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EXPERIMENTAL EVALUATION OF A SNAP-8 TURBINE-ALTERNATOR

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Cleveland, Ohio
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ABSTRACT

The steady-state performance of a SNAP-8 turbine-alternator was evaluated as part of an investigation of system startup characteristics. The turbine-alternator accumulated 157 hours and was subjected to 135 startups and shutdowns. During the test series, alternator power was varied from 49 to 66 kilowatts at system design mercury flow rate of 12,300 lbm/hr. The minimum alternator power obtained at system self-sustaining mercury flow of 6600 lbm/hr was 21 kilowatts. The large number of startups and shutdowns of the turbine alternator did not result in degradation in performance or operating characteristics.

E-5826.

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SUMMARY

An extensive system test program was conducted on a test version of the SNAP-8 space power system. The tests were mainly directed towards evaluating system startup-shutdown procedures. However, considerable information was obtained on the operating characteristics and steady-state performance of system components including the turbine-alternator. Alternator power was varied from 49 to 66 kilowatts of system design mercury flow rate of 12,300 lbm/hr. The minimum alternator power obtained at system self-sustaining mercury flow of 6600 lbm/hr was 21 kilowatts. The large number of startups and shutdowns of the turbine-alternator did not result in degradation in performance or operating characteristics.

INTRODUCTION

SNAP-8 is a reactor powered mercury Rankine power system being developed for space flight applications. The system is designed to develop a minimum of 35 kilowatts of useful electric power for at least 10,000 hours. Heat from the reactor is transferred to the mercury boiler by pump-circulated NaK (eutectic mixture of sodium and potassium). Mercury vapor drives the turbine-alternator assembly in the power loop. Waste heat is transferred from the mercury condenser to a space radiator by the pump-driven NaK heat-rejection loop. A polyphenyl-ether mixture (4P3E) cools and lubricates the turbine-alternator and mercury-pump motor bearings. Centrifugal pumps driven by electric-induction motors are used to circulate the fluids. The pump motor power is normally supplied by the turbine-alternator assembly.

A test program was conducted in the SNAP-8 test facility at the Lewis Research Center to evaluate SNAP-8 system startup and shutdown procedures (refs. 1 through 7). Although the test program was mainly concerned with evaluating system operating characteristics, considerable turbine-alternator performance data were obtained. The turboalternator was operated for 157 hours at mercury flow rates of 6100 to 12,400 lbm/hr. A significant data point in the reliability and performance of the turbine-alternator was the 135 startups and shutdowns of the unit. This report presents and discusses the steady-state information obtained on the turboalternator during the system startup-shutdown test program. The performance of other SNAP-8 turbine-alternators is presented in references 8 and 9.

DESCRIPTION OF SNAP-8 TEST SYSTEM AND INSTRUMENTATION

Test System

The SNAP-8 test system utilized all of the major SNAP-8 components with the exception of the reactor and radiator. An analog-computer-controlled electric heater in the primary loop simulated the reactor (ref. 10), and air-cooled heat exchangers were used to simulate the waste-heat space radiator (ref. 11).

A four-loop system (fig. 1) was used in the test: two NaK loops, one mercury loop and an oil loop. The four-loop SNAP-8 test system is described in reference 1.

Turbine-alternator. - A cutaway view of the SNAP-8 turbine-alternator is shown in figure 2. Two separate assemblies make up the turbine-alternator: the turbine assembly and the alternator assembly. The turbine and alternator shafts are connected with a splined quill shaft (fig. 2). The figure does not show the oil lines required for the lubricant and coolant (L/C) fluid to and from the bearings and heat exchangers. Intermixing of the L/C fluid and mercury is minimized by means of a low leakage space seal located between the turbine and its support bearing. Details of the space seal are shown in figure 3.

The seal consists of visco and molecular pumps on the mercury side of the shaft and a series slinger and molecular pump on the oil side. A L/C fluid heat exchanger surrounds the mercury visco pump and provides a mercury liquid-vapor interface by condensing mercury vapor in this area of the seal. Any mercury or oil vapor is returned to the liquid interface by the molecular pump. Molecules that escape the molecular pump are vented to space, or a vacuum system during ground testing. References 12 and 13 present details of the space seal design. Carbon face seals (fig. 3) are used in the turboalternator startup and shutdown phases of operation. These are required since the normal shaft seals are less effective when the shaft is rotating at less than design speed. Pressurized bellows lift the face seals off the shaft after the turbine-alternator reaches a minimum speed of 8500 rpm.

Turbine Assembly. - The components that make up the turbine assembly are shown in figure 4. The four-stage impulse turbine is designed with partial admission (38 percent) in the first and second stage stators and full admission in the third and fourth stages. Two angular contact ball bearings support the overhung turbine assembly. The ball bearings are spring loaded in a back-to-back arrangement and lubricated by jet injection of the L/C fluid. Nonflooded bearing operation is maintained by slinger pumps located on both sides of each bearing. A balance piston located at the overhung position of the turbine counteracts the thrust load on the shaft, thereby, reducing bearing axial loads. Figure 2 shows the piping that supplies turbine exhaust pressure to the thrust balance piston.

Alternator Assembly. - A cutaway view of the alternator assembly is shown in figure 2. The alternator is a three-phase-homopolar inductor type machine rated at 80 kilovolt-ampere, 120/208 volt, 400 hertz service, at a rotating speed of 12,000 rpm. It incorporates a brushless solid rotor straddle mounted on two spring loaded angular contact ball bearings. Bearing lubrication is the same as for the turbine assembly. L/C fluid passed through a heat exchanger that surrounds the stator cools the alternator. The hermetically sealed power terminals, splined quill shaft, and alternator heat exchanger are shown in figure 2. The alternator rotor-stator cavity was vented to the facility vacuum system.

Electrical System. - A schematic diagram of the SNAP-8 electrical system is shown in figure 5. The static exciter is connected to the alternator output and provides the necessary field excitation. The voltage regulator maintains a constant alternator voltage by regulating the power transfer between the static exciter and alternator field (ref. 14). Alternator electrical output is divided among three loads, the parasitic load resistor of the speed control, the vehicle load and the pump load. In the test program, an auxiliary load bank was used in place of the SNAP-8 parasitic load resistor.

The auxiliary load bank, together with the saturable reactor and speed-control module functioned as the turbine speed regulator. By parasitically loading the alternator to match the power developed by the turbine, constant speed operation was attained. The speed-control module detects changes in alternator line frequency, which is directly proportional to turbine speed, and supplies a control signal to the saturable reactor, which controls the electric power to the parasitic load (ref. 15). For example, in the case of an increase in turbine speed, the speed control senses an increase in alternator line frequency and allows more current to pass through the saturable reactor. The resulting increase in parasitic load power puts an additional load on the the alternator and increases the turbine shaft torque required. A reverse process occurs for a decrease in turbine speed.

The vehicle load was simulated by a fully adjustable 125 kilovolt-ampere, 0.75 power-factor (pf) lagging load bank.

The pump load consisted of the four prototype system pumps (fig. 5) needed to maintain loop operation. A 400 hertz, 120/208 volt motor-generator set was used as an auxiliary power source for the pumps during system startup. The pump loads were transferred to the alternator and back to the auxiliary power source as required by the test program.

Instrumentation

Static pressures in the turbine were measured by slack-diaphragm, capillary-tube absolute pressure transducers. The transducers were calibrated against a Bourdon-tube reference gage ($\frac{1}{4}$ percent accuracy).

The mercury weight flow was measured at the boiler inlet and outlet with calibrated venturi flowmeters utilizing differential pressure transducers of the slack-diaphragm type with capillary tubes.

The oil flow to the turbine-alternator was measured with turbine flowmeters. Oil temperatures were measured with ISA standard calibration J (iron-constantan) thermocouples. Complete information on the oil-loop instrumentation is found in reference 16.

The alternator output, parasitic and vehicle load electrical power measurements were made with true rms thermoelement-type wattmeters. True rms thermoelement-type voltmeters were used for both voltage and current readings. Current measurements were made by measuring the voltage across a precision shunt placed in the current transformer secondary circuit. All power instrumentation provided direct-current analog outputs. In general, the instrumentation used for pressure, flow, temperature, speed and power measurements was accurate to $\pm$ 1 percent.

The turbine-alternator speed was measured by an electromagnetic reluctance probe which sensed the movement of a multiple tooth gear on the rotating shaft. The output of the reluctance probe was fed into a frequency dc converter. NaK and mercury temperatures were measured by Instrument Society of American (ISA) standard K (Chromel-Alumel) thermocouples.

A computerized digital data system (ref. 17) was used to record data presented in this report, along with strip chart recorders, digital counters and panel meters. The digital data system had a capacity of 400 data points and recorded a cycle of data every 11.43 seconds.

A complete description of the instrumentation employed in the SNAP-8 test facility is given in reference 18.

PROCEDURE

During the test program, turbine-alternator startups were performed both manually and automatically. Manual starts required operator manipulation of valves and switches, while the automatic starts were accomplished with an electronic start programer (ref. 14) initiating and controlling the startup. Of the 135 turbine-alternator starts, the first 108 were manual and the last 27 were automatic. The sequence of events were the same for both the manual and automatic starts.

A typical turbine-alternator start was accomplished as follows: Prior to each start, all mercury lines between the boiler inlet and condenser outlet were filled with liquid mercury (fig. 1). All of the pumps were running on auxiliary power. The turboalternator was started by flowing mercury through the preheated 1300° F boiler. Mercury was injected at a predetermined ramp rate into the loop by manipulating valve V-230 and manually pressurizing the standpipe (fig. 1). As the mercury flow increased toward system "self sustaining" flow rate of 6600 lbm/hr, the turboalternator began to accelerate. System "self-sustaining" flow is defined as the mercury flow rate that provides safe margin of alternator power over that required by all pumps and electrical controls when the turboalternator and pumps are at rated speed. As the alternator accelerated through pump transfer frequency, the pumps were transferred to alternator electrical power. At the termination of the first phase of system startup, the mercury flow was 6600 lbm/hr, the turboalternator was at its rated speed of 12,000 rpm and the pumps running on alternator power.

The second phase of system startup involves ramping the mercury flow from 6600 to 12,300 lbm/hr. This was done by opening valve V-230 at a rate that results in the required ramp rate in flow. Alternator power not needed for pump operation during the ramp was dissipated in the parasitic load bank and vehicle load bank. This general startup procedure was followed for all 135 turbine-alternator starts.

RESULTS AND DISCUSSION

The steady-state data system design mercury flow of 12,300 lbm/hr are presented in figures 6 through 11 and table I. Included is a continuous run of over five hours following start number 122 (figs. 9, 10, and 11). This run maps the turbine performance through a range of turbine back pressures of 6.9 to 27.5 psia. In figures 6, 7, and 8, the data presented are plotted against the turboalternator start number. In general, each data point was taken after system flow rates, temperatures and pressures reached steady-state conditions. All mercury flow rates presented were measured at a liquid flow station.

The turbine inlet data are shown in figures 6 and 9. The mercury vapor quality associated with these data ranged between 93 and 97 percent based on heat balance calculations (ref. 19). Since the small amount of liquid leaving the boiler tends to evaporate prior to reaching the turbine, the mercury vapor flow into the turbine is considered equal to the liquid mercury flow into the boiler. The mercury weight flow varied from 11,938 to 12,382 lbm/hr. The turbine inlet pressure follows the small variations in mercury flow. The inlet pressure to the fourth stage turbine wheel was not obtainable since the turboalternator tested was not instrumented for this measurement. The table below presents the design, adjusted design, and actual pressure ratios for the first two stages obtained early and late in the test program.

Stage	Design Pressure Ratio	Adjusted Design Pressure Ratio	Pressure Ratio at Start No. 8	Pressure Ratio at Start No. 134
1	1.84	1.985	2.075	2.055
2	1.91	1.885	2.112	2.125

Both stages are operating at pressure ratios greater than the design or adjusted design values. The difference between the design and adjusted design pressure ratios is the result of changes that occurred after the turbine design was completed (ref. 9). The major changes were an increase in mercury vapor flow from 11,600 to 11,800 lb/hr and an increase in thrust and interstage seal clearances. The first stage appears to be working close to its adjusted pressure ratio. The second stage measured value is about 12 percent greater than the adjusted design value. The increase in the measured pressure ratio could be the result of the increase in thrust and seal clearances, turbine fabrication tolerances or the accumulation of mass transfer products in the nozzle passages. Due to the relatively small changes in pressure ratios noted between start numbers 8 and 134, the accumulation of mass transfer products in the nozzle passages can probably be eliminated as a cause for the pressure ratio differences. A definitive evaluation of the design-to-experimental data descrepancies requires dissassembly and inspection of the turbine unit which has not been accomplished at this writing.

The turbine inlet temperatures (1237 to 1263° F) followed the reactor simulator controller deadband of 1280 to 1320° F at the simulator outlet.

The turboalternator losses, speed, efficiency and alternator output power are presented in figures 7 and 10. The alternator output power ranged from 49.2 to 66.2 kilowatts (0.79 to 0.93 power factor (pf)). The power fluctuation was the result of turbine back pressure variations and changes in mercury flow rate above and below the system design flow. The design power output for the alternator was 57.9 kW at 1.0 pf. The turbine overall efficiency

$$\frac{\text{Turbine Shaft Power}}{\text{Ideal Enthalphy}} \times \frac{\text{Flow Ratio Quality}}{\text{Heat Balance Quality}}$$

varied from 52.7 to 59.4 percent. The 52.7 percent efficiency occurred during off-design turbine operation with a back pressure of 6.9 psia. The remaining turbine efficiencies were equal to or greater than the design minimum value of 56 percent.

Turboalternator overall efficiency

$$\frac{\text{Alternator Output Power}}{\text{Enthalpy Change}}$$

was in the range of 43.5 to 47.6 percent. As in the case of the turbine efficiency, off-design turbine operation resulted in the low turboalternator efficiency. The design efficiency was 47.9 percent. The turboalternator speed varied from 11,964 to 12,041 rpm. This was well within the speed control design limits of 11,800 to 12,120 rpm (± 1 percent, ref. 12). The plots of turbine bearing, turbine and alternator space seal heat exchangers thermal power losses illustrate effects of changes in alternator power and operating conditions.

Alternator electrical data are presented in figures 8 and 11. The alternator line frequency deviation was from 398.8 to 401.4 hertz and was within the design limits of 396 to 404 hertz (± 1 percent). Fluctuations of alternator terminal voltage, line current and power factor are attributed to changes in alternator load and turbine operating conditions.

The effect of turbine back pressure on alternator output power is illustrated in figure 12. Data are presented for SNAP-8 system design flow (12,300 lbm/hr) and system self-sustaining (6600 lbm/hr) mercury flow rates. Superimposed on the two curves are the data of a similar turbine-alternator tested at Aerojet General Corporation in Azusa, California. The performance correlation for the two turboalternators was good.

Figures 13 through 18 and table II present the steady-state data for mercury flows close to the system self-sustaining liquid mercury flow rate of 6600 lbm/hr. Included is data for a one hour and 20 minute continuous run following start number 93. The turbine back pressure for this run was varied from 5.07 to 16.14 psia (figs. 16, 17, and 18). The quality of mercury vapor from the boiler was 85 to 95 percent based on heat balance calculations (ref. 19).

The significant result of the nominal 6600 lbm/hr mercury flow operation was that adequate alternator power output was available to power the system pumps and controls despite significant variations in turbine input variables. The power requirements for system "self-sustaining" operation were 14.5 kW for the pumps and 2.5 kW for the electrical controls. Figures 13 through 18 show the alternator power levels ranged from 20.8 to 33.3 kW with mercury flow rates of 6100 to 6961 lbm/hr with turbine back pressures of 3 to 15 psia. The 20.8 kW level occurred with a mercury flow rate of 6617 lbm/hr and a turbine back pressure of 14.5 psia. The high alternator power output level of 33.3 kW was obtained with a flow rate of 6961 lbm/hr and a back pressure of 3.23 psia. The 6100 lbm/hr mercury flow rate with a turbine back pressure of 10.86 psia produced an alternator power output of 22.5 kW.

CONCLUDING REMARKS

The evaluation of data obtained during the operation of the SNAP-8 turbine-alternator yield the following conclusions.

(1) The turboalternator was subjected to 135 startups and shutdowns in 157 hours of operation with no significant change in performance. The turbine pressure ratios for the first two stages showed virtually no change from the start to the conclusion of testing at 12,300 lbm/hr mercury flow.

(2) The turbine-alternator gross electrical power output at rated liquid mercury flow of 12,300 lbm/hr exceeded the design requirement of 57.9 kW at 14 psia turbine back pressure. The turboalternator tested produced 61 kW with a mercury flow of 12,266 lbm/hr and 13.78 psia back pressure.

(3) The turbine-alternator gross electrical power output at system self-sustaining mercury flow of 6600 lbm/hr (nominal) was more than adequate to power the system pumps and control requirements of 17 kW. The lowest power output recorded was 20.8 kW with a mercury flow of 6617 lbm/hr and turbine back pressure of 14.5 psia.

(4) The speed controller maintained a steady turboalternator speed of 11,964 to 12,041 rpm, well within the design of 12,000 ± 120 rpm.

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National Aeronautics and Space Administration
Cleveland, Ohio June 19, 1970

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START NO.	DATE TIME HR. MIN 1969	HG LIQ FLOW LBm/HR	TURBINE PRESSURES INLET PSIA	2ND/3RD STAGE IN PSIA	OUTLET PSIA	TURBINE INLET TEMP °F	EFF. %	TAA EFF. %	ELECT POWER KW	SPEED RPM	THERMAL PWR. LOSS TURB BRG. KW	TURB SP. SEAL KW	ALT HB. KW	ALTERNATOR FREQ HERTZ	ΦA CURR AMPS	VOLT. V	POWER FACTOR
8	4/9	12097	244.81	117.8/55.8	14.84	1243	58.8	46.4	58.8	12000	3.91	2.47	4.18	400.0	205.10	120.3	0.794
10	4/10	12382	248.53	120.1/57.3	13.36	1238	58.2	46.0	61.7	12012	3.93	2.81	4.05	400.4	211.26	121.0	0.801
50	5/22	12071	242.30	118.9/55.4	14.54	1240	55.6	45.5	56.9	12011	5.37	2.96	3.46	400.4	196.20	122.2	0.794
81	6/7	11942	237.70	116.6/54.4	15.06	1242	57.7	46.7	57.1	12018	4.21	2.96	2.60	400.6	170.20	121.9	0.904
84	6/8	11938	238.10	115.8/54.4	13.55	1243	57.4	46.6	58.4	12015	4.39	3.07	2.92	400.5	181.20	121.2	0.890
98	6/10	12137	243.90	119.7/55.8	14.98	1244	57.8	46.5	58.6	11975	4.35	3.14	3.24	399.2	192.10	121.5	0.830
99	6/11	12295	246.70	120.1/56.5	16.49	1244	57.4	46.8	58.3	11964	4.40	3.08	3.15	398.8	189.10	121.3	0.834
107	6/12	12103	243.20	118.7/55.7	14.43	1247	58.0	46.7	59.4	12012	4.42	3.03	2.79	400.4	183.40	119.8	0.897
113	6/23	12221	245.60	120.3/56.5	14.67	1263	57.7	47.0	59.9	12022	4.26	3.09	3.44	400.7	206.30	121.0	0.800
122	0-4	12207	244.90	119.4/55.7	11.24	1246	56.4	45.5	62.7	12035	4.43	2.98	3.02	401.2	188.67	121.0	0.914
	0-17	12244	244.30	119.1/56.5	12.80	1248	57.3	46.3	61.6	12037	4.58	3.02	3.24	401.2	186.53	120.0	0.909
	0-34	12266	244.70	119.8/56.0	13.78	1248	57.8	47.0	61.0	12035	4.54	3.02	3.29	401.2	184.67	120.1	0.911
	0-52	12248	245.20	119.7/55.5	16.85	1250	57.6	47.1	57.9	12038	4.51	3.14	3.23	401.3	178.59	120.0	0.894
	0-58	12279	244.76	120.0/55.6	20.71	1250	59.0	47.4	54.7	12028	4.58	3.22	3.08	400.9	171.80	120.4	0.881
	1-7	12276	244.99	120.0/55.9	23.24	1248	58.9	47.2	52.3	12034	4.50	3.42	2.85	401.1	163.73	121.1	0.883
	1-17	12226	245.54	120.3/55.8	12.31	1249	56.5	45.8	61.5	12041	4.59	3.06	3.27	401.4	186.66	119.9	0.904
	1-25	12227	245.53	120.3/56.1	12.41	1250	57.8	46.4	62.1	12034	4.57	2.97	3.41	401.1	189.96	120.1	0.909
	1-33	12239	244.29	119.5/55.8	12.01	1250	56.1	46.4	62.4	12032	4.96	2.91	3.59	401.1	186.55	120.5	0.925
	1-39	12213	244.36	119.4/56.1	11.72	1247	56.8	45.9	62.0	12040	4.94	2.93	3.39	401.3	187.03	120.3	0.917
	6/25 2-0	12203	245.17	119.4/55.8	15.00	1249	57.1	46.4	59.0	12037	4.90	2.96	3.32	401.2	179.89	120.1	0.909
	2-8	12235	245.57	120.3/55.9	16.43	1250	57.6	46.7	57.9	12038	4.68	3.03	3.24	401.3	178.69	120.4	0.899
	2-16	12273	245.54	119.7/55.5	20.53	1248	57.7	47.1	54.6	12038	4.66	3.21	3.12	401.3	168.69	119.9	0.894
	2-35	12193	244.73	119.8/55.5	12.88	1248	57.6	46.3	61.3	12037	4.72	2.86	3.35	401.2	184.36	120.3	0.918
	2-48	12119	245.00	120.0/55.6	10.53	1247	56.0	45.7	63.5	12034	4.72	2.81	3.49	401.1	189.03	119.9	0.926
	2-56	12344	244.89	119.8/55.5	11.12	1247	56.4	46.2	63.3	12025	4.64	2.89	3.45	400.8	189.72	121.1	0.930
	3-5	12189	244.50	119.5/55.6	13.87	1250	57.7	46.2	60.1	12031	4.75	2.93	3.43	401.0	184.04	120.6	0.904

TABLE I. – TURBOALTERNATOR OPERATING PARAMETERS AT 12,300 LBm/HR LIQUID MERCURY FLOW

START NO	DATE TIME HR-MIN 1969	HG LIQ FLOW LBm/HR	TURBINE PRESSURES			TURBINE		TAA EFF %	ELECT POWER KW	SPEED RPM	THERMAL PWR LOSS			ALTERNATOR			
			INLET PSIA	2ND/3RD STAGE IN. PSIA	OUTLET PSIA	INLET TEMP °F	EFF. %				TURB BRG KW	TURB SP.SEAL KW	ALT HE KW	FREQ HERTZ	ΦA CURR AMPS	VOLT V	POWER FACTOR
122	3-13	12215	244.56	119.5/55.5	16.47	1250	57.2	47.2	58.2	12031	4.73	3.11	3.24	401.0	176.73	119.7	0.911
	3-19	12245	245.42	120.1/56.0	20.54	1250	57.8	46.6	54.2	12037	4.71	3.26	3.11	401.2	168.70	119.7	0.885
	3-29	12323	245.30	120.0/56.0	22.81	1249	59.2	46.8	52.5	12031	4.71	3.29	3.09	401.0	165.67	120.2	0.880
	3-38	12199	245.44	120.0/56.4	27.47	1249	58.9	46.8	49.2	12027	4.66	3.52	2.97	400.9	154.66	119.7	0.875
	3-46	12241	244.94	120.0/55.8	23.45	1250	58.7	47.2	52.2	12028	4.73	3.41	2.69	400.9	163.21	119.9	0.884
	3-54	12166	244.19	119.3/55.6	21.36	1250	58.6	47.2	53.7	12034	4.73	3.14	3.10	401.1	168.19	119.8	0.889
	4-9	12182	245.33	119.9/56.1	24.67	1249	59.3	47.3	51.3	12021	4.67	3.38	2.98	400.7	161.70	119.7	0.878
	4-20	12250	245.77	120.4/55.8	18.19	1251	58.2	47.3	56.8	12033	4.65	3.09	3.18	401.1	174.58	119.7	0.903
	4-29	12267	245.87	120.2/55.7	14.79	1252	57.5	47.1	60.0	12031	4.70	2.98	3.34	401.0	181.64	120.1	0.915
	4-34	12279	245.83	120.2/55.8	12.87	1249	56.6	46.3	61.2	12031	4.76	2.94	3.37	401.0	184.23	120.1	0.921
	4-37	12228	245.77	119.9/55.8	10.96	1250	55.7	45.5	62.7	12031	4.74	2.89	3.43	401.0	188.11	120.2	0.920
	4-40	12289	245.96	120.7/55.8	8.98	1250	55.2	45.2	65.2	12033	4.73	2.81	3.48	401.1	194.00	120.1	0.931
	4-43	12267	245.47	120.0/55.7	6.89	1251	52.7	43.5	66.2	12034	4.75	2.74	3.56	401.1	196.44	120.0	0.928
	5-17	12232	245.52	120.2/55.8	20.05	1249	59.4	47.6	55.4	12029	4.68	3.27	3.02	401.0	168.96	119.9	0.907
134	6/27	12267	242.57	118.9/58.1	15.02	1237	58.1	46.5	58.2	12027	4.71	3.15	2.18	400.9	173.93	120.8	0.920

TABLE 1. — CONTINUED

START NO.	DATE TIME MIN 1969	HG LIQ FLOW LBm/HR	TURBINE PRESSURES			TURBINE		TAA EFF %	ELECT POWER KW	SPEED RPM	THERMAL PWR LOSS			ALTERNATOR			
			INLET PSIA	2ND/3RD STAGE IN. PSIA	OUTLET PSIA	INLET TEMP °F	EFF %				TURB BRG KW	TURB SR SEAL KW	ALT H.E. KW	FREQ HERTZ	φA CURR. AMPS	VOLT V.	POWER FACTOR
4	3/11	6100	120.45	53.4/25.2	10.86	1223	57.3	41.4	22.5	11982	3.57	2.56	1.79	399.4	109.10	120.56	0.602
9	4/10	6741	133.80	60.1/28.1	7.49	1228	54.5	43.2	29.7	12010	3.35	2.22	1.76	400.3	115.20	121.20	0.721
15	4/22	6961	135.20	62.8/28.8	3.23	1207	49.6	39.5	33.3	12002	3.34	2.14	2.31	400.1	150.60	121.70	0.613
39	5/19	6855	135.70	62.7/28.7	10.77	1232	57.7	43.4	27.1	12012	3.58	2.66	2.16	400.4	108.80	120.93	0.688
50	5/22	6617	126.30	57.8/26.7	14.50	1195	55.1	40.2	20.8	11946	3.72	2.75	2.33	398.2	115.20	121.40	0.497
57	6/4	6726	133.40	59.7/27.8	11.10	1248	58.4	42.8	25.9	11994	3.58	2.66	2.13	399.8	134.60	121.60	0.529
64	6/5	6748	131.30	60.2/27.8	11.55	1217	56.6	42.6	25.2	12010	3.59	2.65	1.76	400.3	106.30	121.30	0.658
81	6/7	6691	128.00	58.7/27.0	11.07	1202	59.0	43.2	25.3	12007	3.63	2.60	2.28	400.2	108.19	120.40	0.654
84	6/8	6807	131.00	61.7/28.1	12.20	1208	56.9	42.3	24.4	12008	3.52	2.73	1.55	400.3	105.66	122.10	0.640
93	6/9 1/2	6743	130.30	57.3/28.1	14.88	1196	55.2	41.8	22.4	12009	3.42	2.85	1.67	400.3	101.62	120.60	0.613
	9	6779	131.05	60.8/27.9	10.34	1198	59.7	43.5	26.7	12007	3.51	2.63	1.81	400.2	109.09	121.24	0.673
	16	6849	132.81	61.3/28.5	13.97	1205	57.2	42.9	24.1	12009	3.55	2.84	1.78	400.3	105.19	121.15	0.650
	23	6757	130.94	60.2/27.7	8.75	1203	56.7	43.5	27.7	12009	3.53	2.38	2.01	400.3	109.63	121.02	0.701
	27	6726	129.3	59.8/27.4	8.25	1204	54.9	42.7	27.5	12015	3.58	2.43	1.97	400.5	112.69	121.30	0.686
	36	6851	131.91	60.8/28.1	8.63	1202	56.8	43.4	28.1	12010	3.47	2.26	2.20	400.3	113.02	121.26	0.700
	54	6825	131.24	60.3/27.6	5.07	1204	53.2	42.1	31.3	12010	3.45	2.30	2.01	400.3	116.47	121.12	0.740
	59	6827	130.68	60.6/27.5	5.48	1205	55.8	42.6	30.9	12003	3.49	2.28	2.02	400.1	118.33	120.99	0.739
	66	6702	129.70	60.1/27.3	8.52	1204	57.2	43.0	27.7	12007	3.48	2.45	2.03	400.2	114.04	121.11	0.687
	73	6779	130.90	60.2/27.7	12.58	1203	56.1	42.7	24.4	12010	3.47	2.60	2.03	400.3	105.76	120.88	0.654
	76	6775	131.09	60.2/28.2	14.97	1204	57.0	42.5	22.8	12010	3.53	2.40	2.27	400.3	102.70	120.61	0.622
	81	6760	130.49	60.1/28.2	16.14	1204	56.5	42.0	21.8	12009	3.49	2.73	1.88	400.3	98.32	120.63	0.617
97	6/10	6747	130.81	60.6/28.4	15.47	1209	55.6	41.7	22.0	12005	3.52	2.94	1.51	400.2	100.47	121.45	0.611
107	6/12	6491	125.00	57.6/26.7	11.82	1211	55.0	42.9	23.6	12000	3.49	2.88	1.58	400.0	103.80	120.70	0.643
113	6/23	6811	131.20	60.2/28.1	14.60	1210	56.0	42.8	23.5	12021	3.60	2.89	2.00	400.7	103.99	120.15	0.638
129	6/26	6836	133.40	62.1/28.3	9.26	1217	55.8	42.8	27.5	12006	3.56	2.71	2.05	400.2	137.80	121.30	0.550
135	6/27	6525	125.40	53.6/26.5	11.85	1207	56.6	43.2	23.8	11992	3.43	2.79	1.93	399.7	127.45	121.11	0.519

TABLE 2. – TURBOALTERNATOR OPERATING PARAMETERS AT 6600 LBm/HR LIQUID MERCURY FLOW

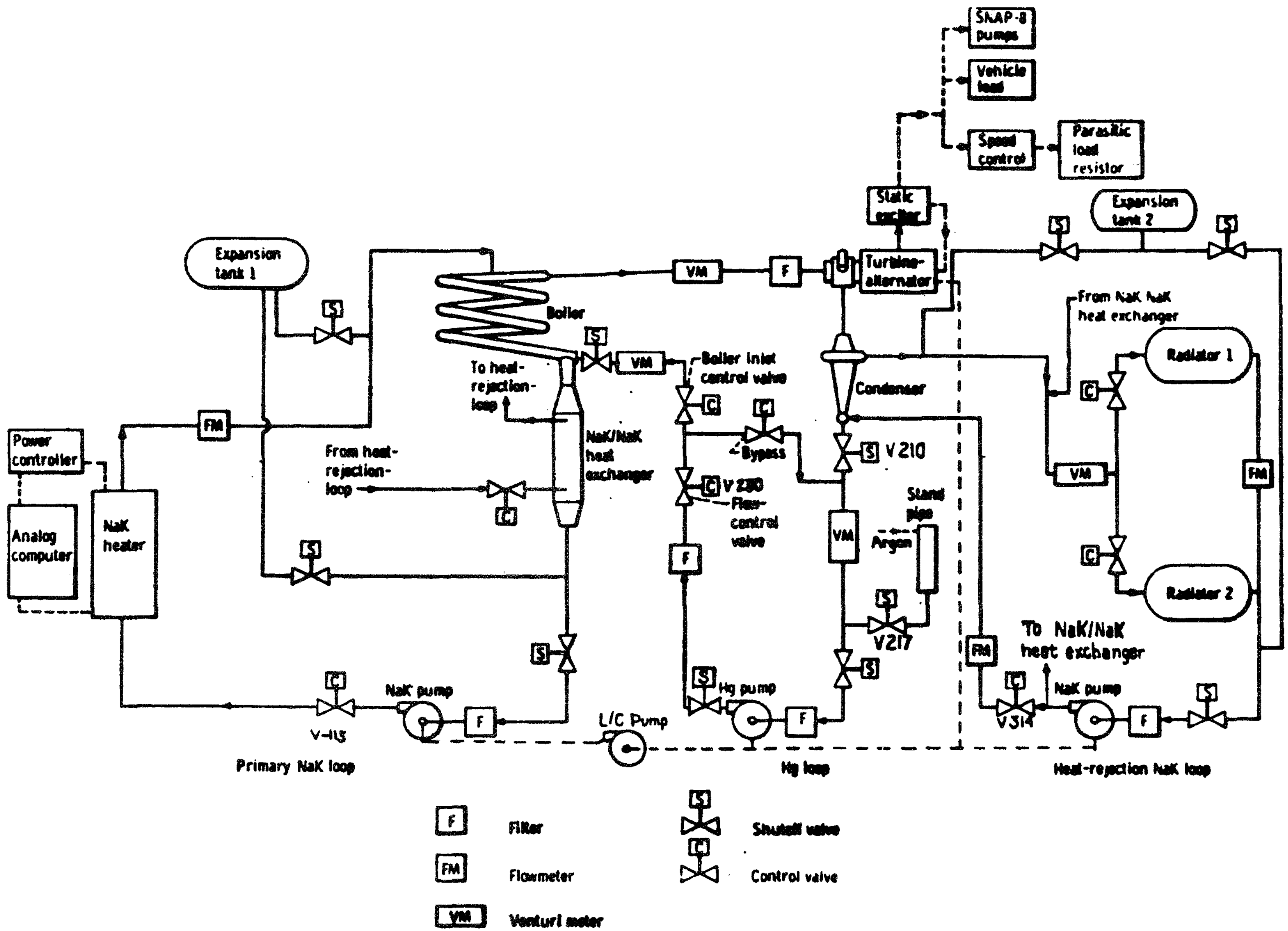

Figure 1. - SNAP-8 Test System Schematic

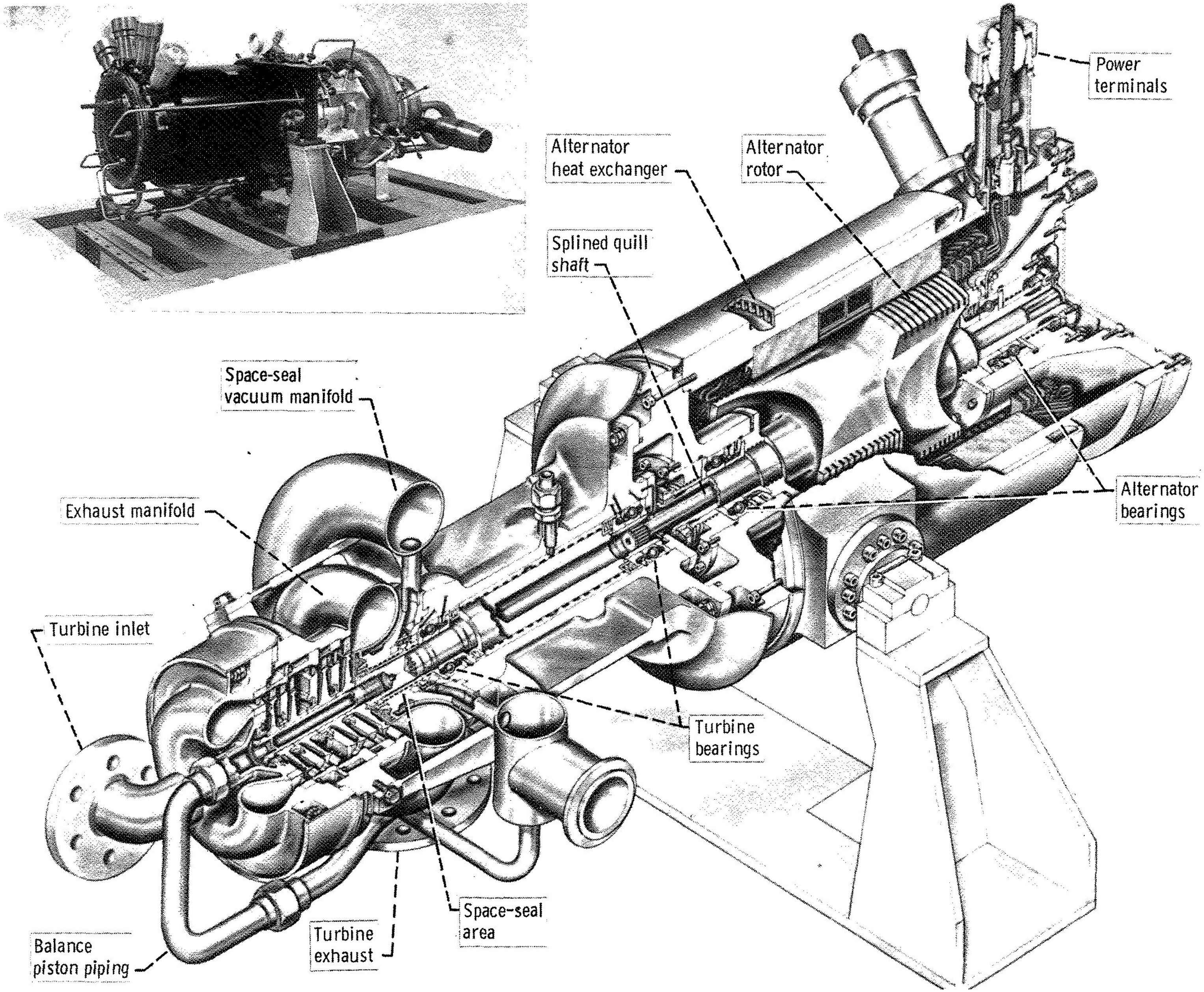

Figure 2. - SNAP-8 turbine-alternator.

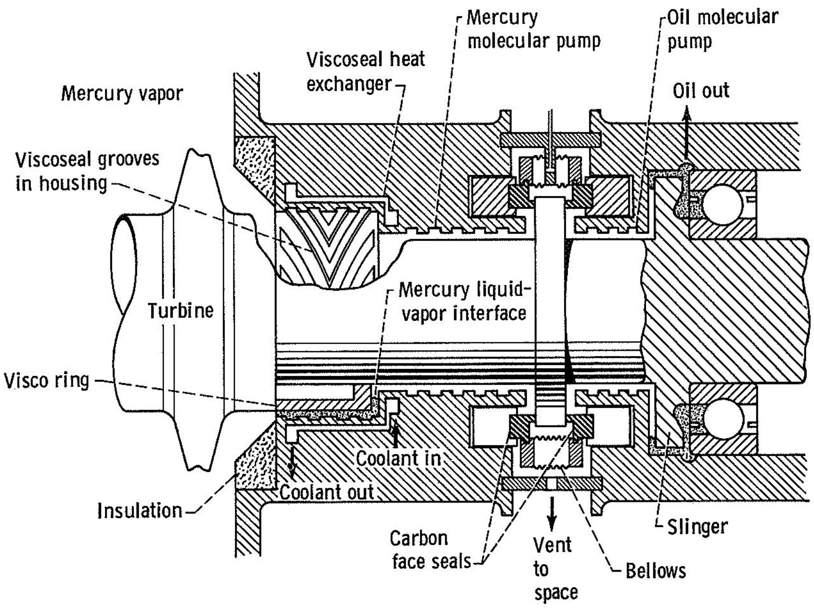

Figure 3. - SNAP-8 space seal.

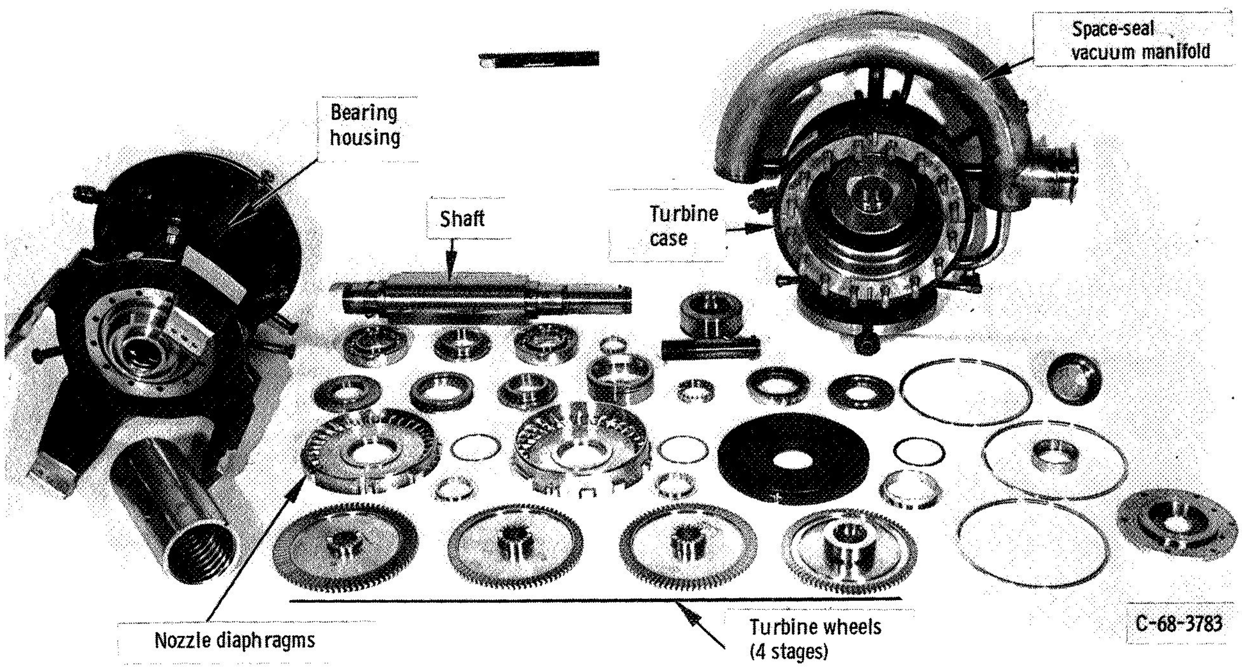

Figure 4. - SNAP-8 turbine-assembly components.

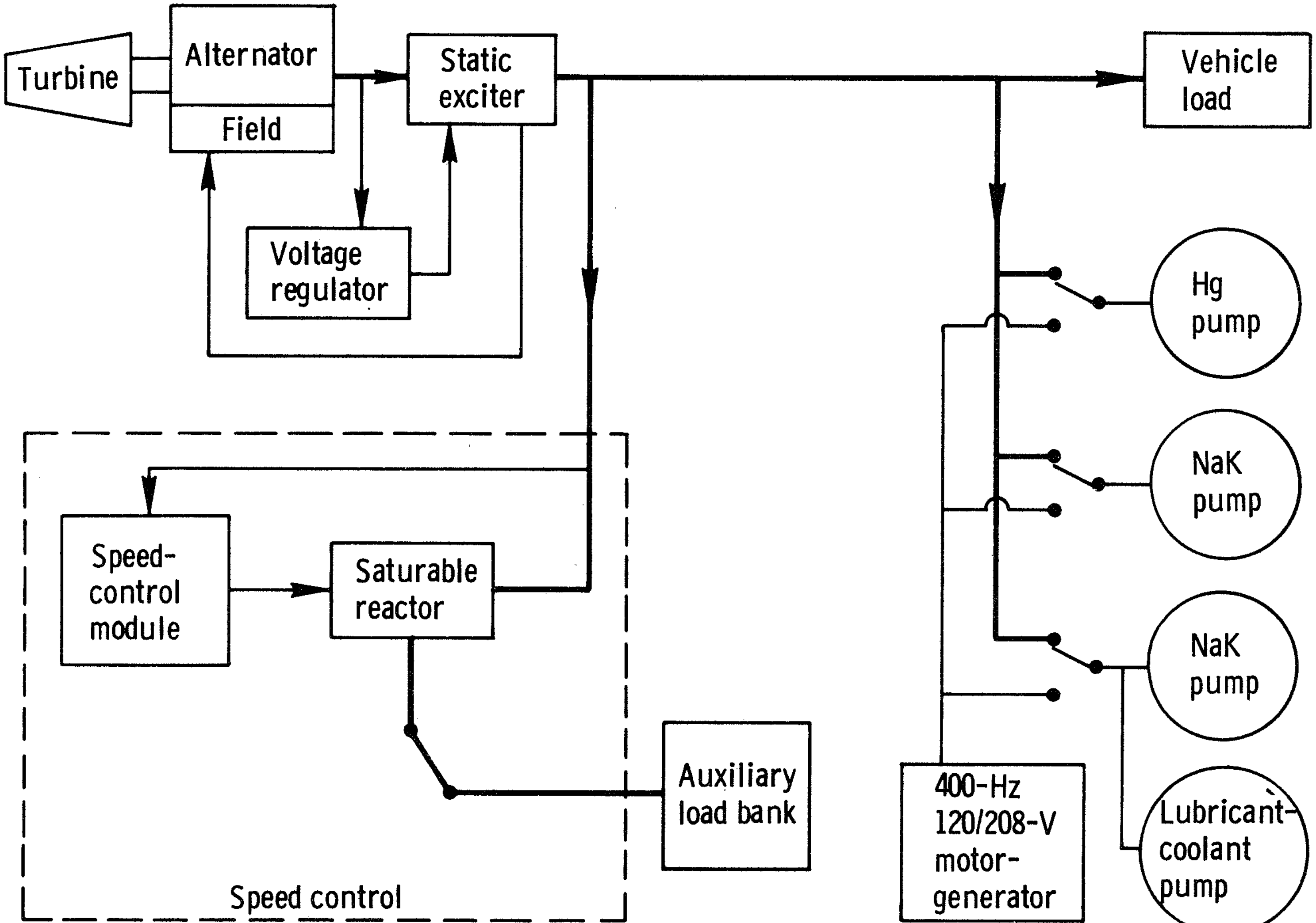

Figure 5. - Schematic diagram of SNAP-8 electrical system.

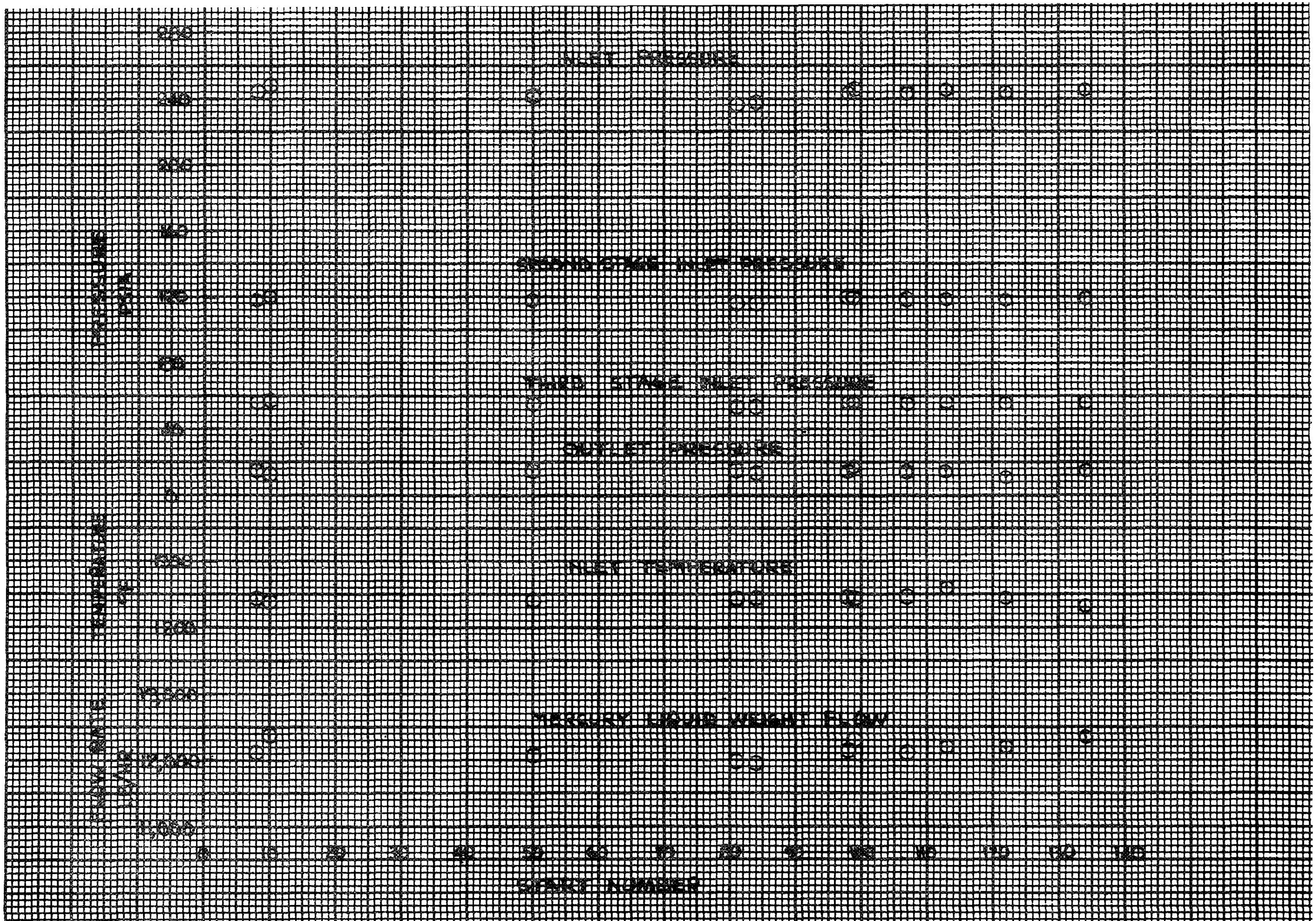

FIGURE 6. - TURBINE INLET PARAMETERS AT 12,500 LB/HR MERCURY FLOW

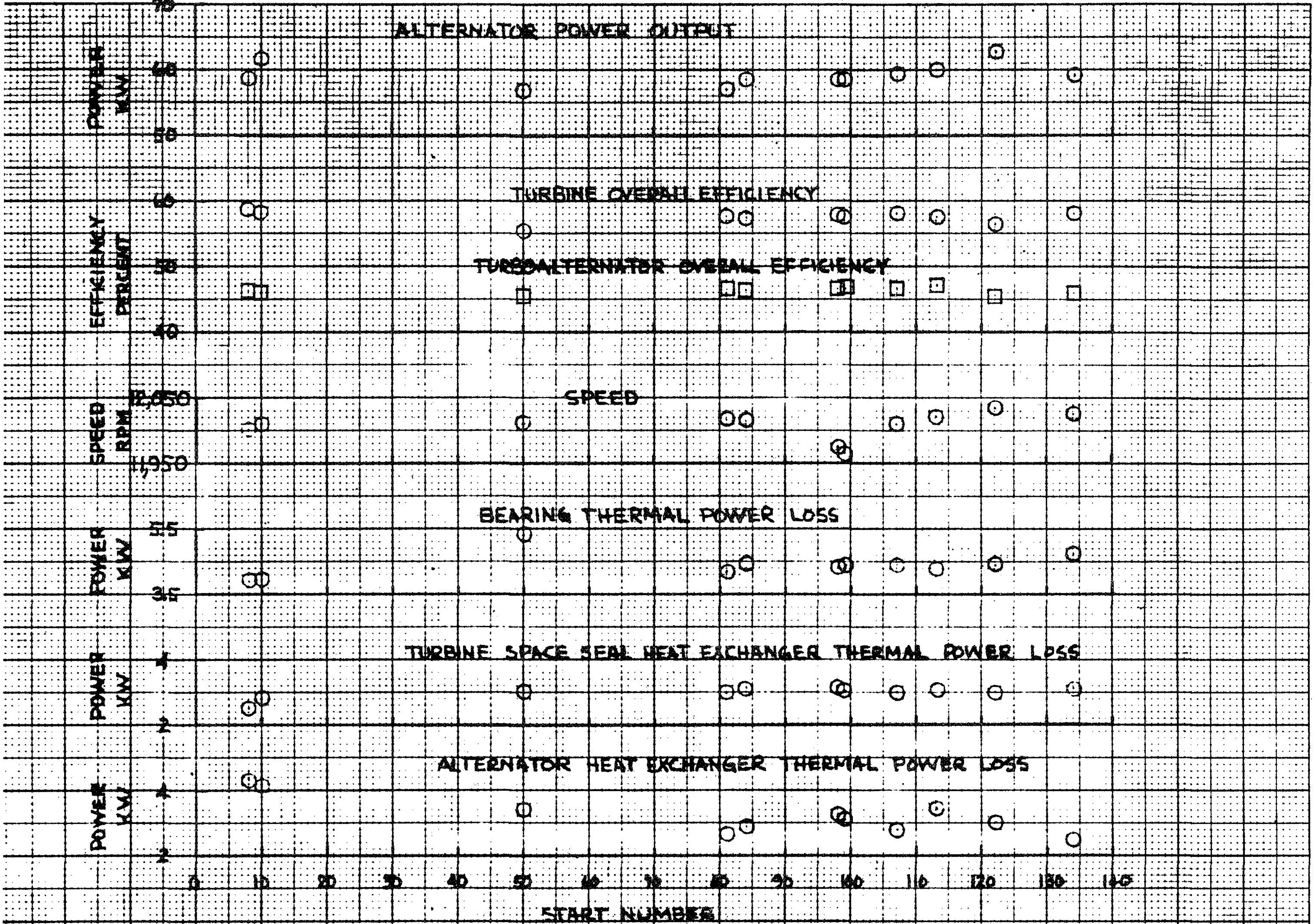

FIGURE 7. - TURBOALTERNATOR OPERATING PARAMETERS AT 12,300 LB/HR MERCURY FLOW

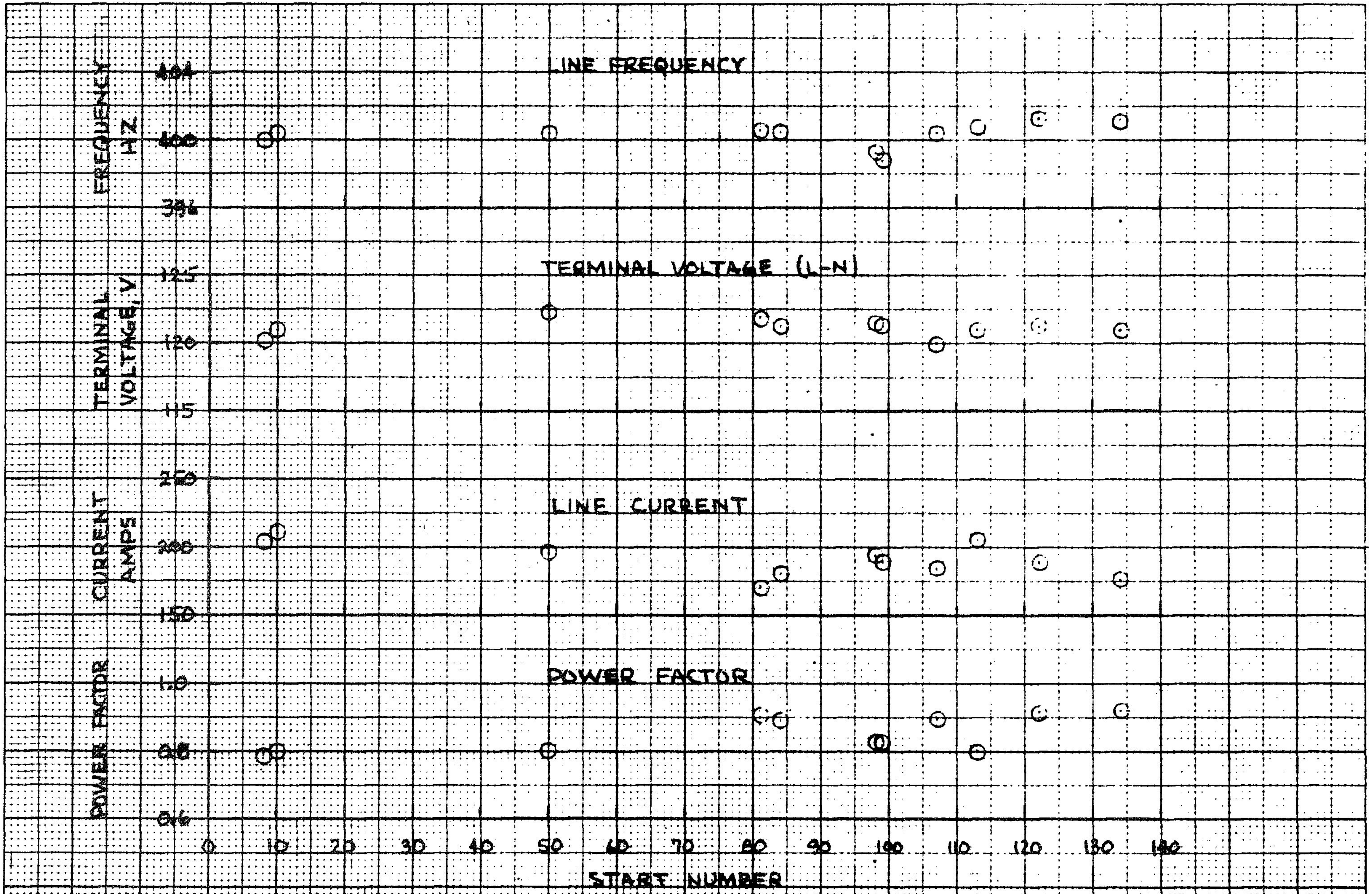

FIGURE 8. - ALTERNATOR ELECTRICAL PARAMETERS AT 12,300 LB/HR MERCURY FLOW

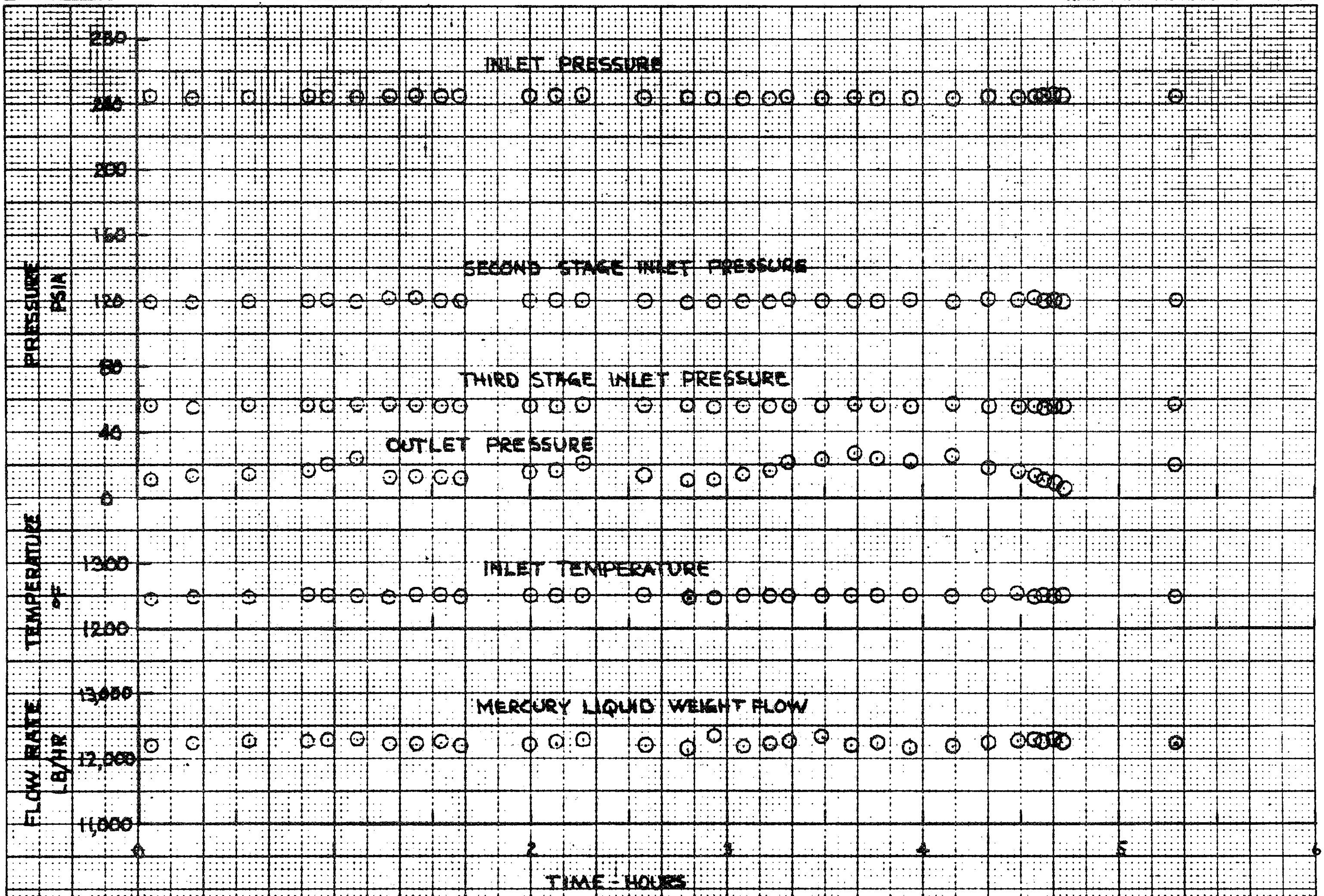

FIGURE 9. - TURBINE INLET PARAMETERS AT 12,300 LB/HR MERCURY FLOW

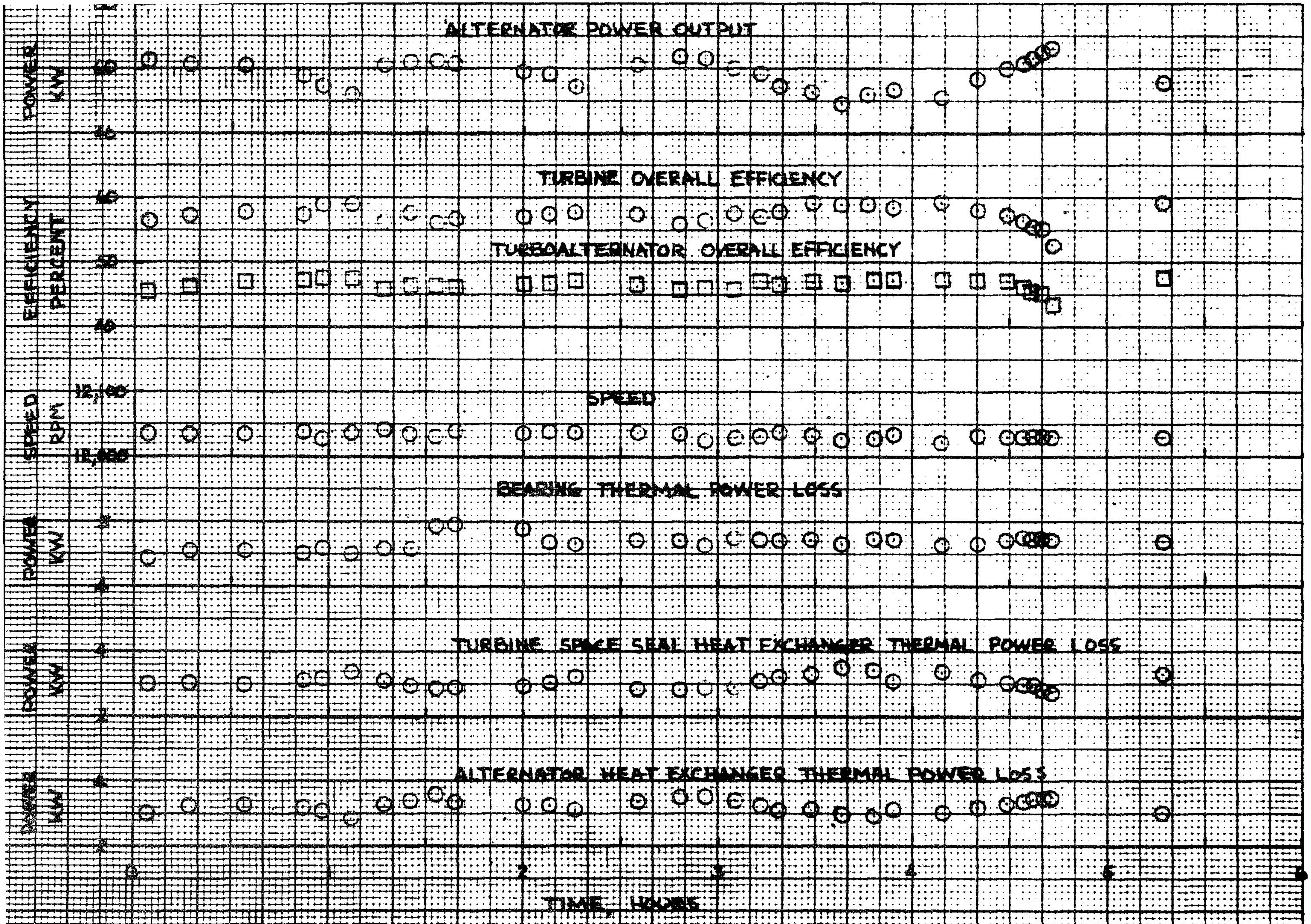

FIGURE 16. - TURBOALTERNATOR OPERATING PARAMETERS AT 12,300 LB/HR MERCURY FLOW

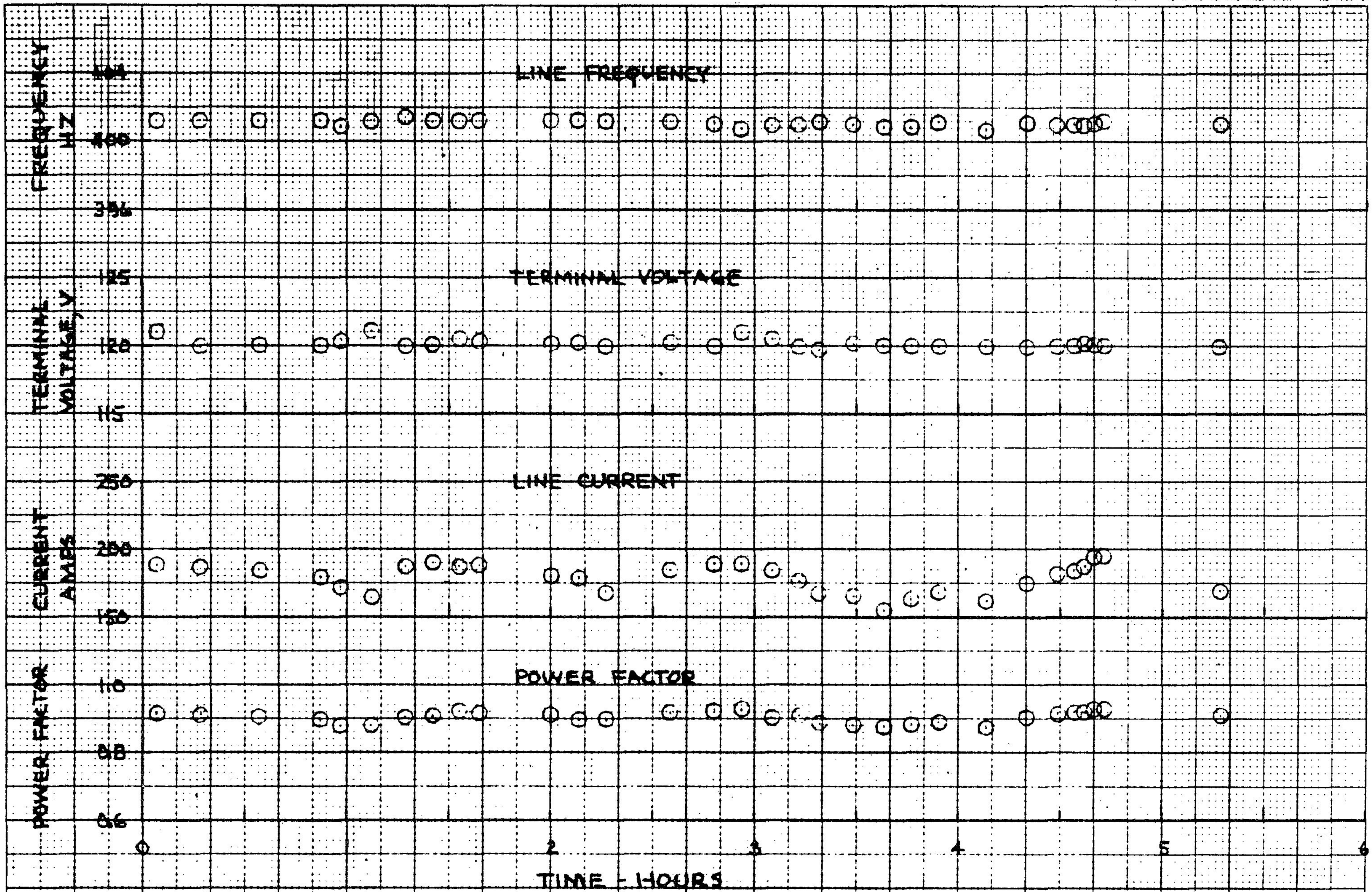

FIGURE 11. - ALTERNATOR ELECTRICAL PARAMETERS AT 12,300 LB/HR MERCURY FLOW

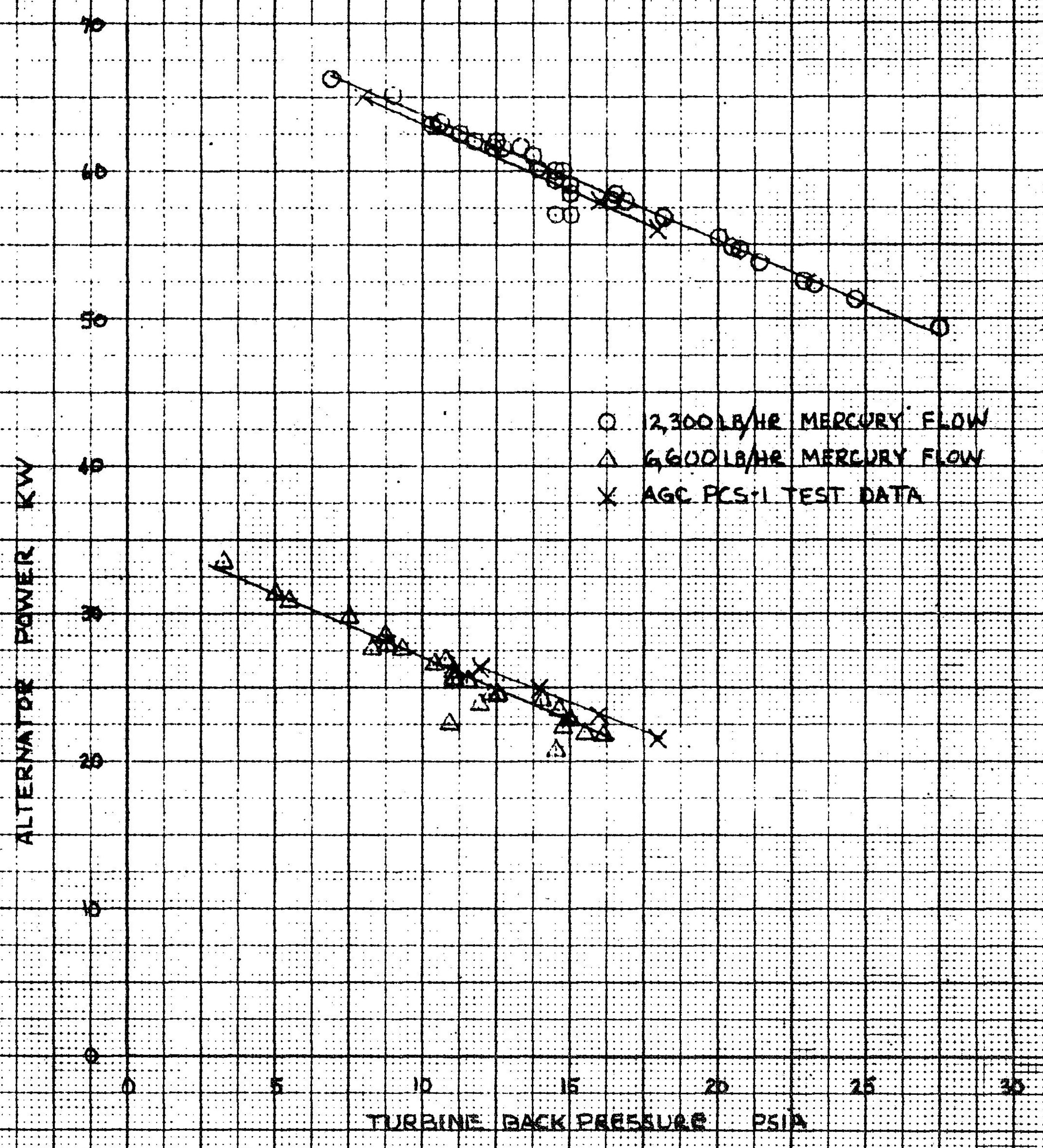

FIGURE 12 - TURBOALTERNATOR POWER OUTPUT PARAMETERS

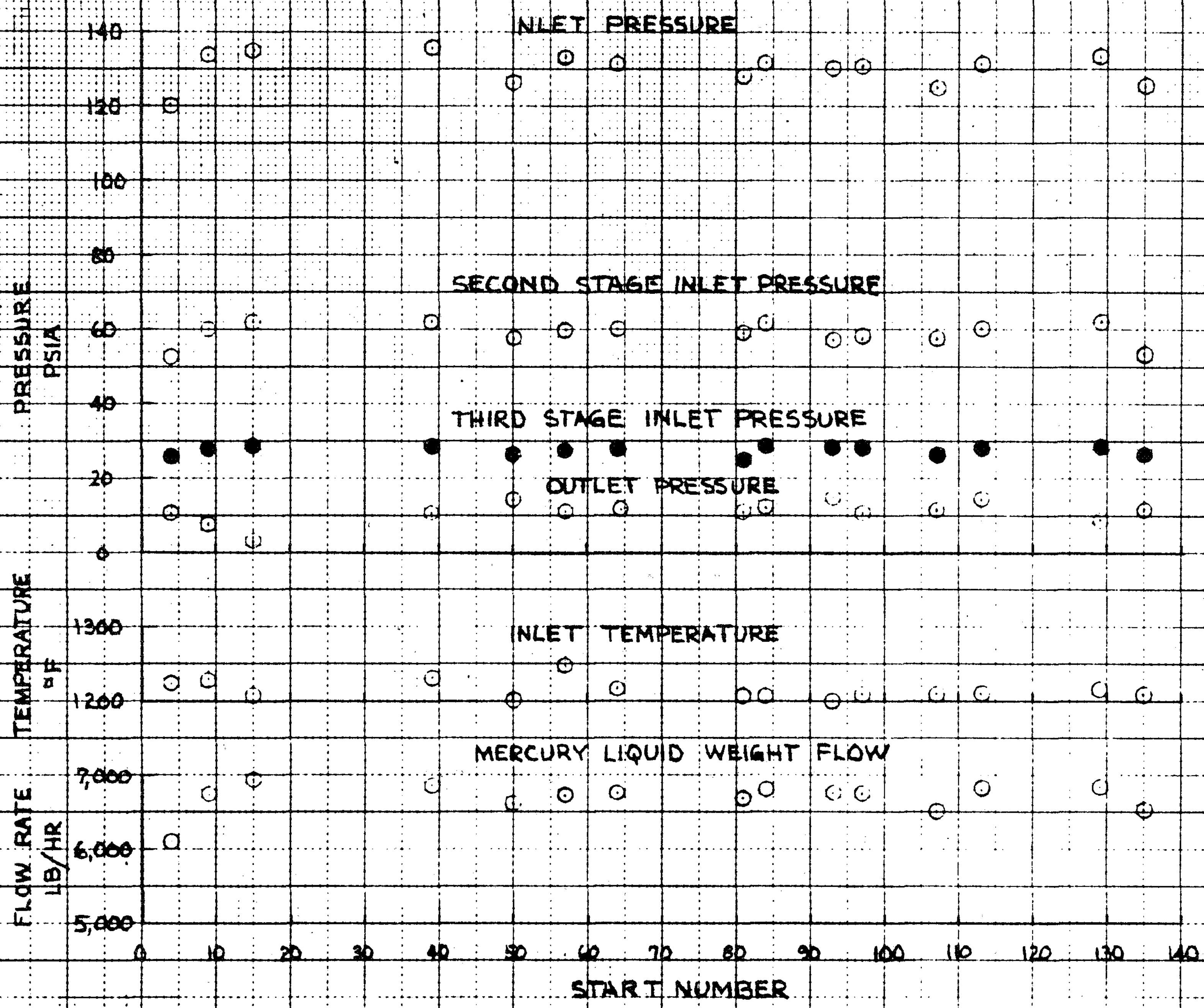

FIGURE 13. - TURBINE INLET PARAMETERS AT 6600 LB/HR MERCURY FLOW

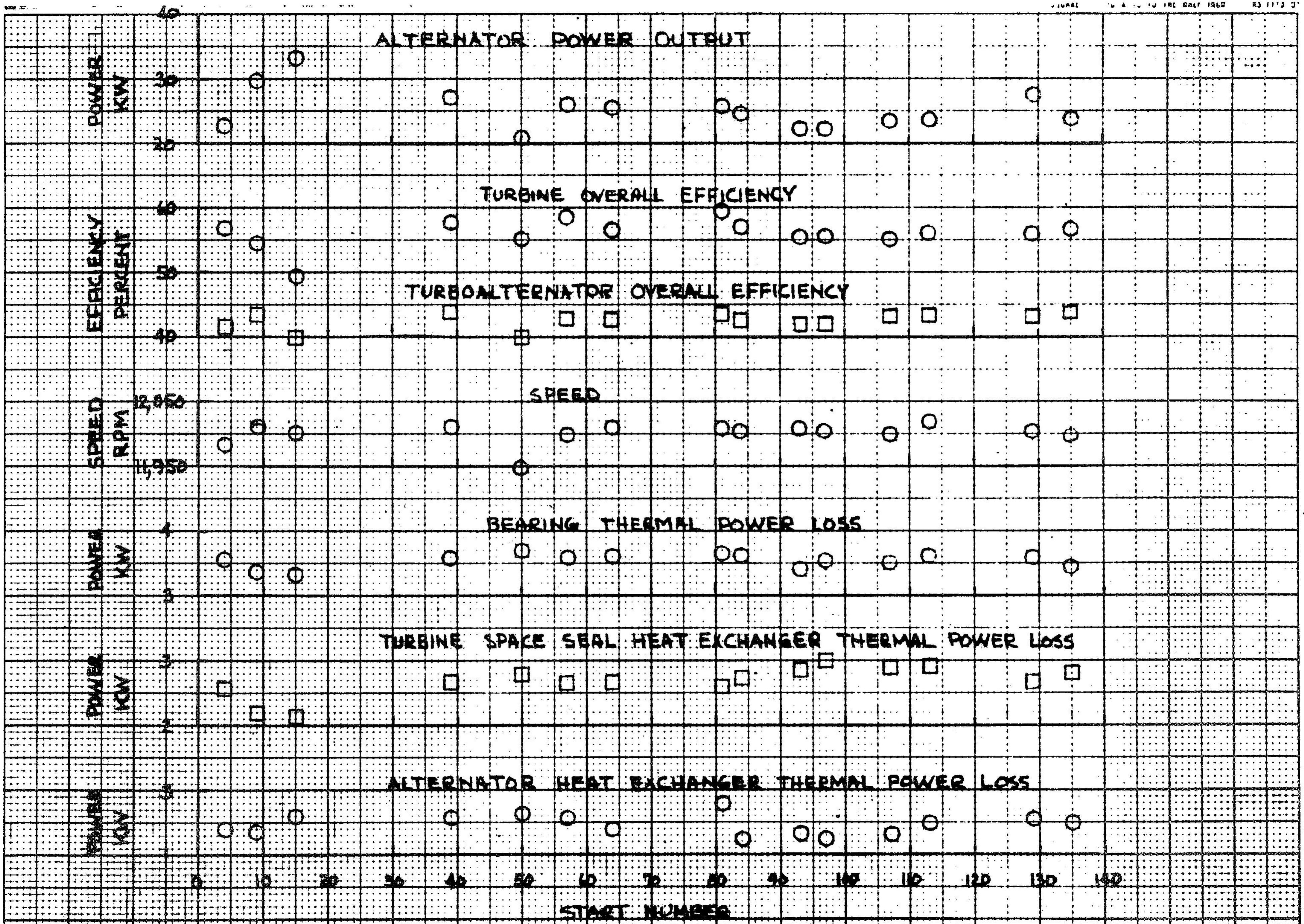

FIGURE 14. - TURBOALTERNATOR OPERATING PARAMETERS AT 6600 LB/HR MERCURY FLOW

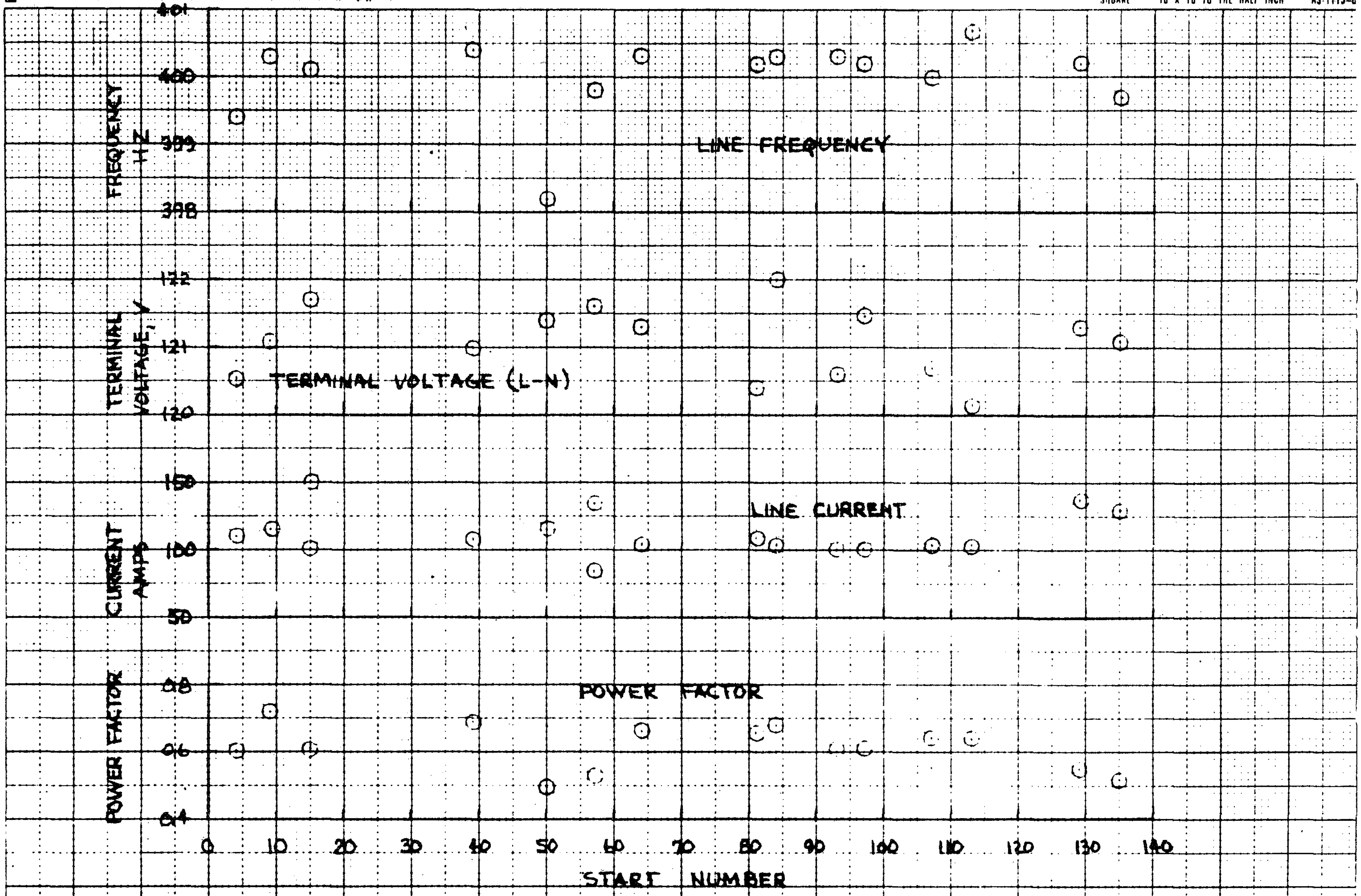

FIGURE 15. - ALTERNATOR ELECTRICAL PARAMETERS AT 6600 LB/HR MERCURY FLOW

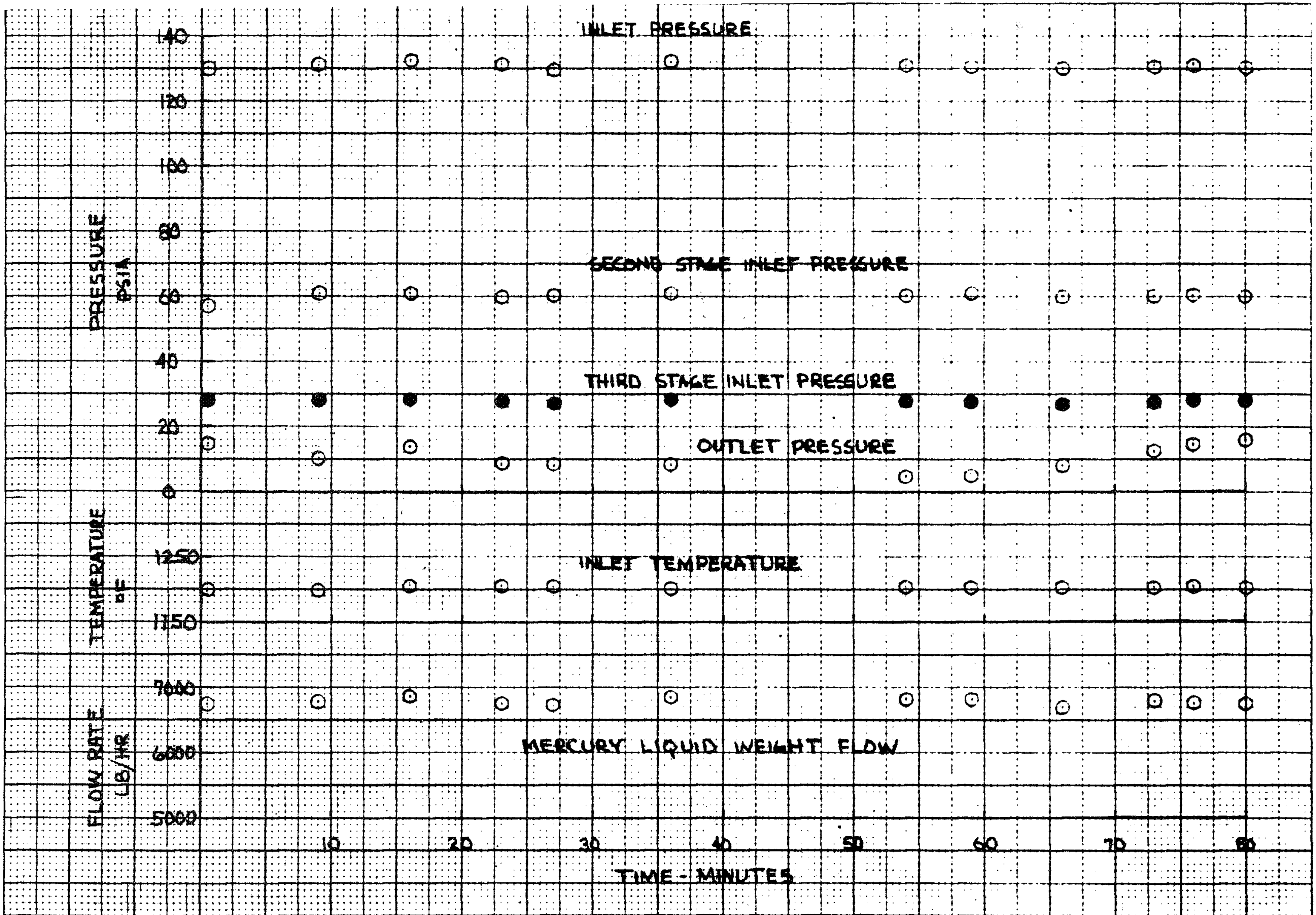

FIGURE 16 - TURBINE INLET PARAMETERS AT 6600 LB/HR MERCURY FLOW

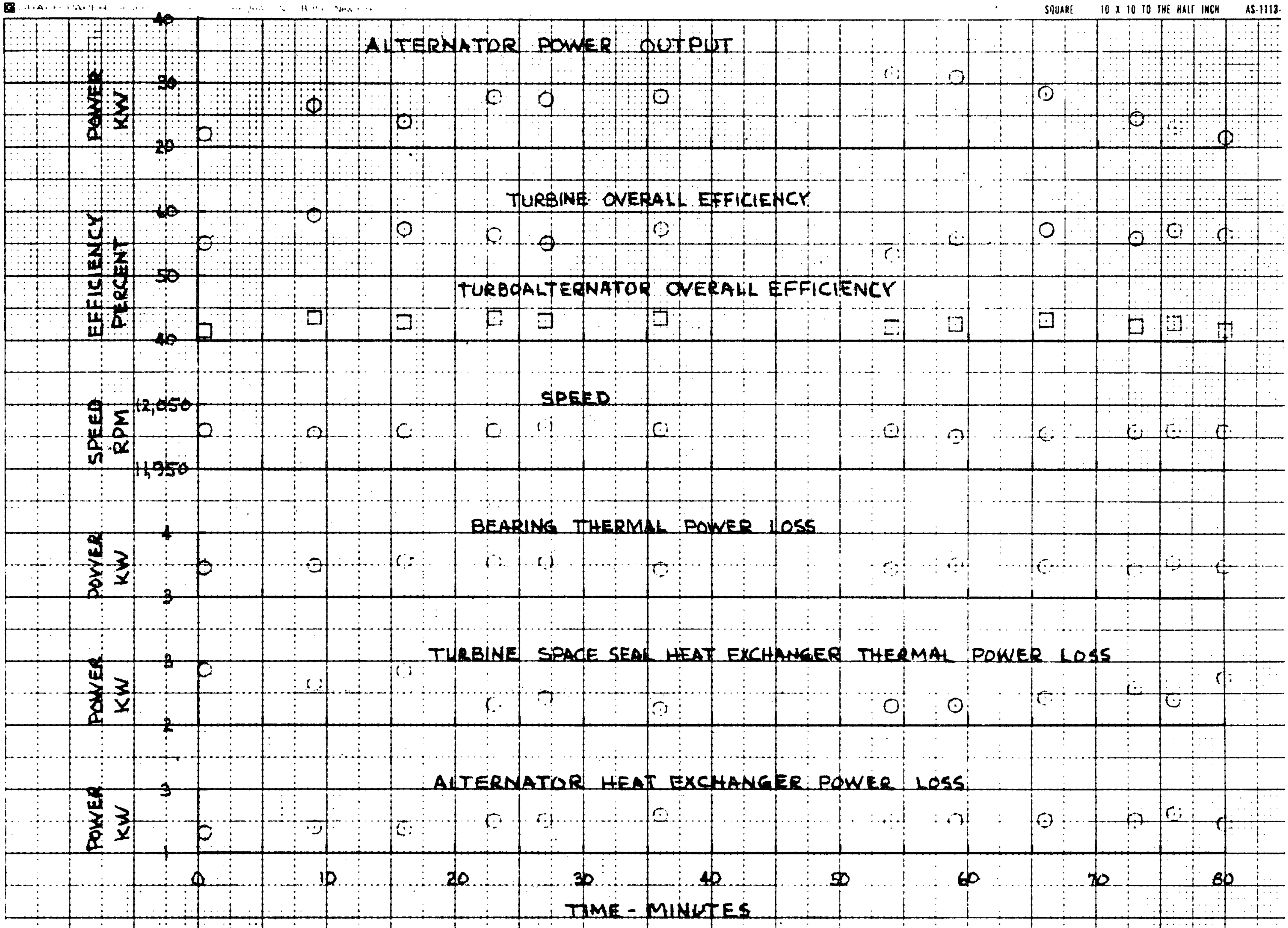

FIGURE 17. - TURBOALTERNATOR OPERATING PARAMETERS AT 6600 LB/HR MERCURY FLOW

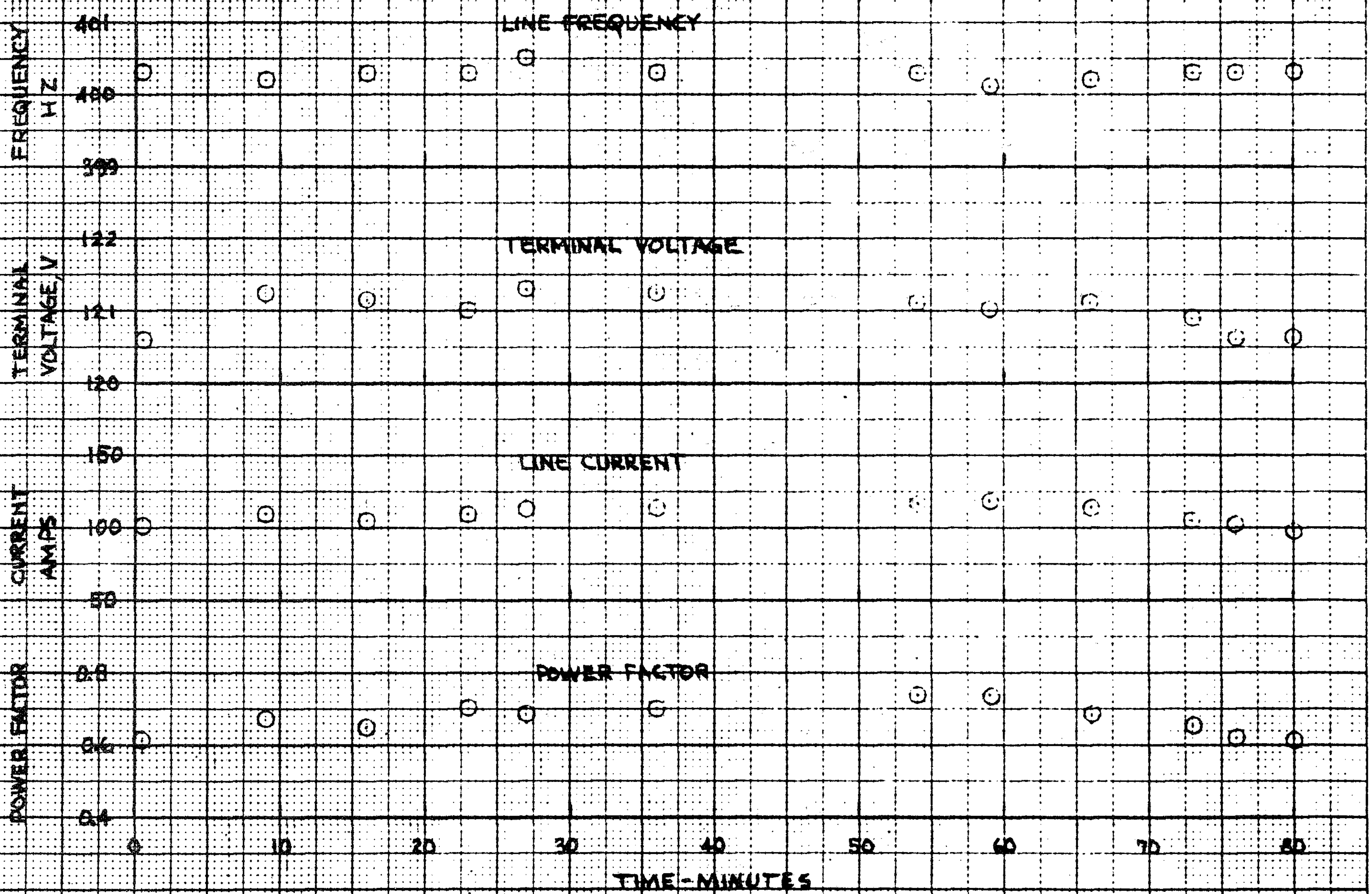

FIGURE 15 - ALTERNATOR ELECTRICAL PARAMETERS AT 6600 LB/HR MERCURY FLOW