82	26.7	178.8	24.1
DC = 7-1/4 inch	1	205.3	0.97	25.5	199.1	26.8
H = 3.818 ft	11	195	1.1	24.5	214.5	28.9
PI = 743 watts	10	183.5	1.24	24	227.5	30.6
	9	157	1.54	21.82	241.8	32.5
	8	139	1.8	20.7	250.2	33.7
	7	123.5	2.05	20	253.2	34.1
	6,5	101.5	2.48	19.4	251.7	33.9
	4,3	85.5	2.86	18.75	244.5	32.9

TEST 4: Wheel with shroud; chute with 10.9 degree angle and intersects wheel 2 inches below top with 1/8 inch gap

BUCKETS DEEP

Test Data	Lights	Volts	Amps	W(rpm)	P_o (watts)	e_T(%)
Q = 0.5 cfs	1	90.3	0.26	17	23.5	17.2
DC = 3-7/16 inch	11	84.1	0.36	16.4	30.3	22.1
H = 3.250 ft	10	77	0.44	16.1	33.9	24.7
PI = 137 watts	9	62.7	0.64	15.8	40.1	29.3
	8	53	0.81	15.5	42.9	31.3
	7	46.1	0.96	15.3	44.3	32.3
	6	40.5	1.11	15.1	44.9	32.8
	5	36.3	1.25	15	45.4	33.1
Q = 1.0 cfs	1	179	0.46	23.1	82.3	27.1
DC = 4-1/2 inch	11	163.1	0.59	21.8	96.2	31.6
H = 3.588 ft	9	130.5	0.87	19.5	113.5	37.3
PI = 304 watts	10	119.4	0.95	18.9	113.4	37.3
	8	99.2	1.17	18.2	116.1	38.2
	7	86.3	1.37	17.6	118.2	38.9
	6,5	69	1.74	17.3	120.1	39.5
	4,3,2	53.3	2.22	17	118.3	38.9
Q = 1.5 cfs	2	187	0.75	24	140.3	30.1
DC = 5-1/2 inch	1	175	0.88	22.9	154.0	33.0
H = 3.672 ft	3	155.2	1.2	21.4	186.2	40.0
PI = 466 watts	11	148	1.34	20.9	198.3	42.6
	4	128.2	1.59	19.7	203.8	43.7
	5	112.5	1.8	19	202.5	43.5
	6,7	87.6	2.18	18.5	191.0	41.0
	8,9,10	73.8	2.6	18.6	191.9	41.2
Q = 2 cfs	2	213.5	0.8	26.1	170.8	26.8
DC = 6-5/8 inch	1	204.5	0.96	25.3	196.3	30.8
H = 3.766 ft	11	193.5	1.1	24.5	212.9	33.4
PI = 637 watts	10	184.5	1.23	24	226.9	35.6
	9	154.5	1.53	22.4	236.4	37.1
	8	138	1.79	21.8	247.0	38.8
	7	124	2.05	21.1	254.2	39.9
	6,5	103.5	2.49	20.5	257.7	40.5
	4,3	88.7	2.88	20	255.5	40.1

APPENDIX B

GENERATOR TEST DATA

Generator Test Data

Machine under test: General Electric Co. Model 5cd14E10A341610E
Serial Number ML8-84
1.5 HP, 1750 RPM
240 Volts, Arm. Amps 5.4, Fld. Amps 0.33

1150 RPM

Friction and Lamp Bank No	Windage Windage Term. Vol	Arm. Amps	20 Watts Field Amps	Load Amps	Armature Resistanc Generato Power	Load Power	3 Ohms Efficiency
0	84	0.12	0.12	0.00	10	0	0.00
1	84	0.23	0.12	0.11	19	9	0.23
1+11	83	0.33	0.12	0.21	27	17	0.36
2	81	0.51	0.12	0.39	41	31	0.50
3	79	0.79	0.11	0.68	62	52	0.62
4	77	1.05	0.11	0.94	81	69	0.67
5	75	1.31	0.11	1.20	98	85	0.69
6	73	1.57	0.11	1.46	115	100	0.70
7	71	1.79	0.10	1.69	127	111	0.71
8	69	2.05	0.10	1.95	141	123	0.70
9	67	2.28	0.10	2.18	153	131	0.70
10	66	2.46	0.10	2.36	162	138	0.69
11	65	2.55	0.10	2.45	166	141	0.68

1250 RPM

Friction And Lamp Bank No	Windage Term. Volts	Arm. Amps	20 Watts Field Amps	Load Amps	Armature Resistanc Generato Power	Load Power	3 Ohms Efficiency
0	111	0.15	0.15	0	17	0	0.00
1	110	0.28	0.15	0.13	31	14	0.28
1+11	109	0.41	0.15	0.26	45	28	0.43
2	107	0.61	0.15	0.46	65	49	0.57
3	105	0.93	0.15	0.78	98	82	0.68
4	103	1.25	0.14	1.11	129	114	0.75
5	102	1.55	0.14	1.41	158	144	0.78
6	100	1.86	0.14	1.72	186	172	0.79
7	98	2.16	0.14	2.02	212	198	0.81
8	96	2.45	0.14	2.31	235	222	0.81
9	94	2.74	0.13	2.61	258	245	0.82
10	93	2.96	0.13	2.83	275	263	0.82
11	93	3.07	0.13	2.94	286	273	0.82

1350 RPM

Friction And Windage			20 Watts		Armature		3 Ohms
Lamp Bank No	Term. Volts	Arm. Amps	Field Amps	Load Amps	Generato Power	Load Power	Efficiency
0	120	0.16	0.16	0	19	0	0.00
1	119	0.30	0.16	0.14	36	17	0.30
1+11	119	0.44	0.16	0.28	52	33	0.46
2	118	0.65	0.16	0.49	77	58	0.59
3	117	0.99	0.16	0.83	116	97	0.70
4	116	1.32	0.16	1.16	153	135	0.75
5	115	1.67	0.16	1.51	192	174	0.79
6	114	2.01	0.16	1.85	229	211	0.81
7	113	2.33	0.16	2.17	263	245	0.82
8	112	2.67	0.15	2.52	299	282	0.83
9	111	2.99	0.15	2.84	332	315	0.83
10	110	3.24	0.15	3.09	356	340	0.83
11	110	3.37	0.15	3.22	371	354	0.83

1450 RPM

Friction And Windage			20 Watts		Armature Resistanc		3 Ohms
Lamp Bank No	Term. Volts	Arm. Amps	Field Amps	Load Amps	Generato Power	Load Power	Efficiency
0	149	0.20	0.20	0.00	30	0	0.00
1	147	0.35	0.20	0.15	51	23	0.32
11	146	0.50	0.19	0.31	73	45	0.48
10	144	0.80	0.19	0.61	115	88	0.64
9	143	1.17	0.19	0.98	167	140	0.73
8	142	1.55	0.19	1.36	220	193	0.78
7	141	1.92	0.19	1.73	271	244	0.81
6	139	2.30	0.18	2.12	320	294	0.83
5	137	2.67	0.18	2.49	366	341	0.84
4	136	3.02	0.18	2.84	411	386	0.84
3	135	3.37	0.18	3.19	455	431	0.85
2	134	3.71	0.18	3.54	497	474	0.85

1550 RPM

Friction And Windage 20 Watts

Armature Resistanc 3 Ohms

Lamp Bank No	Term. Volts	Arm. Amps	Field Amps	Load Amps	Gerator Power	Load Power	Efficiency
0	162	0.21	0.21	0.00	34	0	0.00
1	161	0.37	0.21	0.16	60	26	0.33
11	160	0.54	0.21	0.33	86	53	0.50
10	159	0.84	0.21	0.64	134	101	0.65
9	158	1.25	0.20	1.05	198	165	0.74
8	156	1.64	0.20	1.44	256	224	0.79
7	155	2.03	0.20	1.83	315	284	0.82
6	154	2.53	0.20	2.33	390	359	0.84
5	153	2.81	0.20	2.61	430	400	0.84
4	152	3.21	0.20	3.01	488	458	0.85
3	151	3.61	0.19	3.42	545	516	0.85
2	149	3.95	0.19	3.76	589	560	0.85

1650 RPM

Friction And Windage 20 Watts

Armature Resistanc 3 Ohms

Lamp Bank No	Term. Volts	Arm. Amps	Field Amps	Load Amps	Generat Power	Load Power	Efficiency
0	221	0.29	0.31	0.00	64	0	0.00
1	220	0.66	0.31	0.35	145	77	0.46
2	218	1.13	0.31	0.82	246	179	0.66
3	217	1.61	0.31	1.30	349	283	0.75
4	215	2.10	0.31	1.80	452	386	0.80
5	214	2.57	0.30	2.27	550	485	0.82
6	212	3.02	0.30	2.72	640	576	0.84
7	211	3.47	0.30	3.17	732	669	0.85
8	210	3.94	0.30	3.64	827	765	0.86
9	208	4.40	0.29	4.11	915	854	0.86
10	207	4.74	0.29	4.45	981	921	0.86
11	206	5.08	0.29	4.79	1046	987	0.86

1750 RPM

Friction And Windage			20 Watts		Armature Resistanc		3 Ohms
Lamp Bank No	Term. Volts	Arm. Amps	Field Amps	Load Amps	Generat Power	Load Power	Efficiency
0	244	0.35	0.36	0.00	85	0	0.00
1	243	0.55	0.35	0.20	134	48	0.31
2	241	1.05	0.35	0.70	253	169	0.61
3	239	1.56	0.34	1.22	373	291	0.73
4	237	2.05	0.34	1.71	486	406	0.78
5	236	2.56	0.34	2.22	604	525	0.82
6	234	3.04	0.33	2.71	711	633	0.83
7	233	3.52	0.33	3.19	820	743	0.85
8	231	4.00	0.33	3.67	924	848	0.86
9	230	4.45	0.33	4.12	1024	949	0.86
10	229	4.67	0.33	4.35	1069	995	0.86
11	228	4.86	0.32	4.54	1108	1034	0.86
12	227	5.03	0.32	4.71	1142	1068	0.86
13	227	5.19	0.32	4.87	1178	1105	0.86
14	226	5.37	0.32	5.05	1214	1141	0.86

1950 RPM

Friction And Windage			20 Watts		Armature		3 Ohms
Lamp Bank No	Term. Volts	Arm. Amps	Field Amps	Load Amps	Generato Power	Load Power	Efficiency
0	167	0.16	0.16	0	27	0	0.00
1	166	0.32	0.16	0.16	53	27	0.36
1+11	166	0.49	0.16	0.33	81	55	0.54
2	165	0.67	0.15	0.52	111	86	0.65
3	164	1.06	0.15	0.91	174	149	0.76
4	162	1.42	0.15	1.27	230	206	0.80
5	161	1.87	0.15	1.72	301	277	0.84
6	159	2.25	0.15	2.10	358	334	0.85
7	158	2.66	0.15	2.51	420	397	0.86
8	158	3.06	0.15	2.91	483	460	0.86
9	156	3.43	0.15	3.28	535	512	0.87
10	155	3.83	0.15	3.68	594	570	0.87
11	154	3.96	0.15	3.81	610	587	0.87

2050 RPM

Friction And Windage			20 Watts		Armature Resistanc		3 Ohms
Lamp Bank No	Term. Volts	Arm. Amps	Field Amps	Load Amps	Generato Power	Load Power	Efficiency
0	205	0.18	0.18	0	37	0	0.00
1	203	0.37	0.18	0.19	75	39	0.40
1+11	202	0.56	0.18	0.38	113	77	0.57
2	202	0.73	0.18	0.55	147	111	0.66
3	200	1.18	0.17	1.01	236	202	0.78
4	198	1.64	0.17	1.47	325	291	0.83
5	197	2.10	0.17	1.93	414	380	0.85
6	195	2.52	0.17	2.35	491	458	0.86
7	194	2.98	0.17	2.81	578	545	0.87
8	193	3.42	0.17	3.25	660	627	0.88
9	192	3.86	0.17	3.69	741	708	0.88
10	190	4.30	0.17	4.13	817	785	0.88
11	189	4.47	0.17	4.30	845	813	0.88

2150 RPM

Friction And Windage			20 Watts		Armature Resistanc		3 Ohms
Lamp Bank No	Term. Volts	Arm. Amps	Field Amps	Load Amps	Generato Power	Load Power	Efficiency
0	221	0.19	0.19	0.00	42	0	0.00
1	219	0.38	0.19	0.19	83	42	0.40
1+11	218	0.58	0.19	0.39	126	85	0.58
2	217	0.86	0.18	0.68	187	148	0.71
3	215	1.35	0.18	1.17	290	252	0.80
4	214	1.81	0.18	1.63	387	349	0.84
5	213	2.28	0.18	2.10	486	447	0.86
6	211	2.75	0.18	2.57	580	542	0.87
7	209	3.21	0.18	3.03	671	633	0.88
8	207	3.66	0.18	3.48	758	720	0.88
9	206	4.13	0.18	3.95	851	814	0.88
10	205	4.47	0.18	4.29	916	879	0.88
11	204	4.65	0.18	4.47	949	912	0.88

2250 RPM

Friction And Windage			20 Watts		Armature Resistanc		3 Ohms
Lamp Bank No	Term. Volts	Arm. Amps	Field Amps	Load Amps	Generato Power	Load Power	Efficiency
0	244	0.20	0.20	0.00	49	0	0.00
1	242	0.41	0.20	0.21	99	51	0.42
1+11	242	0.61	0.20	0.41	148	99	0.59
2	240	0.91	0.20	0.71	218	170	0.71
3	238	1.42	0.20	1.22	338	290	0.80
4	236	1.92	0.20	1.72	453	406	0.84
5	234	2.41	0.20	2.21	564	517	0.86
6	233	2.89	0.20	2.69	673	627	0.87
7	231	3.37	0.19	3.18	778	735	0.88
8	229	3.87	0.19	3.68	886	843	0.89
9	228	4.35	0.19	4.16	992	948	0.89
10	226	4.72	0.19	4.53	1067	1024	0.89
11	224	4.90	0.19	4.71	1098	1055	0.89

2350 RPM

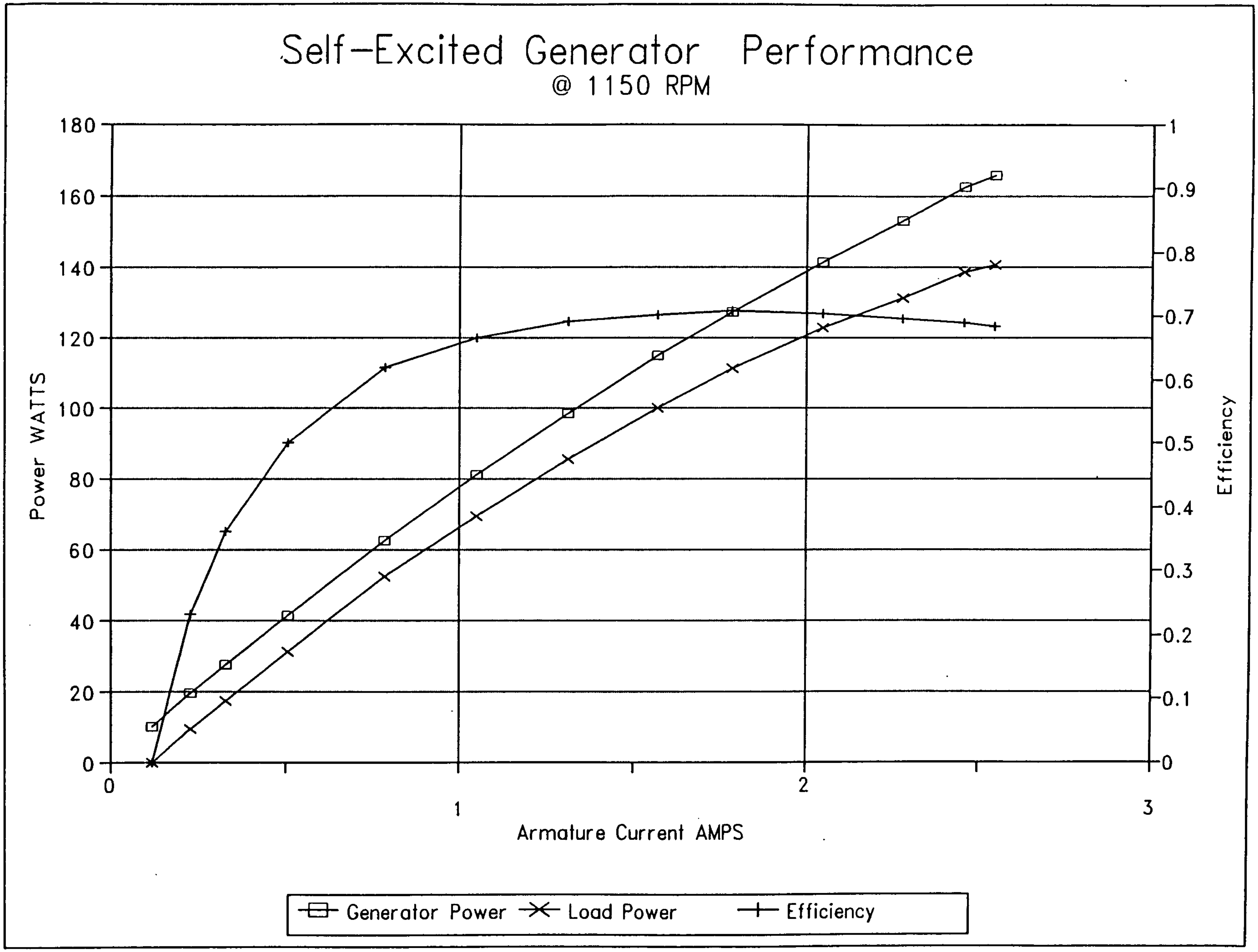
Friction And Windage			20 Watts		Armature Resistanc		3 Ohms
Lamp Bank No	Term. Volts	Arm. Amps	Field Amps	Load Amps	Generato Power	Load Power	Efficiency
0	261	0.21	0.21	0.00	55	0	0.00
1	258	0.42	0.21	0.21	108	54	0.42
1+11	258	0.63	0.21	0.42	163	109	0.59
2	256	0.94	0.21	0.73	241	188	0.71
3	253	1.47	0.21	1.26	372	320	0.80
4	252	2.00	0.21	1.80	504	452	0.84
5	250	2.51	0.20	2.31	628	577	0.87
6	249	3.04	0.20	2.84	757	706	0.88
7	247	3.53	0.20	3.33	872	822	0.88
8	245	4.07	0.20	3.87	997	948	0.89
9	243	4.55	0.20	4.35	1106	1057	0.89
10	242	4.92	0.20	4.72	1191	1143	0.89
11	240	5.10	0.20	4.90	1224	1176	0.89

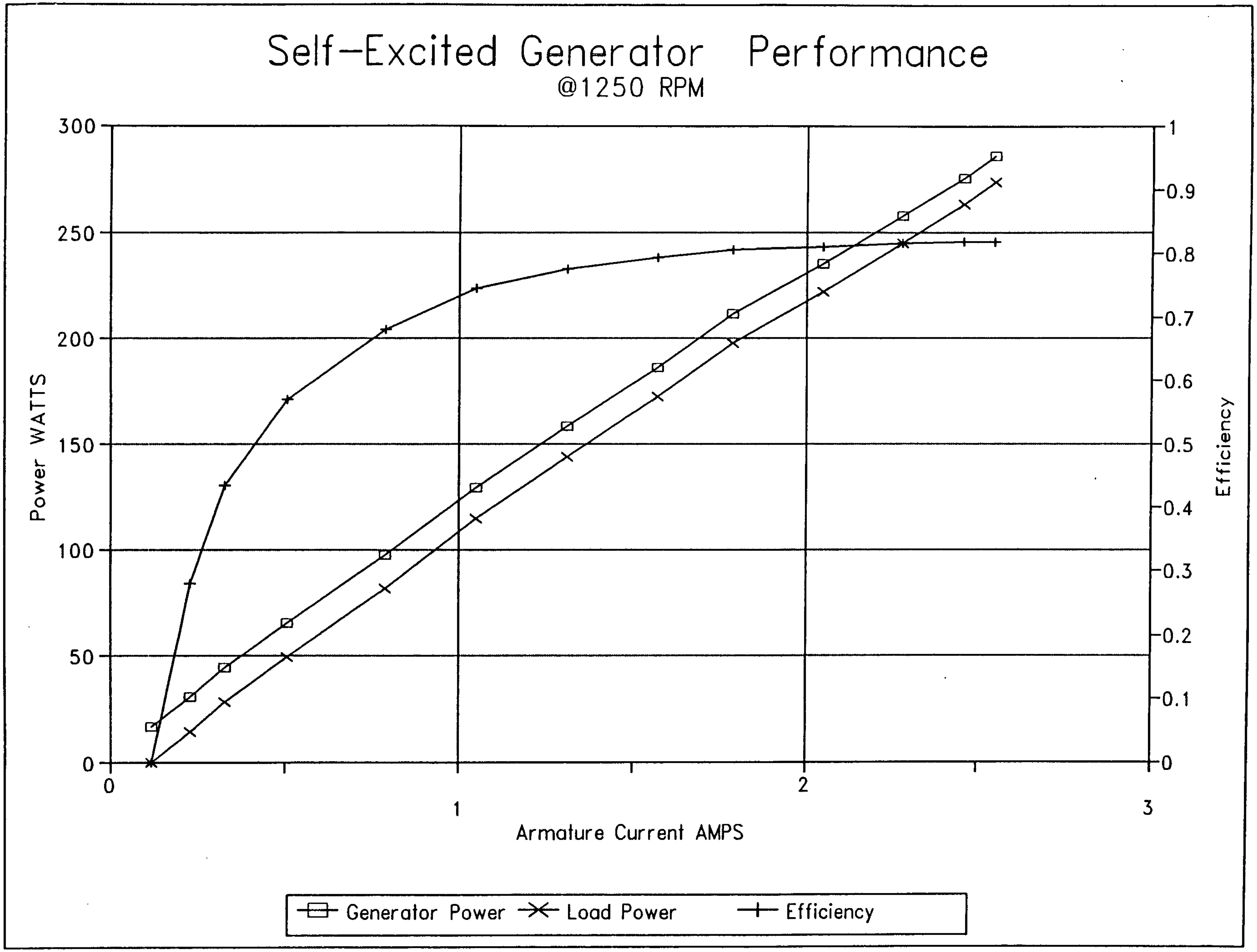
2450 RPM

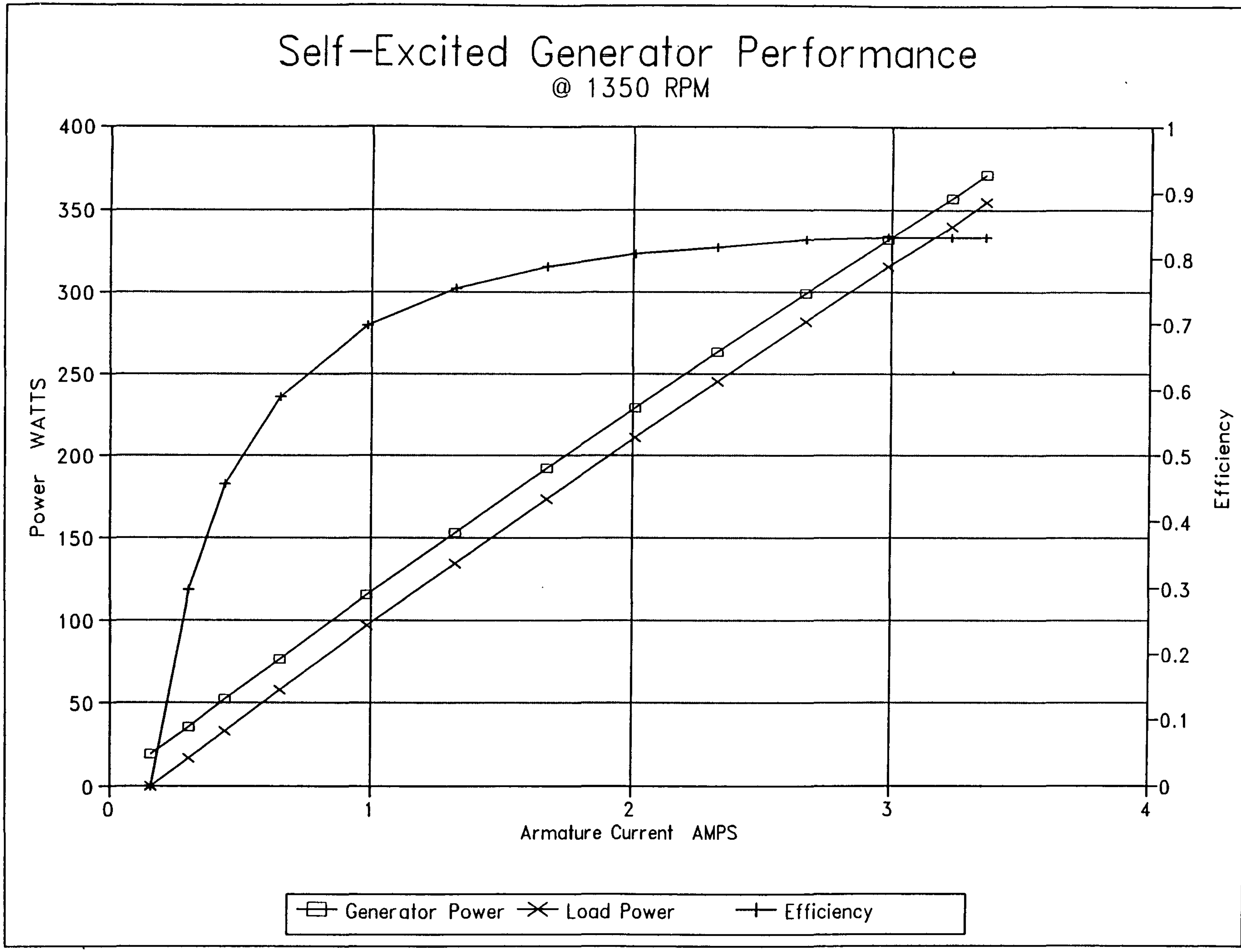
Friction And Windage			20 Watts		Armature Resistanc		3 Ohms
Lamp Bank No	Term. Volts	Arm. Amps	Field Amps	Load Amps	Generato Power	Load Power	Efficiency
0	280	0.22	0.22	0.00	62	0	0.00
1	278	0.45	0.22	0.23	125	64	0.44
1+11	278	0.67	0.22	0.45	186	125	0.60
2	276	0.98	0.22	0.76	270	210	0.72
3	274	1.51	0.22	1.29	414	354	0.80
4	273	2.07	0.22	1.85	565	506	0.85
5	271	2.60	0.22	2.38	705	646	0.87
6	270	3.13	0.22	2.92	845	787	0.88
7	268	3.66	0.21	3.45	981	924	0.89
8	265	4.18	0.21	3.97	1108	1051	0.89
9	264	4.72	0.21	4.51	1246	1190	0.89
10	263	5.13	0.21	4.92	1349	1294	0.89

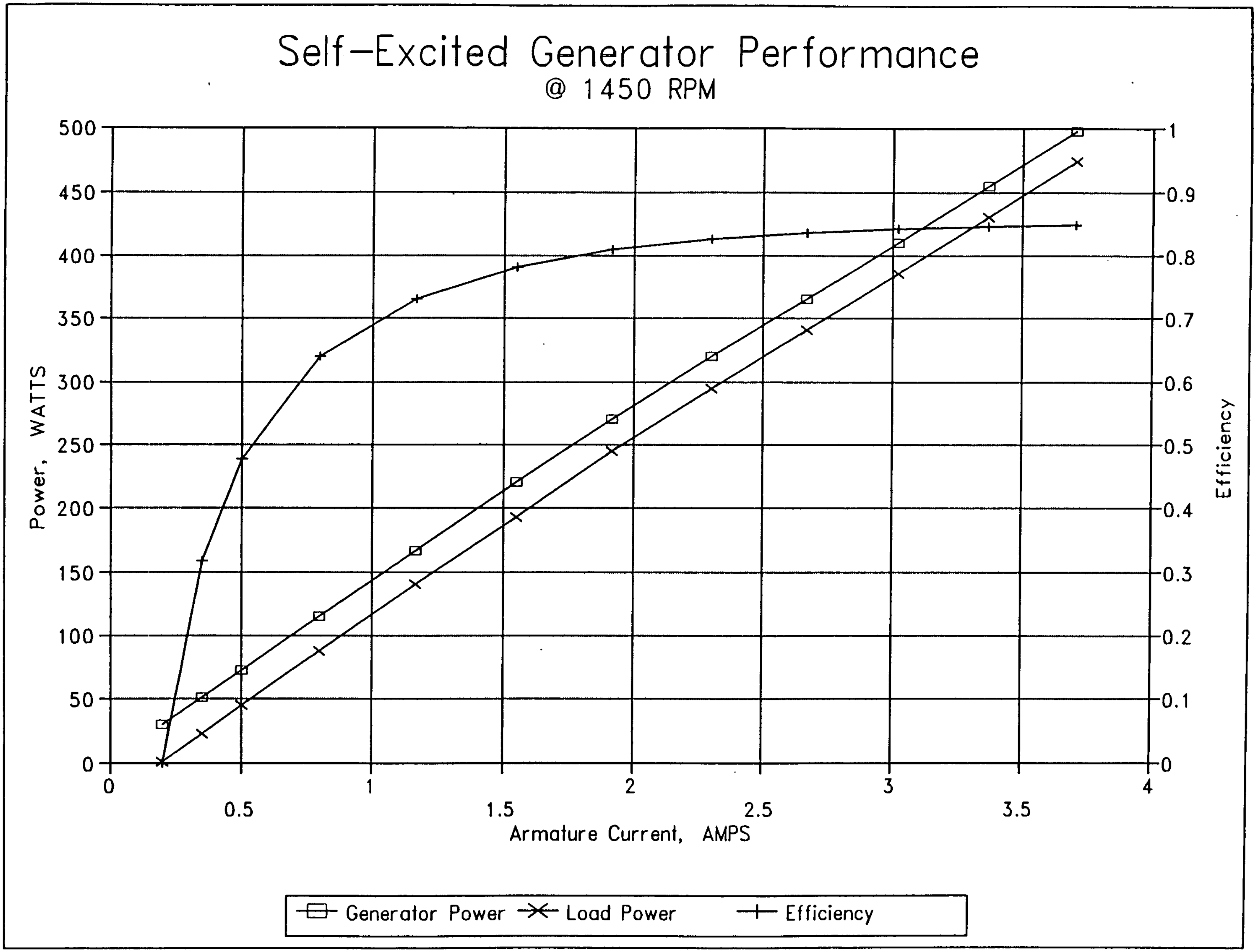
Open Circuit Characteristic

	@1750 RPM		@1450 Rpm	
Field Amps	Term. Volts	Term. Volts	Term. Volts	Term. Volts
0	11.5	13	11	11
0.055	48	63	42	52
0.1	95	112	80	93
0.15	138	154	115	128
0.2	175	188	146	156
0.25	204	211	169	175
0.3	225		186	

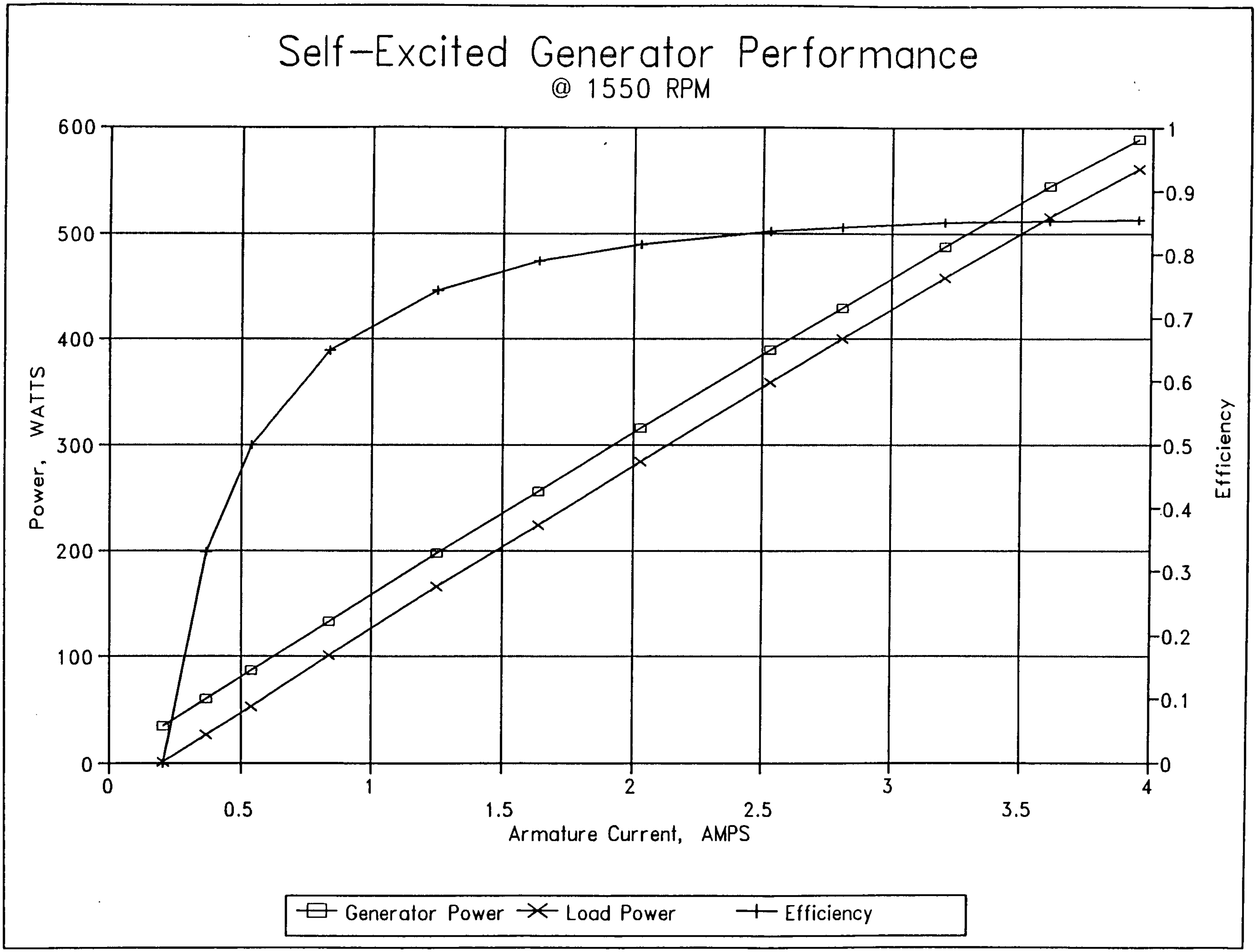

Self-Excited Generator Performance
@ 1150 RPM
Power WATTS
Efficiency
Armature Current AMPS
0
20
40
60
80
100
120
140
160
180
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
Generator Power
Load Power
Efficiency

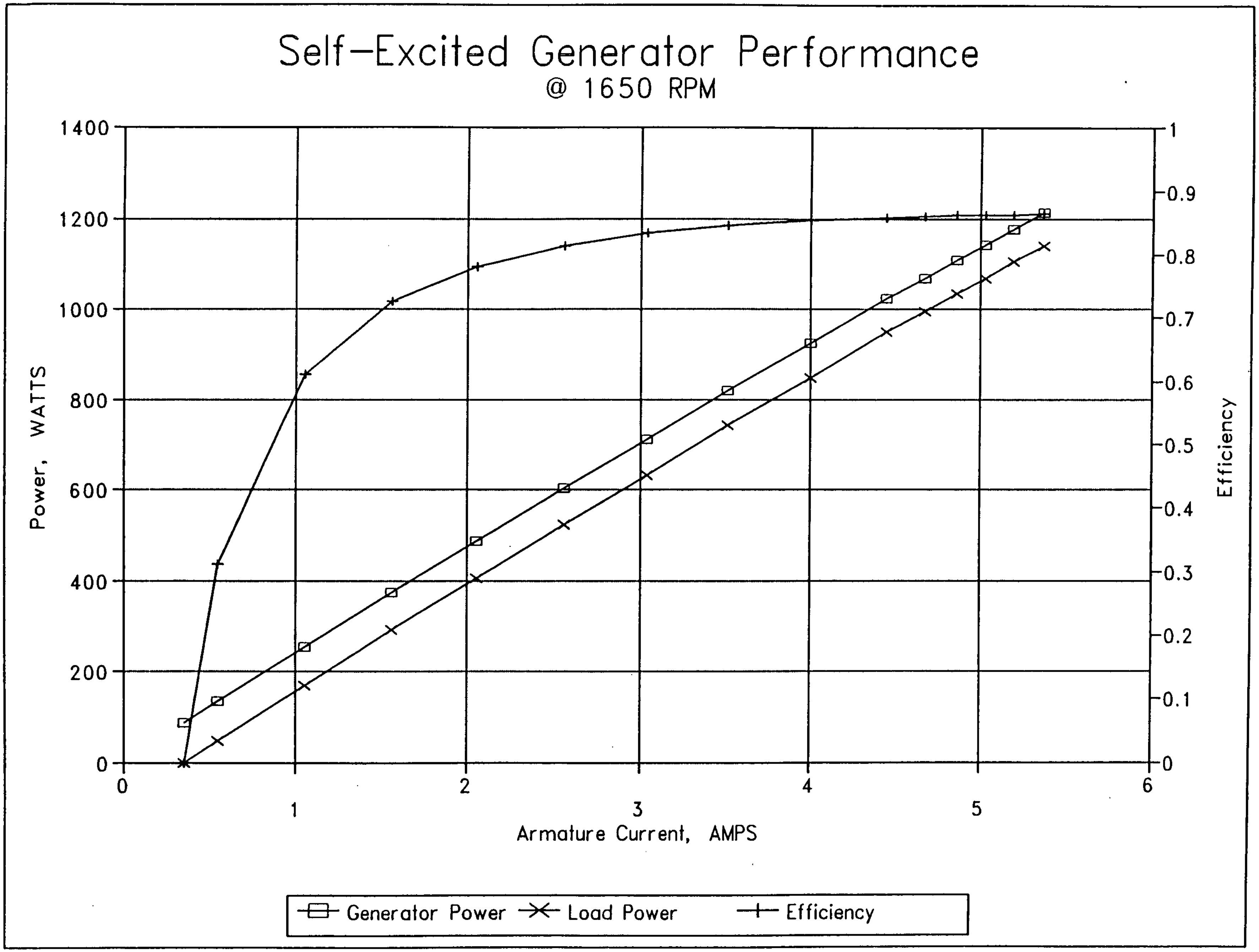

Self-Excited Generator Performance
@1250 RPM
Power WATTS
Efficiency
Armature Current AMPS
300
250
200
150
100
50
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
Generator Power
Load Power
Efficiency

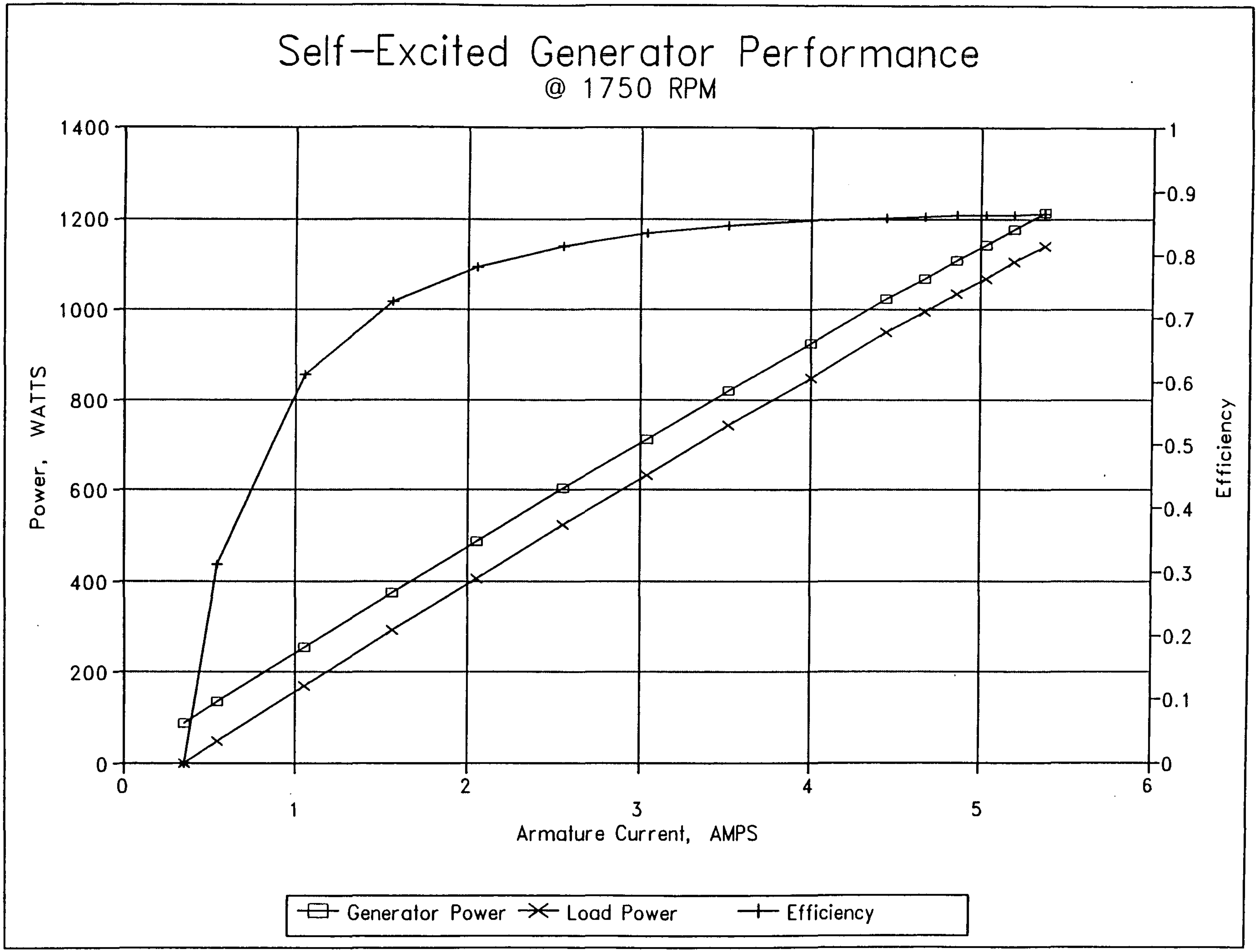

Self-Excited Generator Performance
@ 1350 RPM
Power WATTS
0
50
100
150
200
250
300
350
400
Efficiency
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Armature Current AMPS
0
1
2
3
4
Generator Power
Load Power
Efficiency



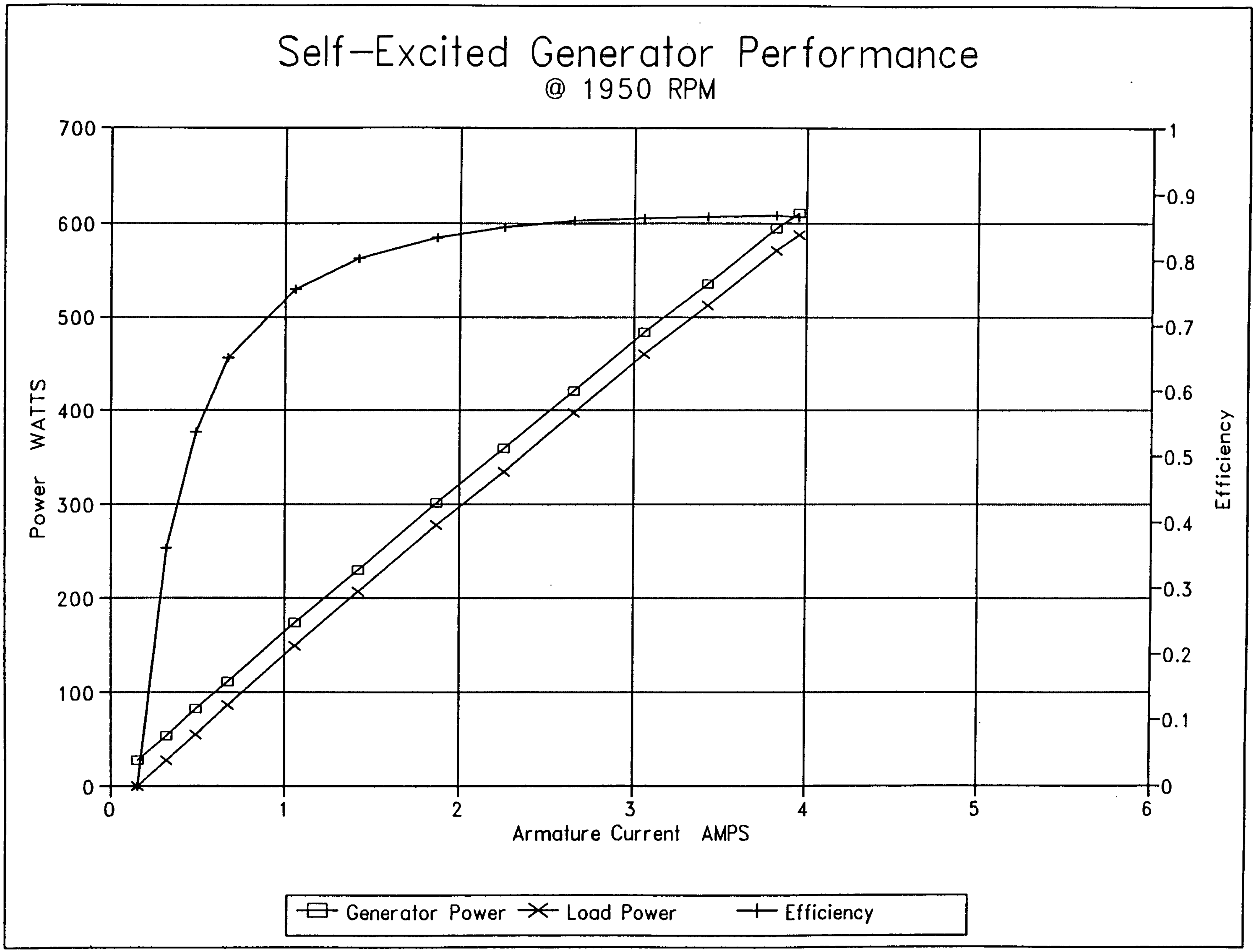
Self-Excited Generator Performance
@ 1450 RPM
Power, WATTS
Efficiency
Armature Current, AMPS
0
50
100
150
200
250
300
350
400
450
500
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.5
1
1.5
2
2.5
3
3.5
4
Generator Power
Load Power
Efficiency

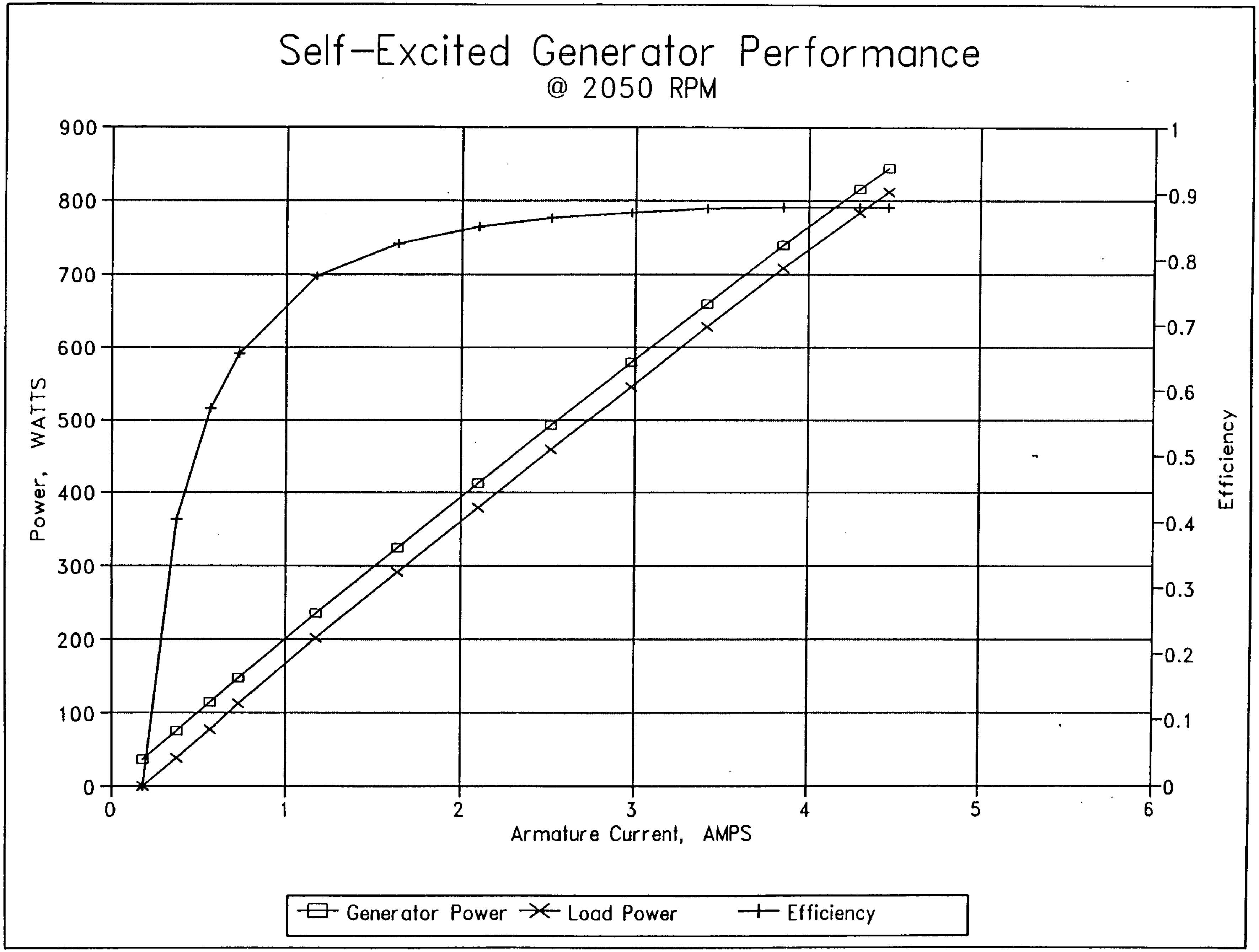

Self-Excited Generator Performance
@ 1550 RPM
Power, WATTS
Efficiency
Armature Current, AMPS
0
100
200
300
400
500
600
0.5
1
1.5
2
2.5
3
3.5
4
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Generator Power
Load Power
Efficiency

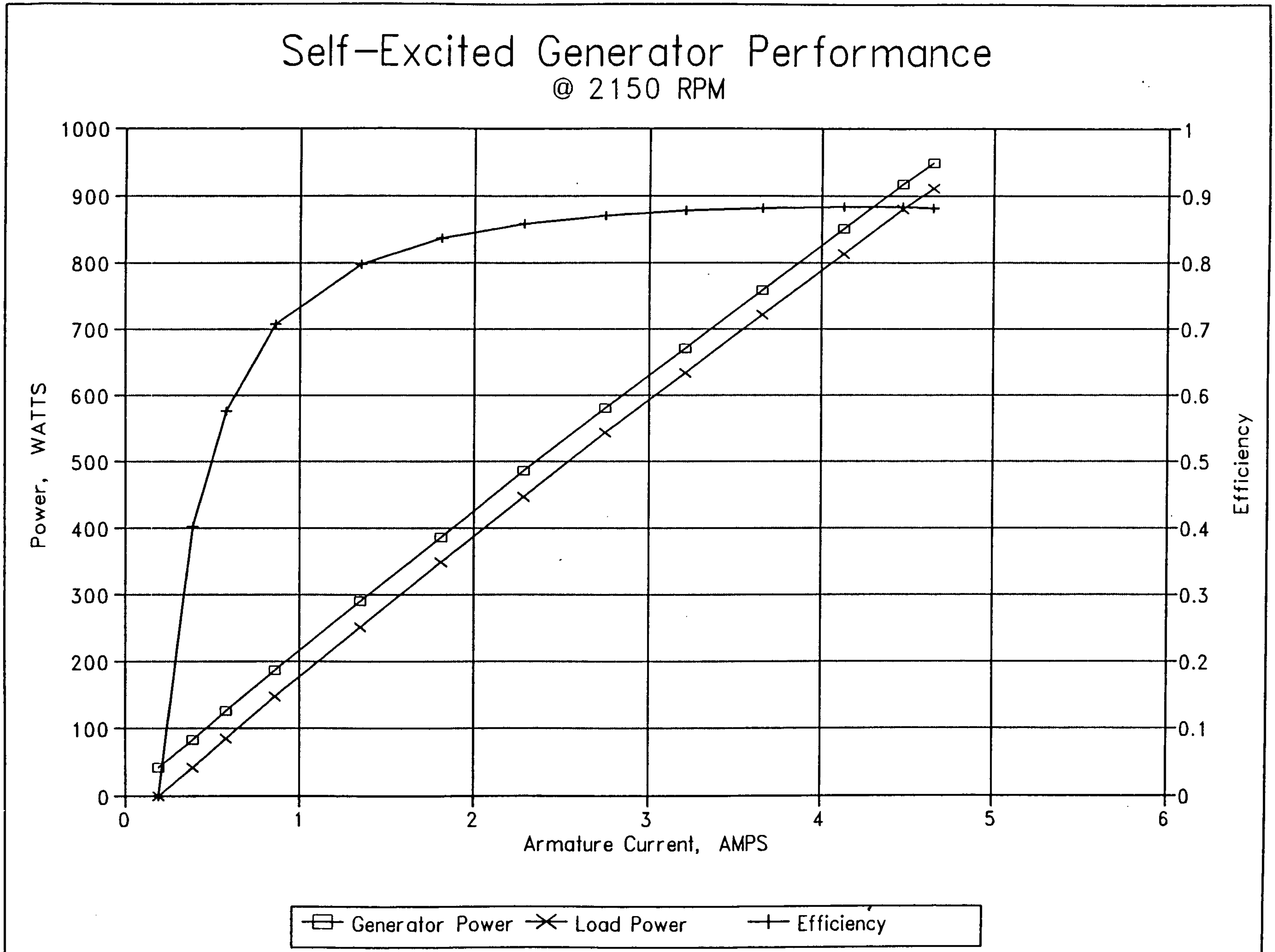

Self-Excited Generator Performance
@ 1650 RPM
Power, WATTS
Efficiency
Armature Current, AMPS
1400
1200
1000
800
600
400
200
0
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
Generator Power
Load Power
Efficiency



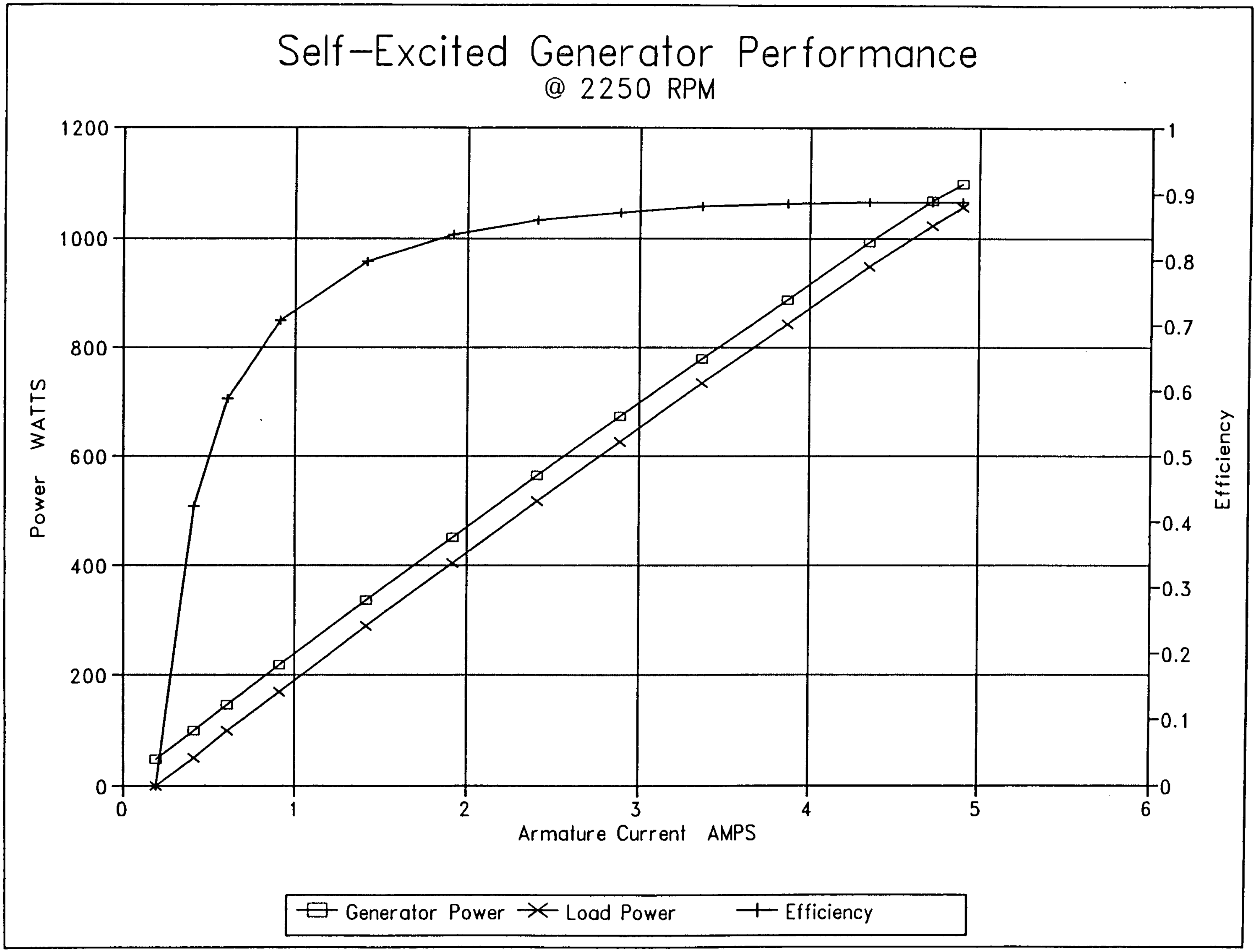
Self-Excited Generator Performance
@ 1750 RPM
Power, WATTS
Efficiency
Armature Current, AMPS
0
200
400
600
800
1000
1200
1400
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6
Generator Power
Load Power
Efficiency

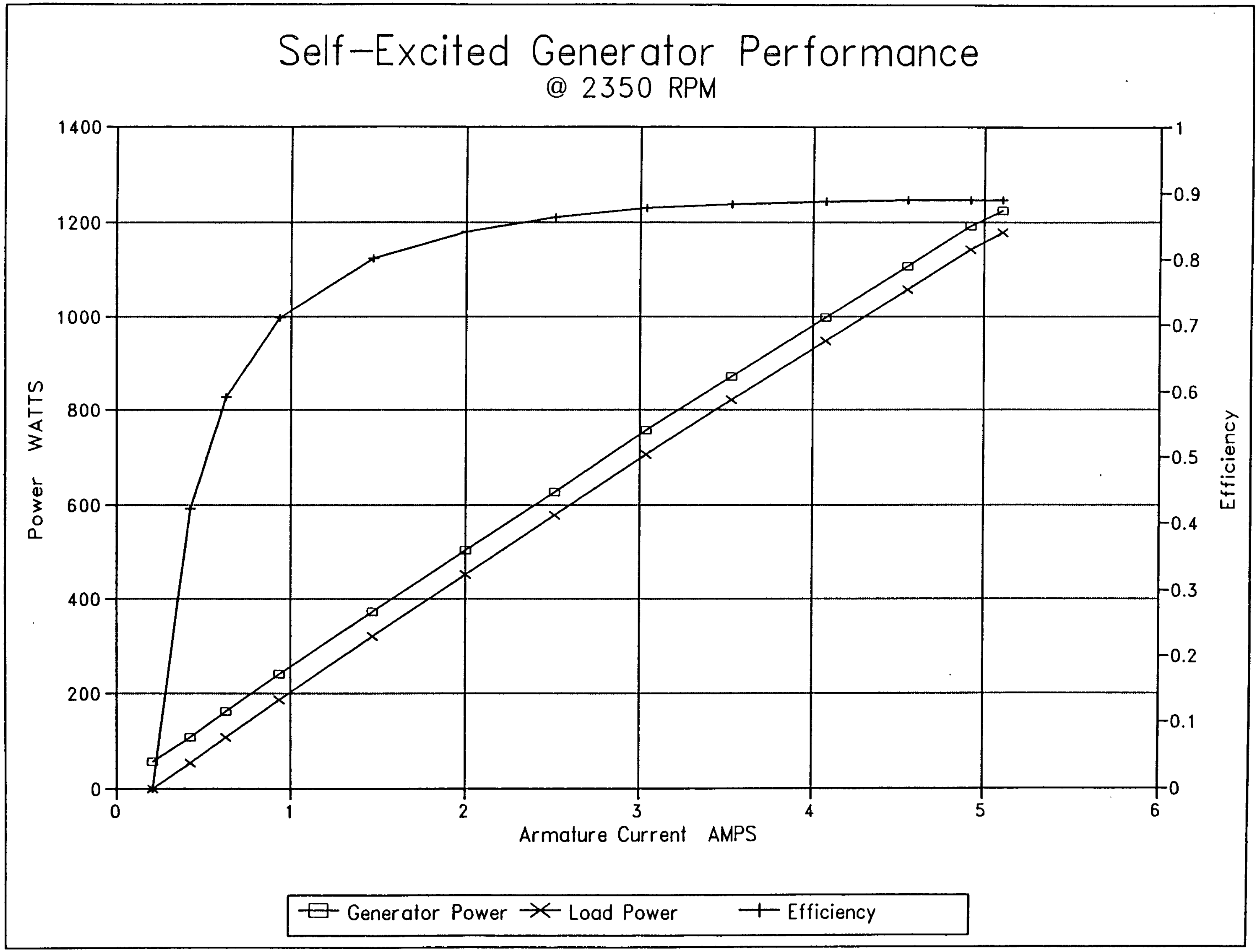

Self-Excited Generator Performance
@ 1950 RPM
700
600
500
400
300
200
100
0
Power WATTS
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Efficiency
0
1
2
3
4
5
6
Armature Current AMPS
Generator Power
Load Power
Efficiency

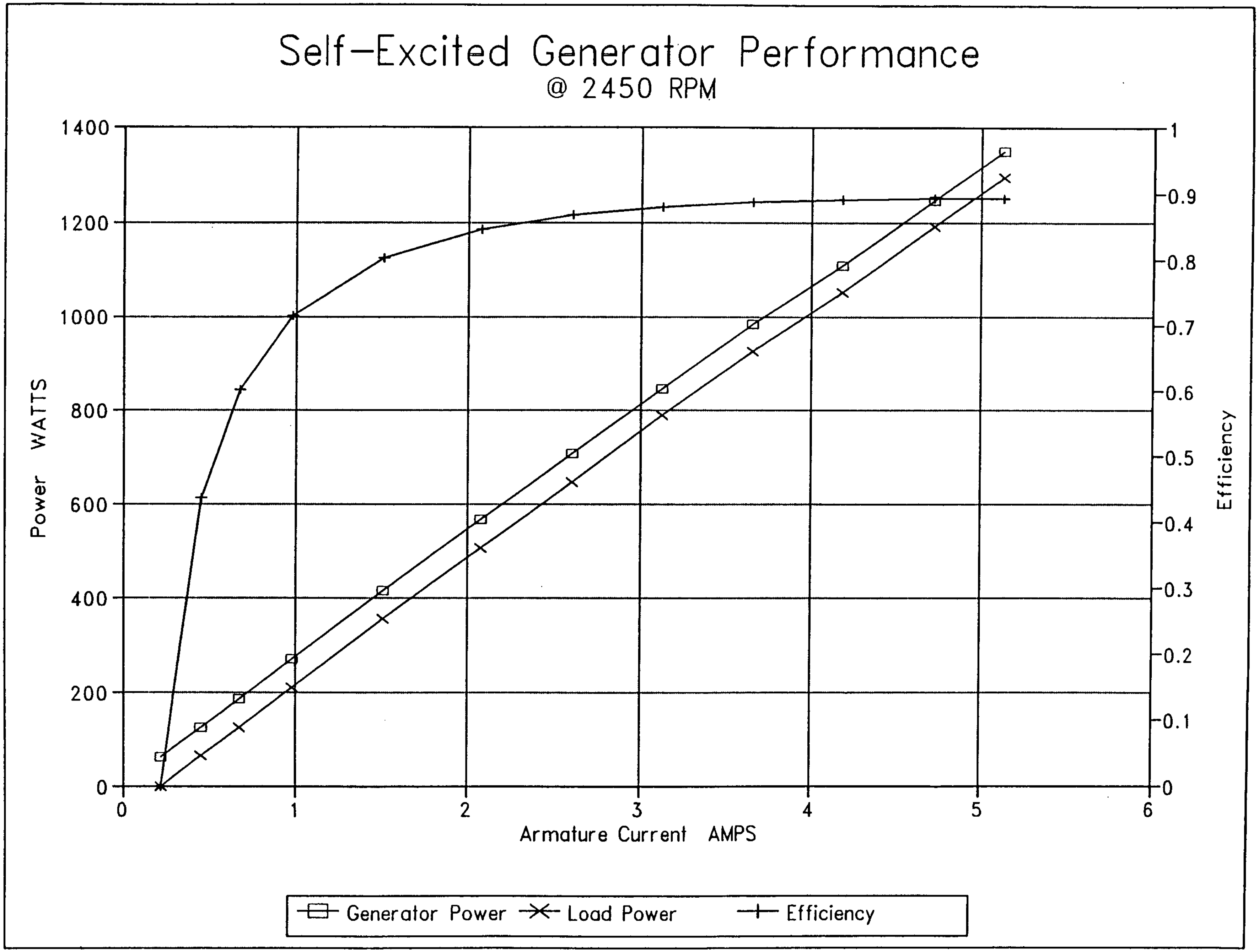

Self-Excited Generator Performance
@ 2050 RPM
Power, WATTS
Efficiency
Armature Current, AMPS
0
100
200
300
400
500
600
700
800
900
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6
Generator Power
Load Power
Efficiency

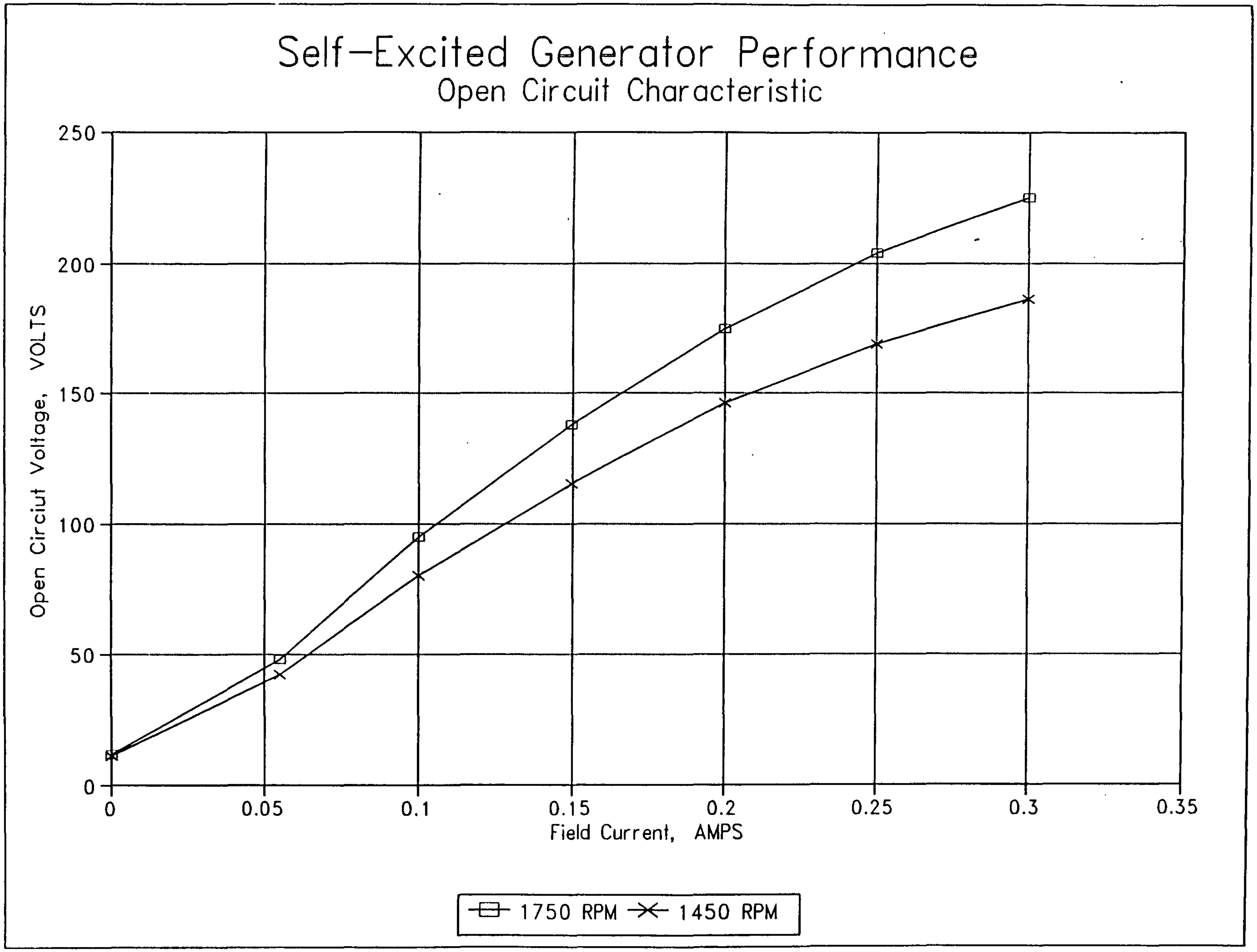


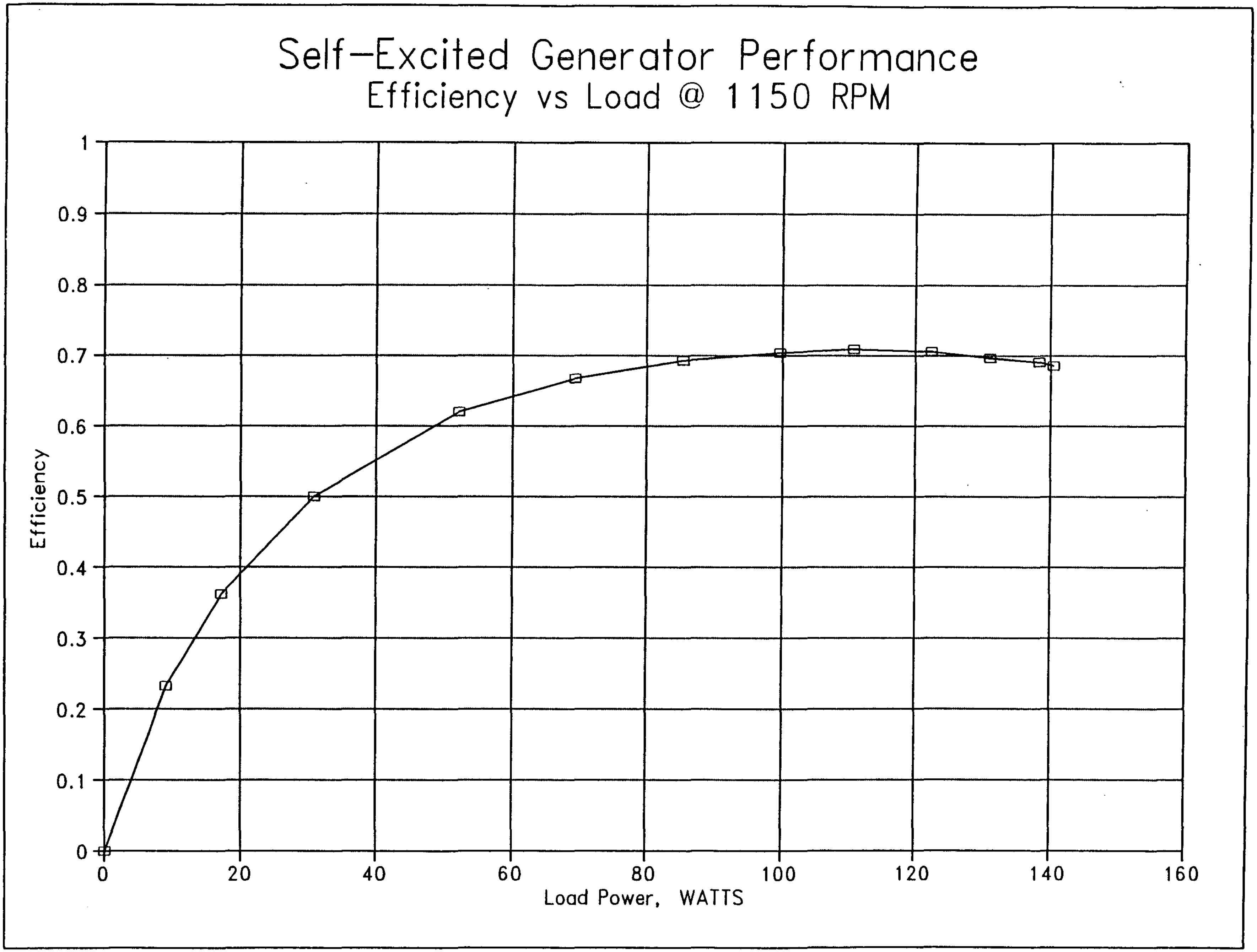
Self-Excited Generator Performance
@ 2150 RPM
Power, WATTS
Efficiency
Armature Current, AMPS
0
100
200
300
400
500
600
700
800
900
1000
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5
6
Generator Power
Load Power
Efficiency

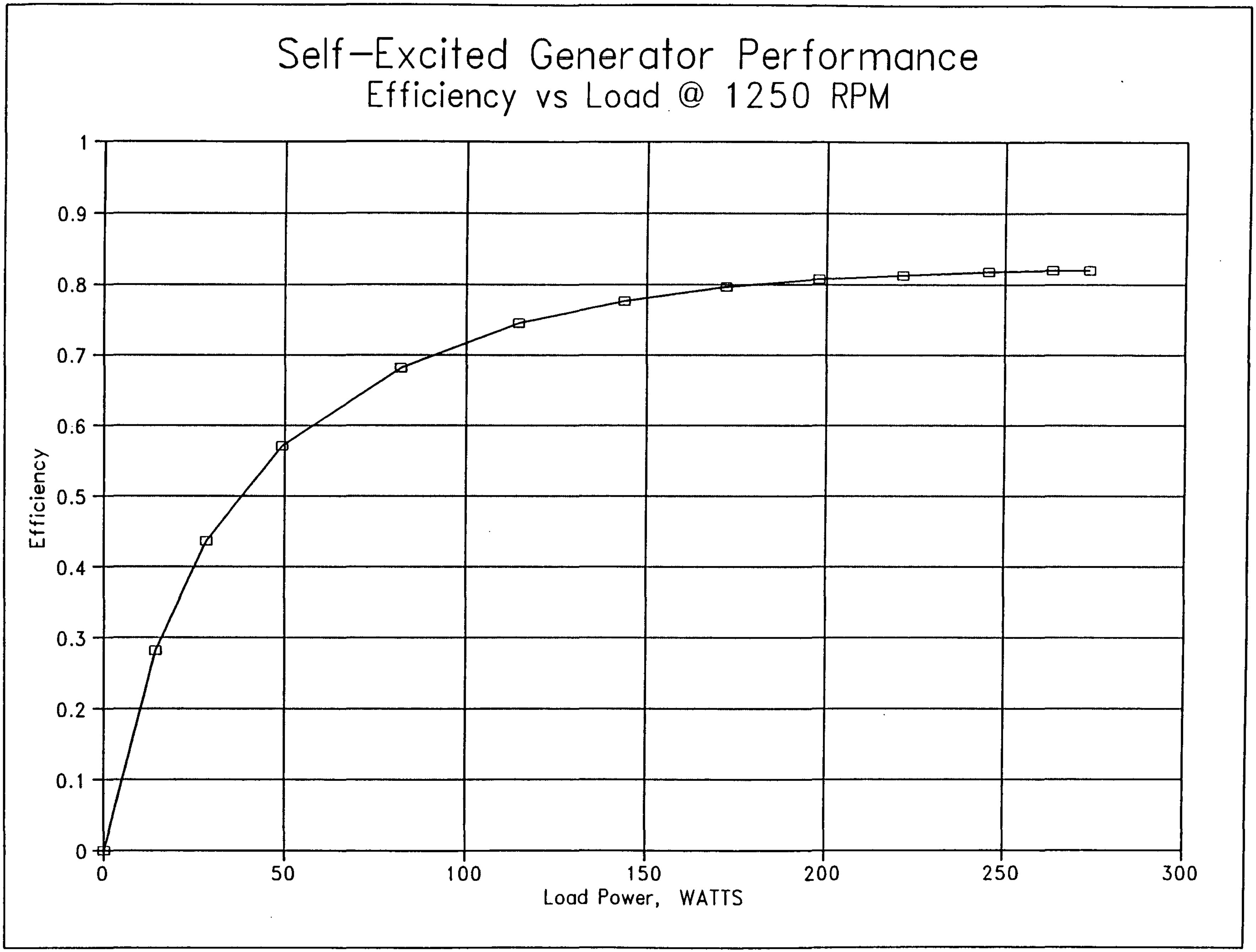

Self-Excited Generator Performance
@ 2250 RPM
Power WATTS
Efficiency
Armature Current AMPS
0
200
400
600
800
1000
1200
0
1
2
3
4
5
6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Generator Power
Load Power
Efficiency


Self-Excited Generator Performance
@ 2350 RPM
Power WATTS
Efficiency
Armature Current AMPS
0
200
400
600
800
1000
1200
1400
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1
2
3
4
5
6
Generator Power
Load Power
Efficiency

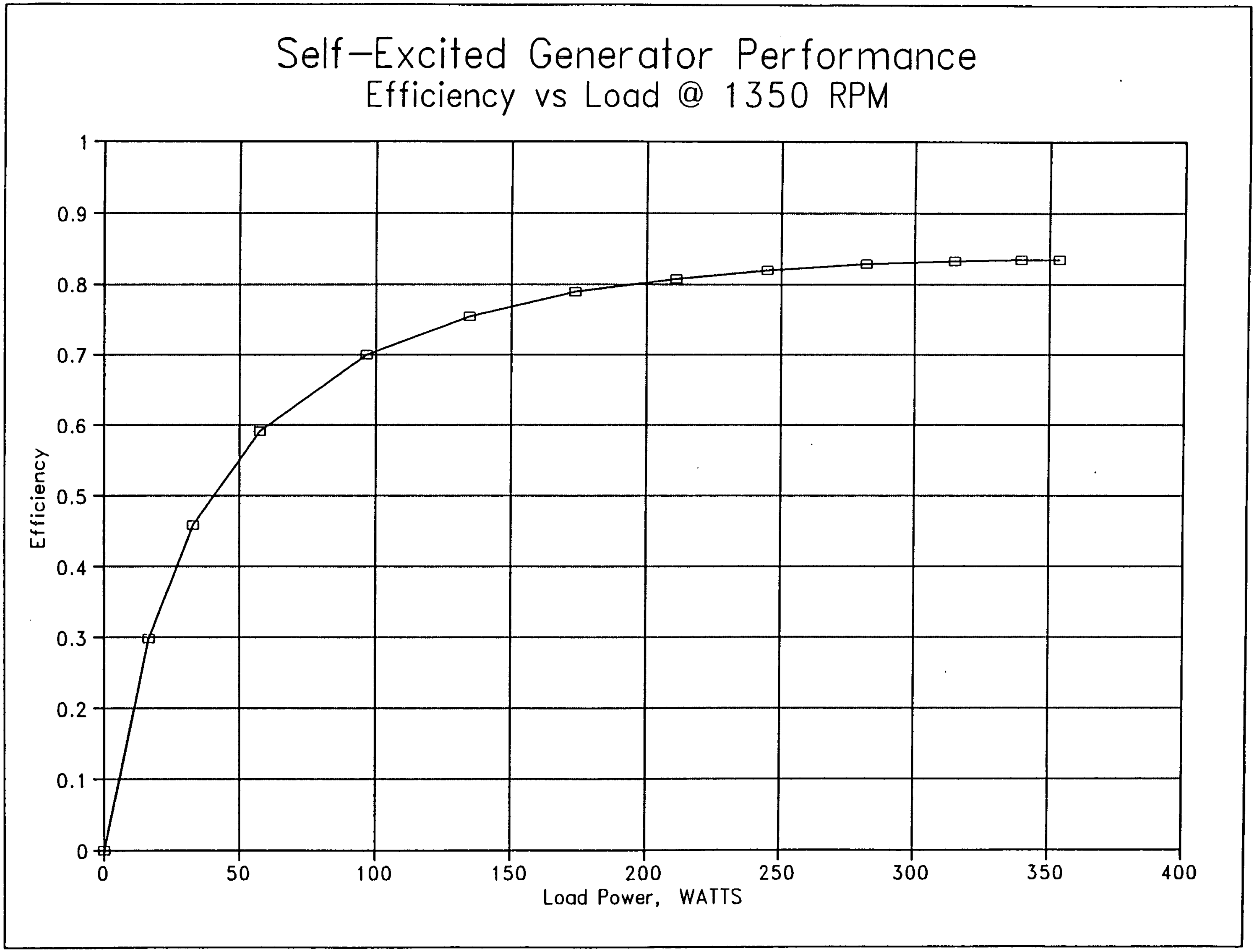

Self-Excited Generator Performance
@ 2450 RPM
Power WATTS
1400
1200
1000
800
600
400
200
0
Efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Armature Current AMPS
0
1
2
3
4
5
6
Generator Power
Load Power
Efficiency

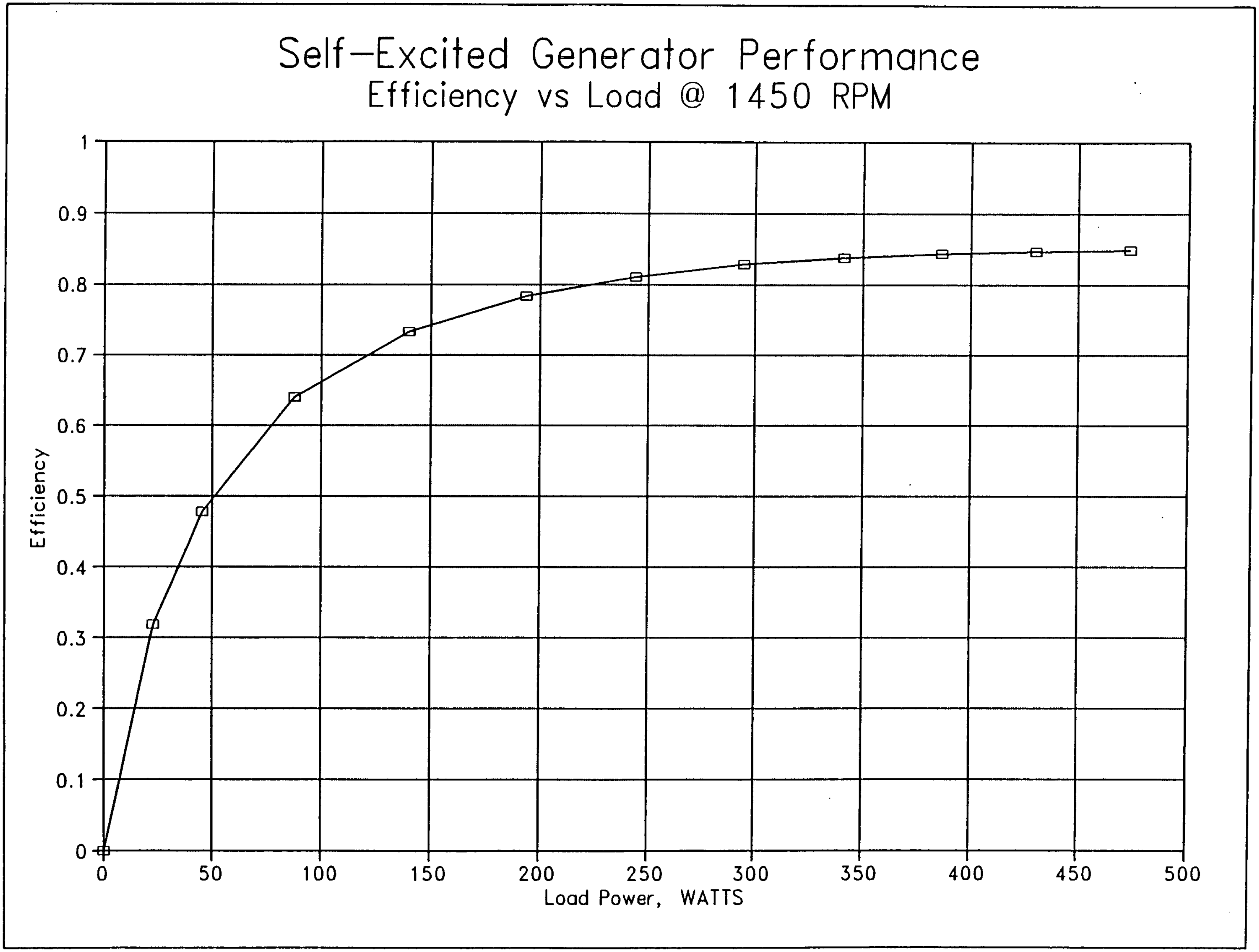

Self-Excited Generator Performance
Open Circuit Characteristic
Open Circiut Voltage, VOLTS
250
200
150
100
50
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Field Current, AMPS
1750 RPM
1450 RPM

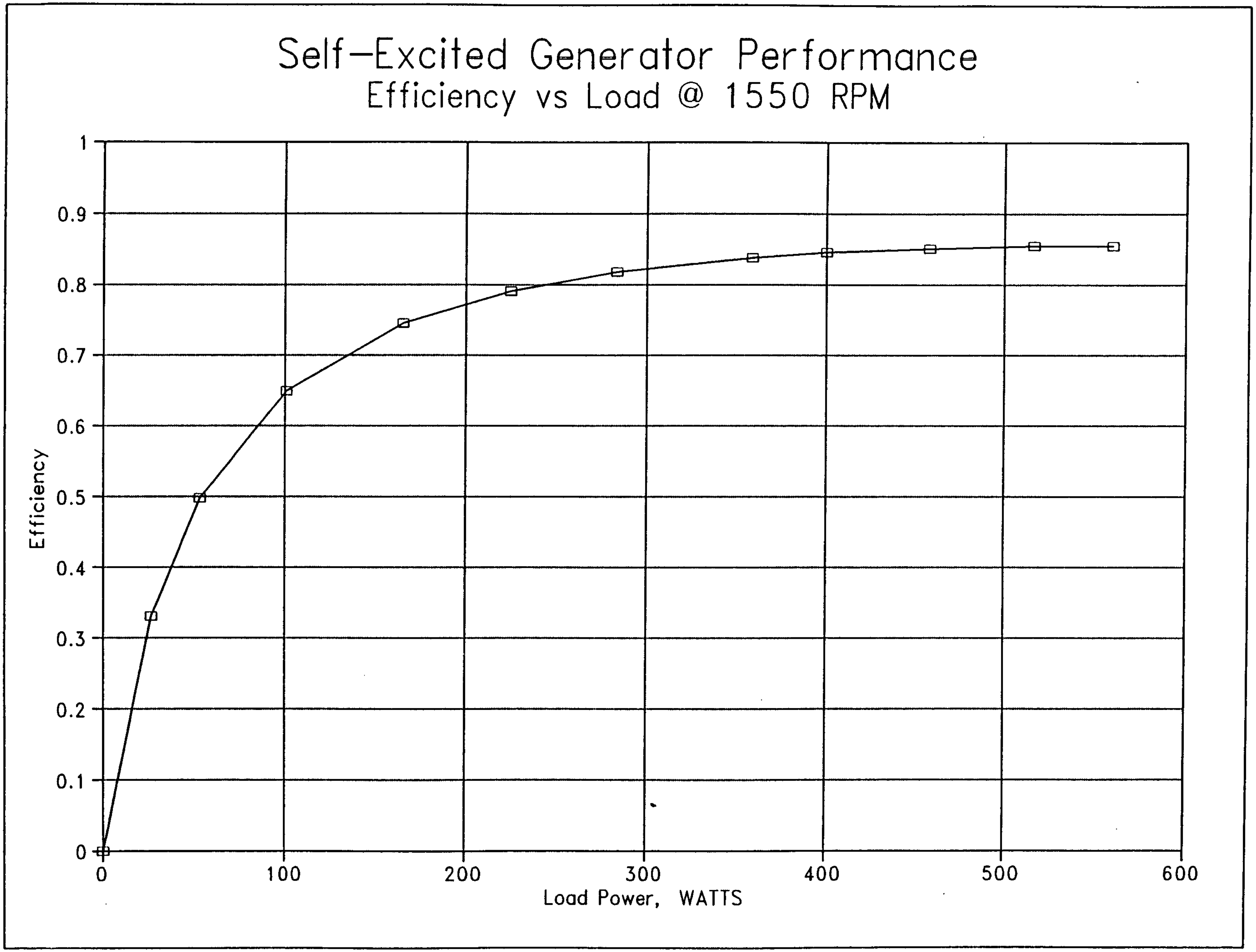

Self-Excited Generator Performance
Efficiency vs Load @ 1150 RPM
Efficiency
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
20
40
60
80
100
120
140
160
Load Power, WATTS

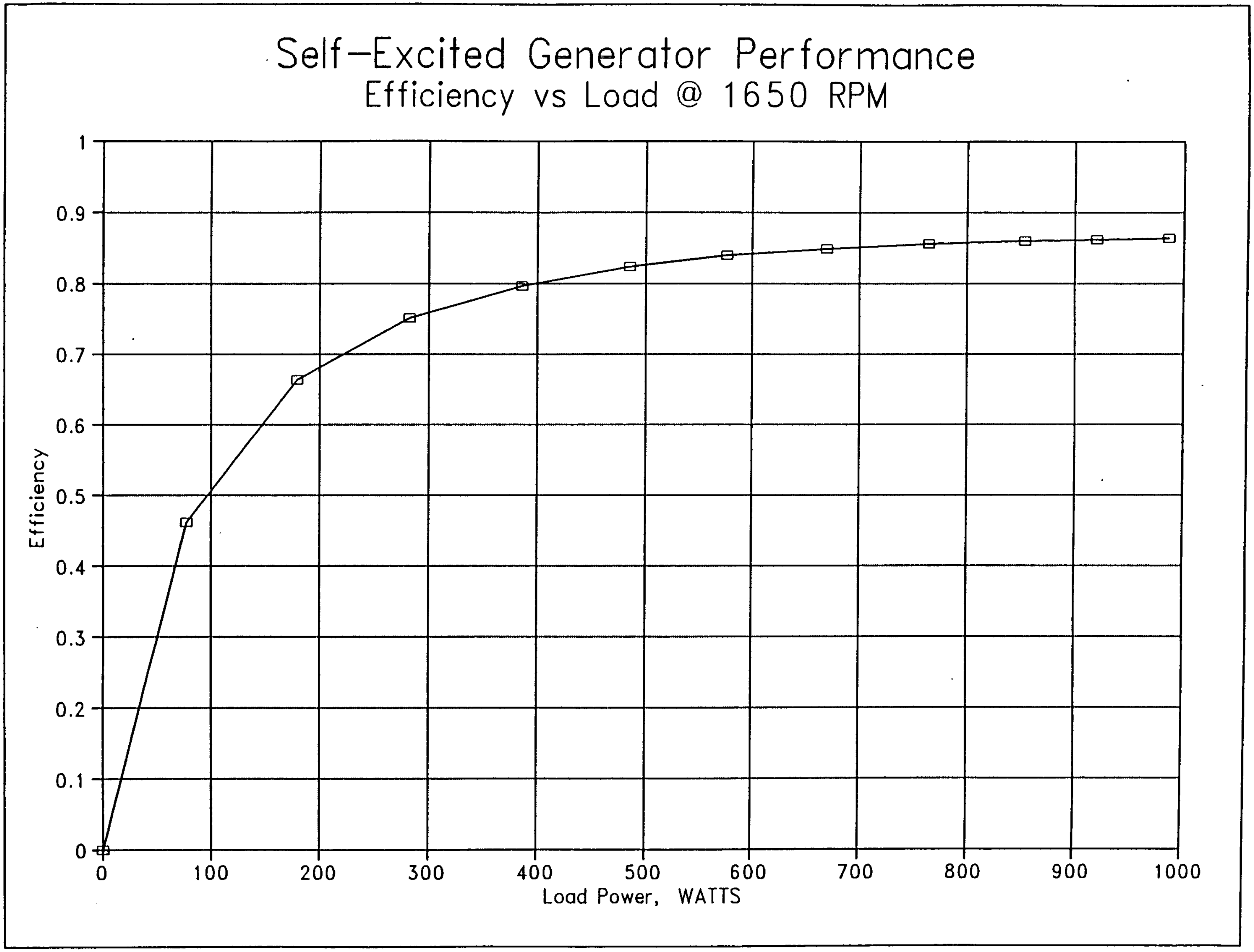


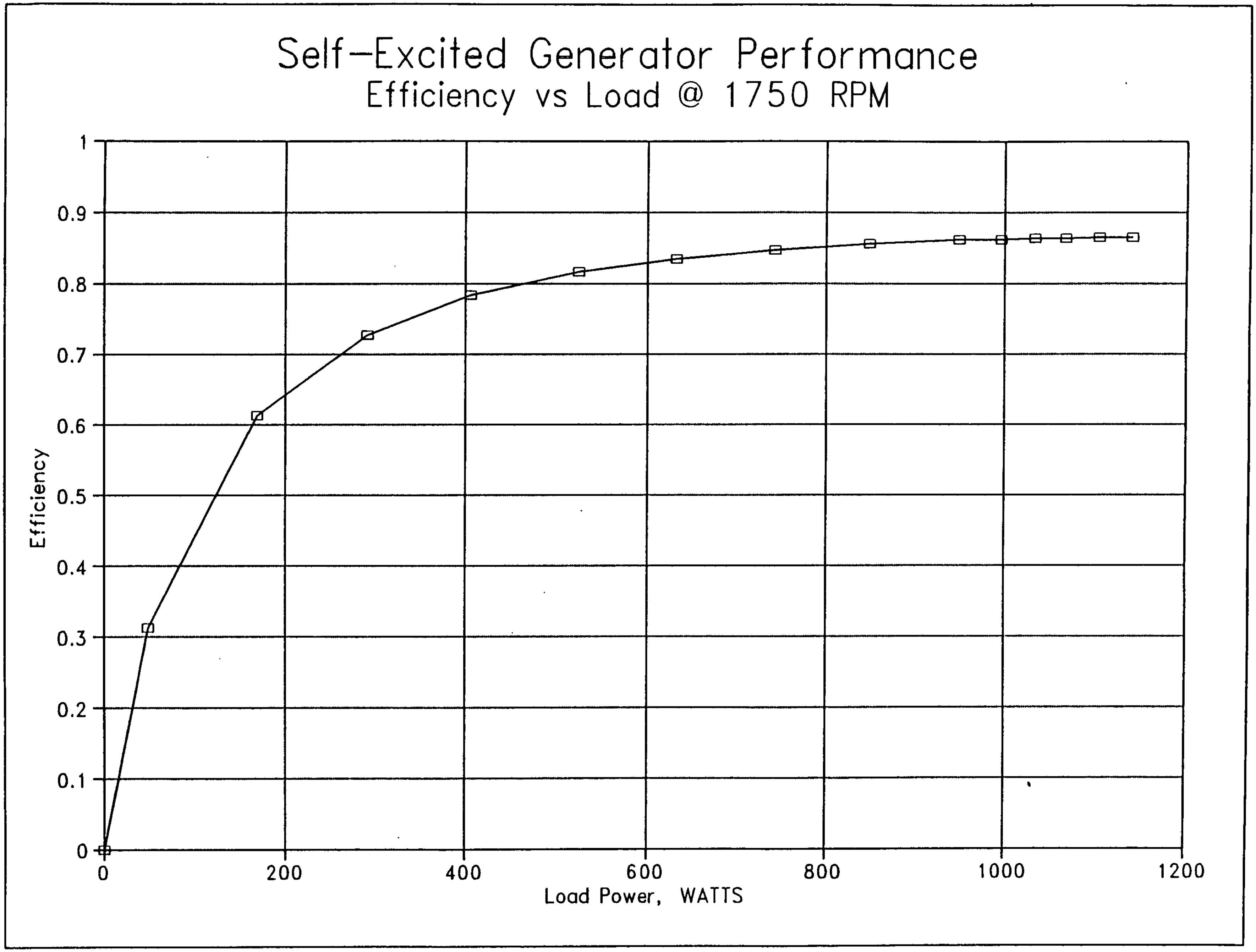
Self-Excited Generator Performance
Efficiency vs Load @ 1250 RPM
Efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
Load Power, WATTS


Self-Excited Generator Performance
Efficiency vs Load @ 1350 RPM
Efficiency
Load Power, WATTS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400

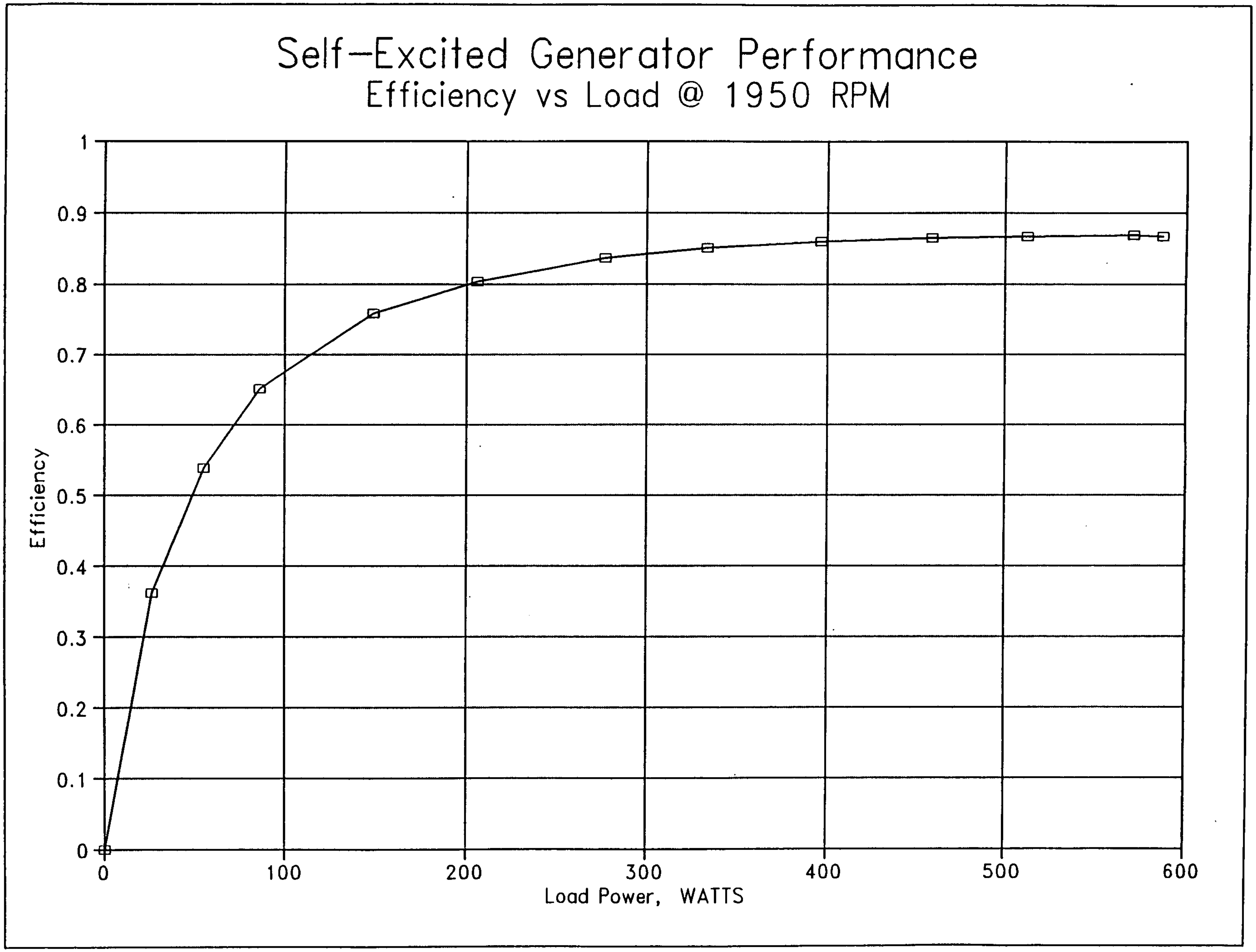

Self–Excited Generator Performance
Efficiency vs Load @ 1450 RPM
Efficiency
Load Power, WATTS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400
450
500

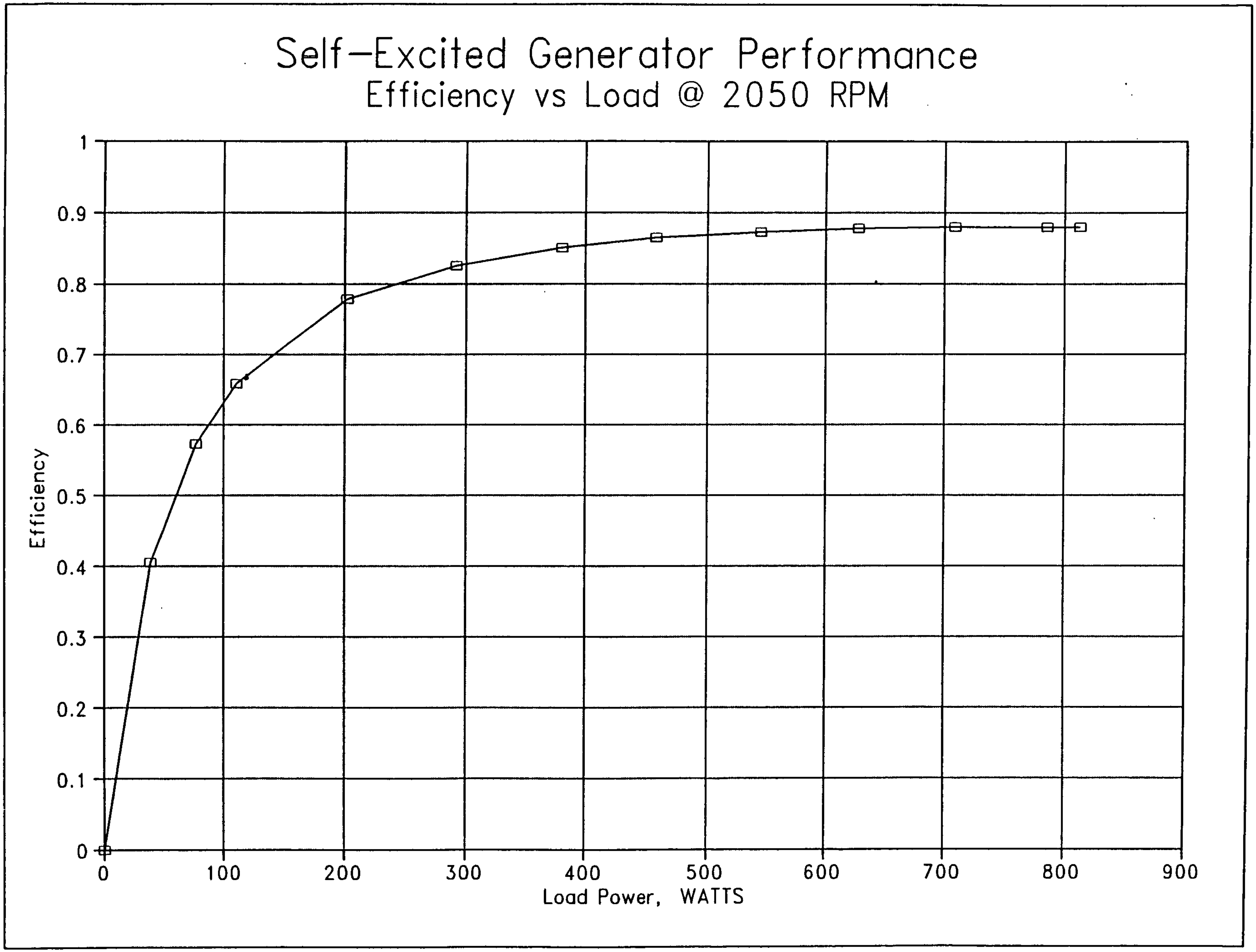

Self-Excited Generator Performance
Efficiency vs Load @ 1550 RPM
Efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
Load Power, WATTS


Self–Excited Generator Performance
Efficiency vs Load @ 1650 RPM
Efficiency
Load Power, WATTS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
700
800
900
1000

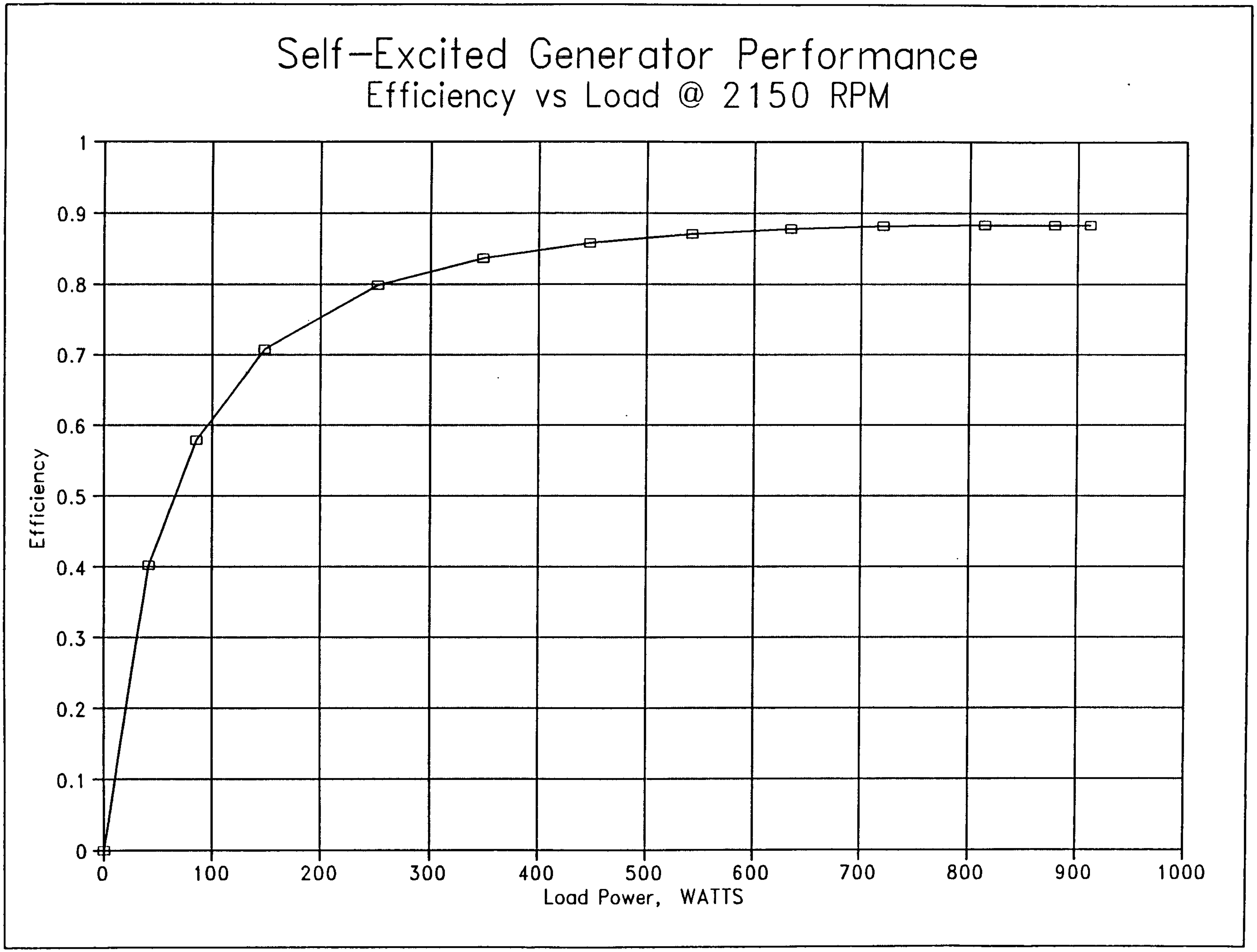


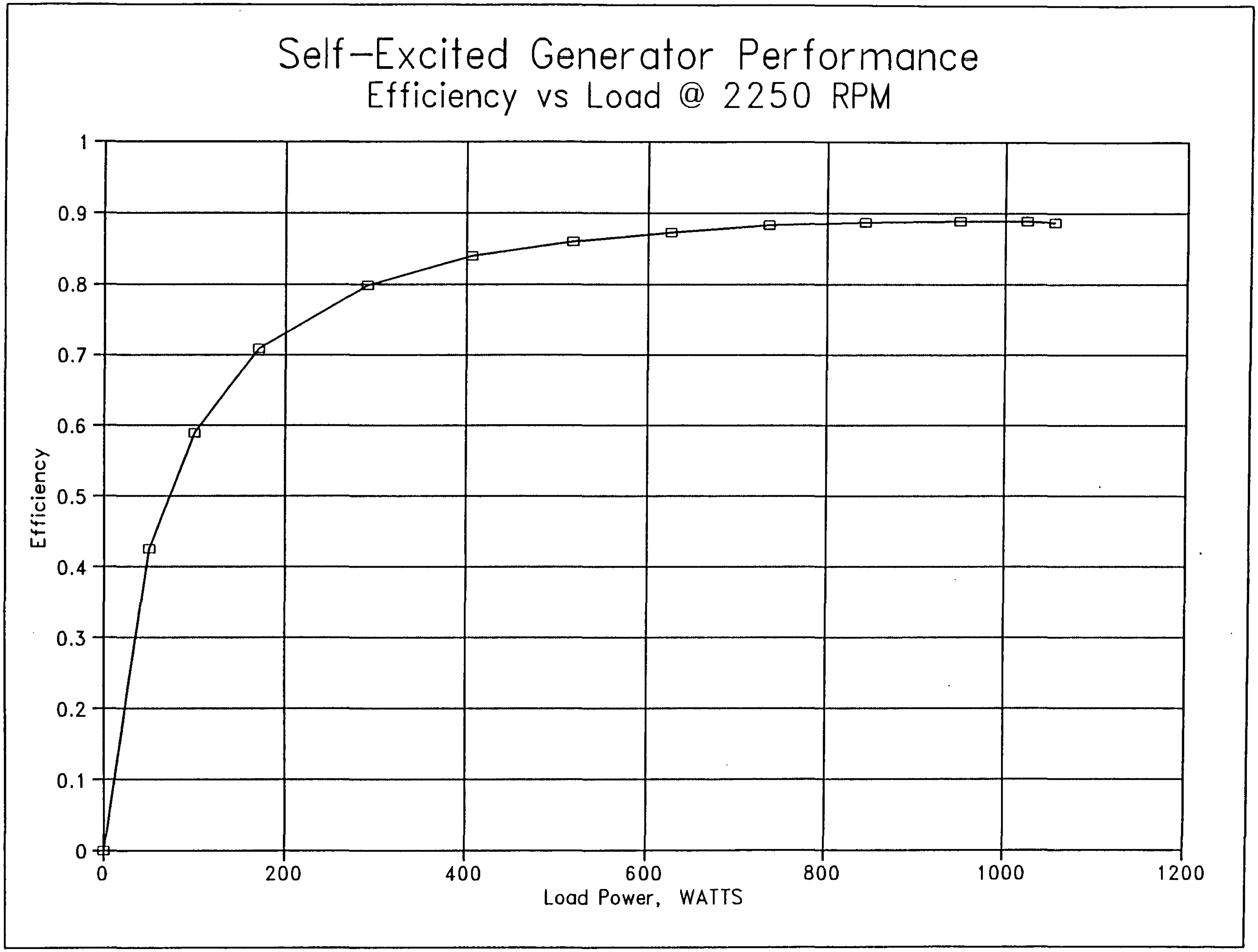
Self-Excited Generator Performance
Efficiency vs Load @ 1750 RPM
Efficiency
Load Power, WATTS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
200
400
600
800
1000
1200

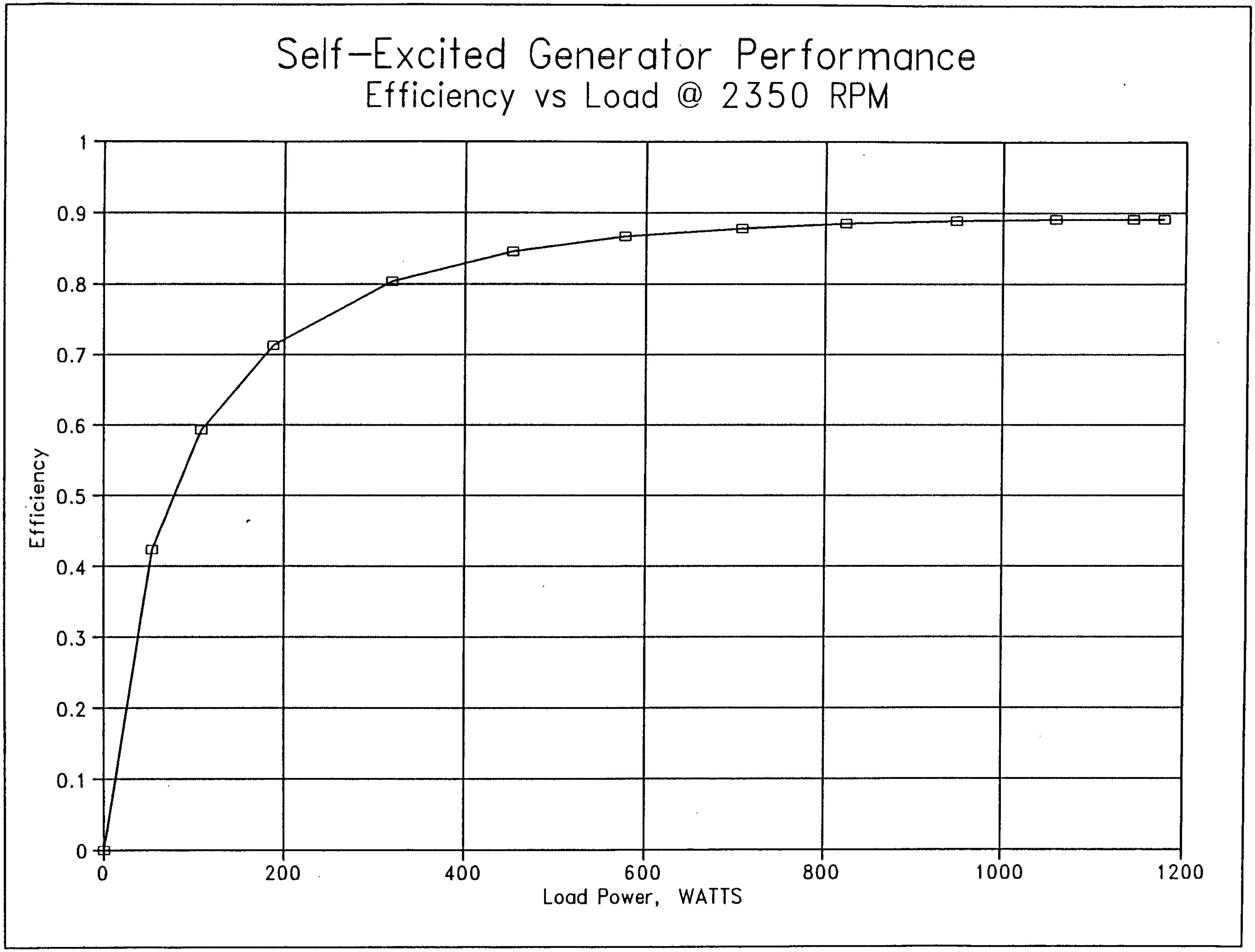

Self-Excited Generator Performance
Efficiency vs Load @ 1950 RPM
Efficiency
Load Power, WATTS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600

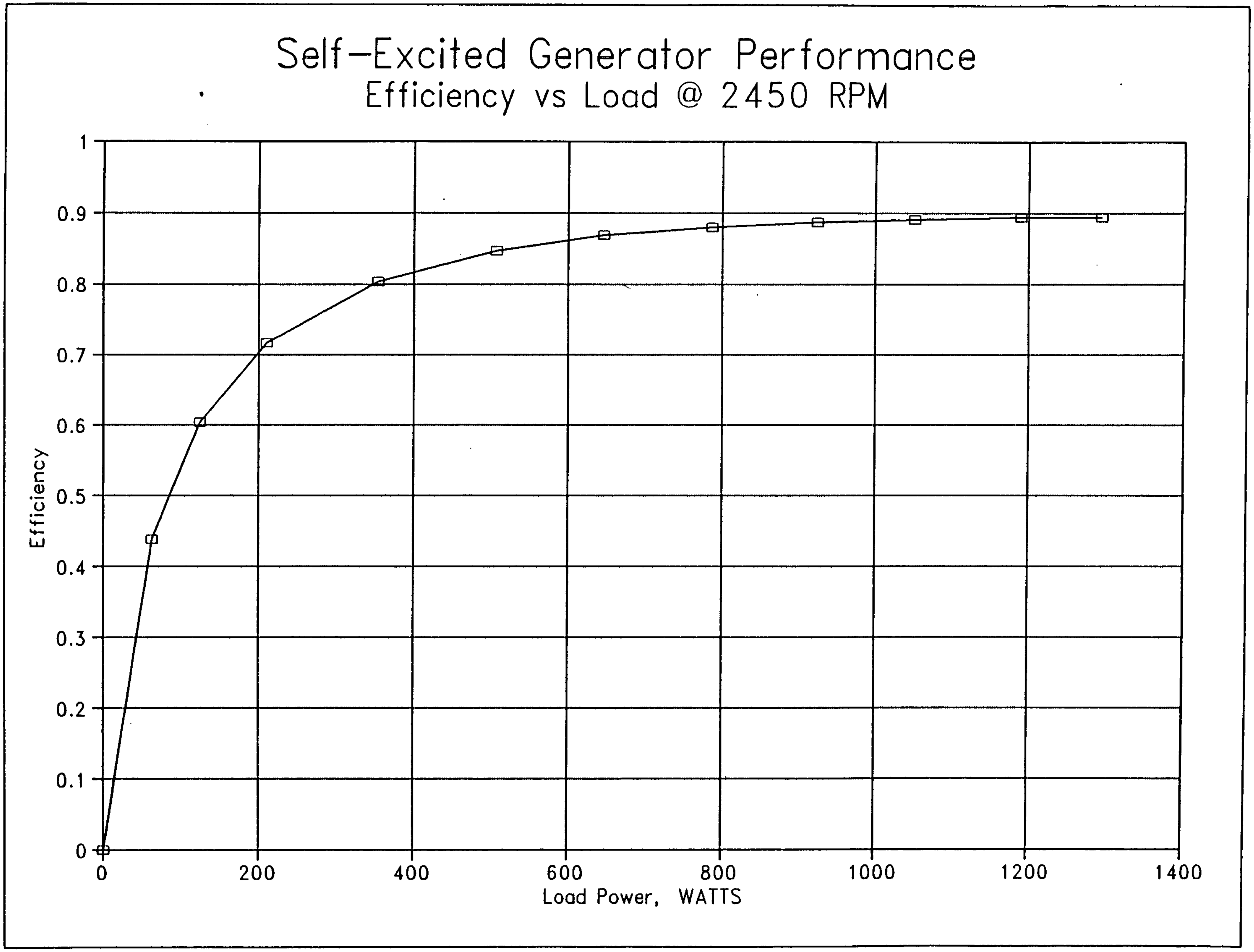


Self–Excited Generator Performance
Efficiency vs Load @ 2050 RPM
Efficiency
Load Power, WATTS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
700
800
900


Self-Excited Generator Performance
Efficiency vs Load @ 2150 RPM
Efficiency
Load Power, WATTS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
700
800
900
1000


Self-Excited Generator Performance
Efficiency vs Load @ 2250 RPM
Efficiency
Load Power, WATTS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
200
400
600
800
1000
1200


Self-Excited Generator Performance
Efficiency vs Load @ 2350 RPM
Efficiency
Load Power, WATTS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
200
400
600
800
1000
1200


Self-Excited Generator Performance
Efficiency vs Load @ 2450 RPM
Efficiency
Load Power, WATTS
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
200
400
600
800
1000
1200
1400