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DYNAMOMETER TEST RESULTS
OF THE
ASI/PINSON HIGH RELIABILITY
WIND TURBINE GENERATOR

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DYNAMOMETER TEST RESULTS OF THE ASI/PINSON HIGH RELIABILITY WIND TURBINE GENERATOR

Introduction:

The Dynamometer Testing Facility at the Rocky Flats Small Wind Systems Test Center (WSTC) is capable of defining small (up to 100 kW) wind energy conversion systems (SWECS) generator/gearbox performance for a variety of loads under controlled input. Data readout gives measurements for input torque, rotor rotational speed, gearbox temperature and output power (watts). Figure 1 depicts the layout used for dynamometer testing of the Aerospace Systems, Inc. (ASI)/Pinson Energy Corporation High Reliability prototype wind system, designed to produce 1 kW at 9 m/s (20 mph).

The prime mover, a dc motor with a variable speed controller, provides input power to the SWECS being tested. A shaft-type torque (T) sensor and a digital speed (N) sensor measure the parameters required to calculate input power in watts (P), thus $P = K \cdot T \cdot N$. In this calculation, K is a constant equal to 0.1420, if T is lb-ft and N is rev/min. Generator output is dissipated with variable resistance loads, batteries, or fed back into the utility system. Generator/gearbox temperature, vibration, frequency, power quality and other parameters of interest can also be measured under these simulated operating conditions.

Test Specimen:

The ASI/Pinson wind system is designed to generate dc power for battery charging. The power producing component of the system is a high-speed, 8-pole alternator with an interrupting type-field winding in the stator. The stator is wound for a three-wire, three-phase output. Maximum design output of the alternator is approximately 2000 watts.

Alternator output is rectified by a full-wave bridge circuit located in the control unit, and dc output voltage is limited by a regulator circuit controlling the alternator field current (Figure 2). The regulator is adjustable and allows regulation at 27 to 30 volts for charging a 24 V battery bank. A float-charge mode permits full charge, but also prevents excessive charging and battery gassing. An equalize charge overcharges the battery to equalize cell voltage.

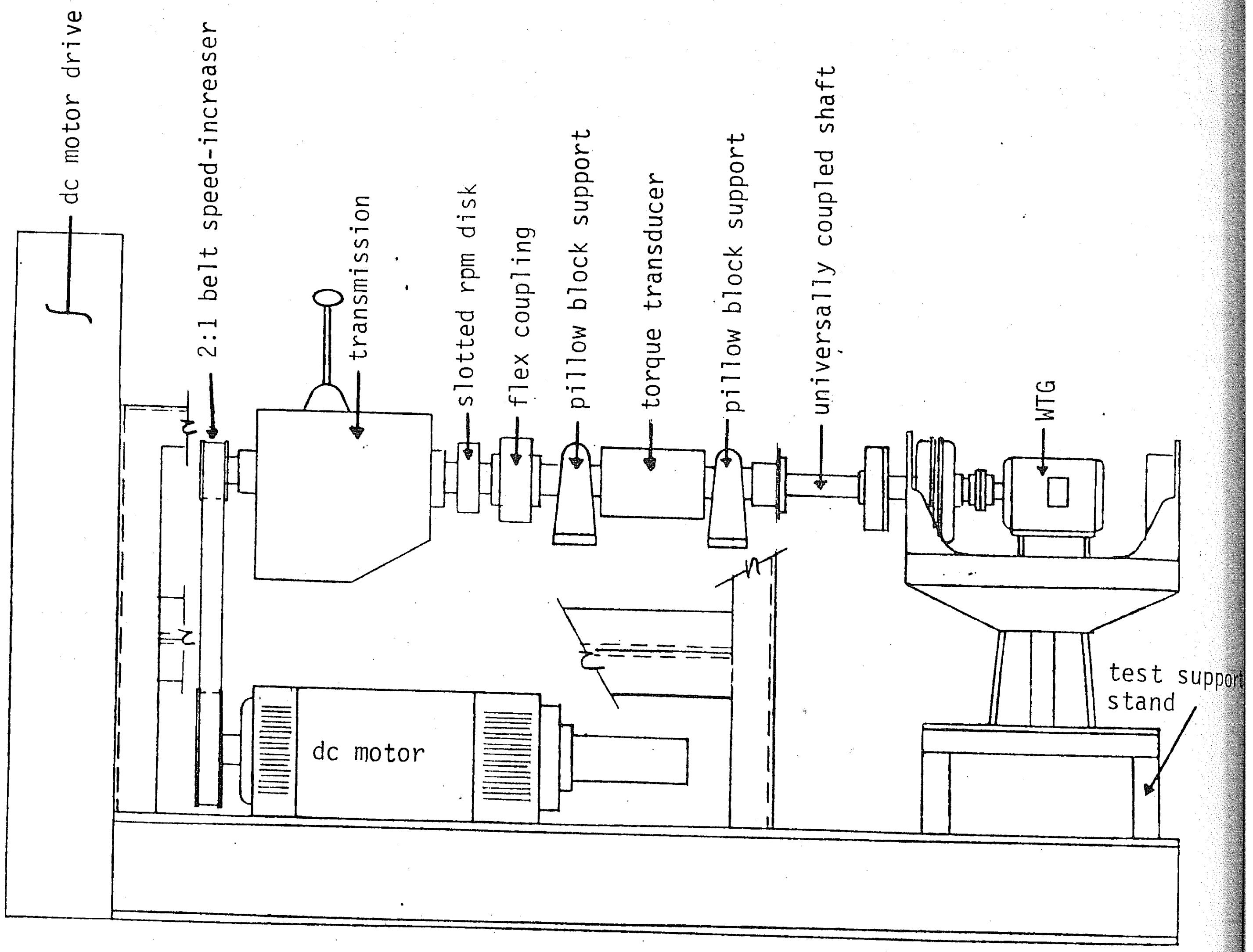


Figure 1
10 kW Dynamometer

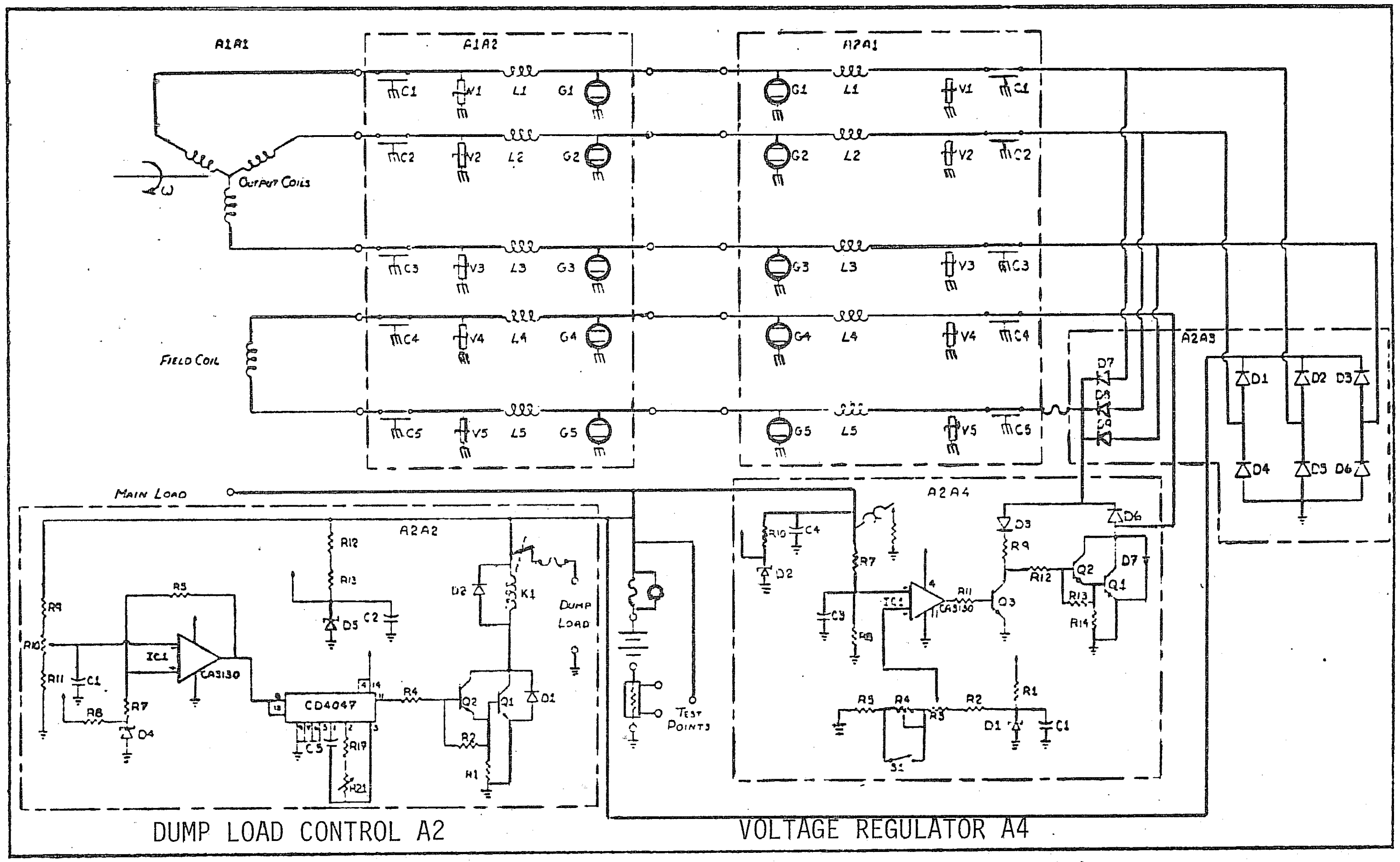


Figure 2
Electrical System Circuit Diagram

For testing at the WSTC, the float-charge was adjusted to 27.5 V, and equalize voltage was set at 28.5 V. A dump circuit adds a resistive load to the output. A control circuit switches the resistive load in at an adjustable voltage. This control circuit was not used during normal testing, but the dump control circuit was checked for proper operation.

The ASI/Pinson gearbox speed ratio is 25:1. The aerodynamic rotor shuts down at approximately 160 rpm (alternator speed of 4000 rpm). The alternator is designed to cut-in at approximately 1000 rpm (rotor rpm of 40).

Test Instrumentation:

A wiring schematic for dynamometer testing of the ASI/Pinson is shown in Figure 3. Alternator ac output was measured by two Magtrol Power Analyzers. Total three-phase alternator output is the sum of the two wattmeter readings. Field current, voltage and power were also monitored by a Magtrol.

DC power, voltage and current were measured with a Clarke-Hess Digital Voltage/Ampere/Wattmeter to compare measurements of the unfiltered dc waveforms (Figure 4). A 24 V lead acid battery was used in parallel with three programmable solid state loads (PSSL's) which were programmed to dissipate power at a specific voltage before the battery reaches its float or equalize charge. This allows the alternator to produce its rated output and produce optimum power curves. Temperature was measured using a temperature to voltage converter and a voltmeter.

Data collected during dynamometer testing of the ASI/Pinson were entered into a Hewlett-Packard 9825A calculator where efficiency, power factor and input power were calculated. Curves were plotted and data tabulated by a Hewlett-Packard 9872B plotter.

All instrumentation used for dynamometer testing of the ASI/Pinson WTG was owned by DOE/Rockwell International. The following is a list of instrumentation used during the tests:

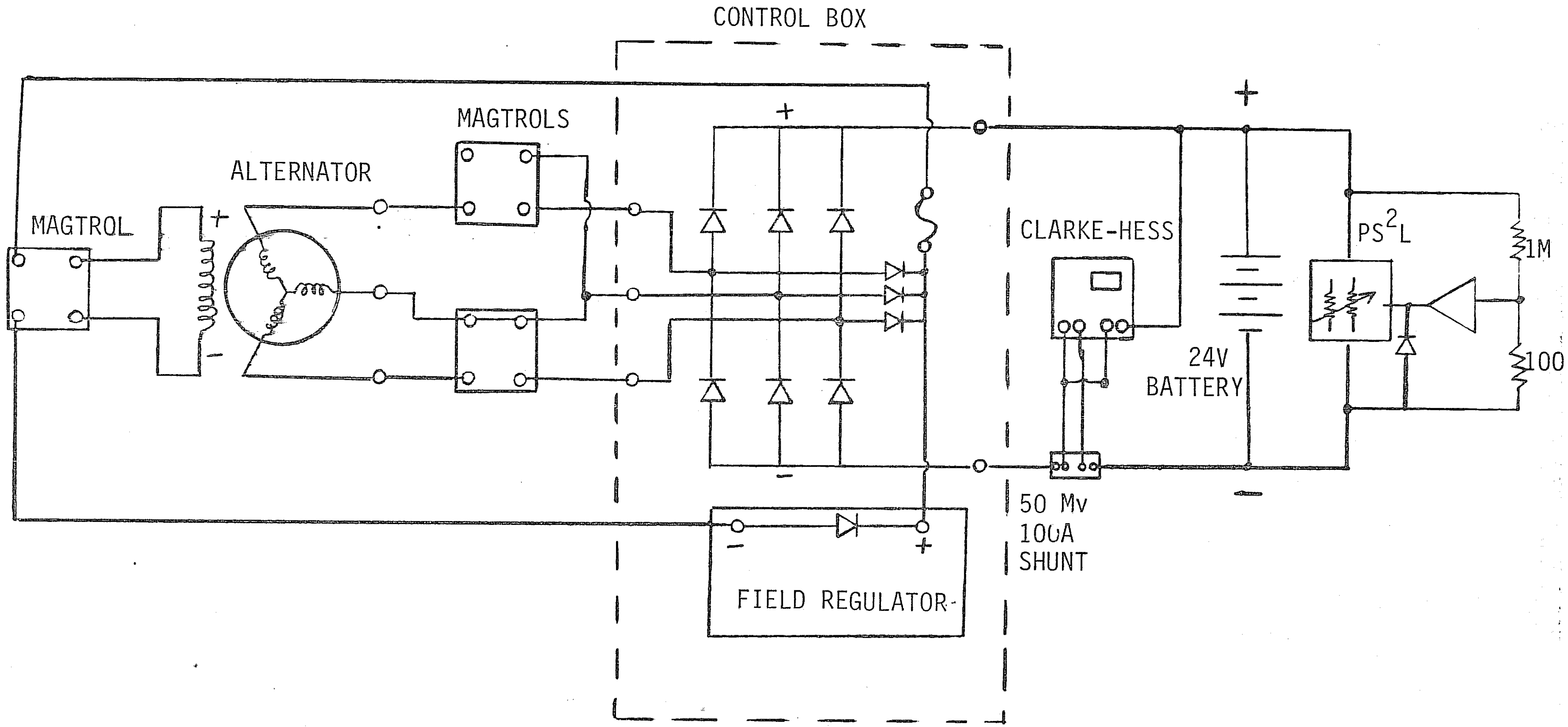


Figure 3
Test Schematic -
ASI/Pinson High Reliability

Table I

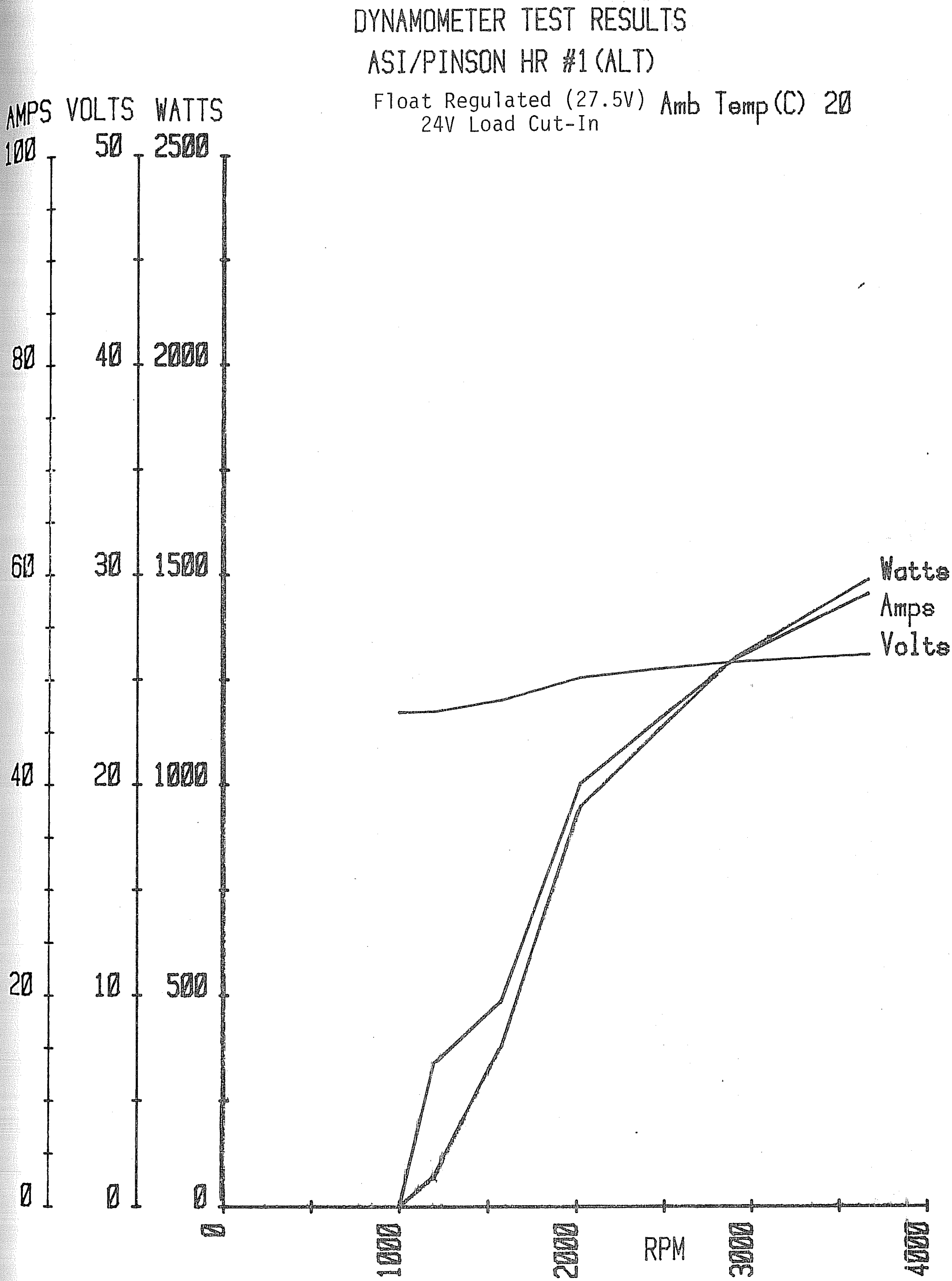
Tabulated Dynamometer Test Results
Float Regulated (27.5V)
24V Load Cut-In

ASI/PINSON HR #1 (ALT)

Amb Temp (C) 20

Volts	RPM	Torq in-lbs	Amps	Watts DC	PF (%)	I (fld)	Wfld	Eff (%)	Wac	Temp-C
23.4	1000	1	0.10	0	0	0.10	0	1	0	21.4
23.5	1198	15	13.60	68	21	1.14	22	51	119	22.2
24.0	1578	35	19.52	380	81	1.37	32	69	471	22.0
25.1	2025	60	40.08	948	94	1.43	35	76	1113	21.8
25.5	2475	60	46.24	1132	96	1.14	22	73	1302	21.7
25.8	2918	60	52.08	1304	97	1.07	20	72	1505	22.9
26.2	3675	55	58.20	1488	98	1.00	17	71	1710	22.9

Figure 5



DYNAMOMETER TEST RESULTS
ASI/PINSON HR #1 (ALT)
Float Regulated (27.5V)
24V Load Cut-In
Amb Temp (C) 20
AMPS VOLTS WATTS
100 50 2500
80 40 2000
60 30 1500
40 20 1000
20 10 500
0 0 0
Watts
Amps
Volts
0
1000
2000
RPM
3000
4000

Figure 6

DYNAMOMETER TEST RESULTS

ASI/PINSON HR #1 (ALT)

Float Regulated (27.5V)
24V Load Cut-In

Amb Temp (C) 20

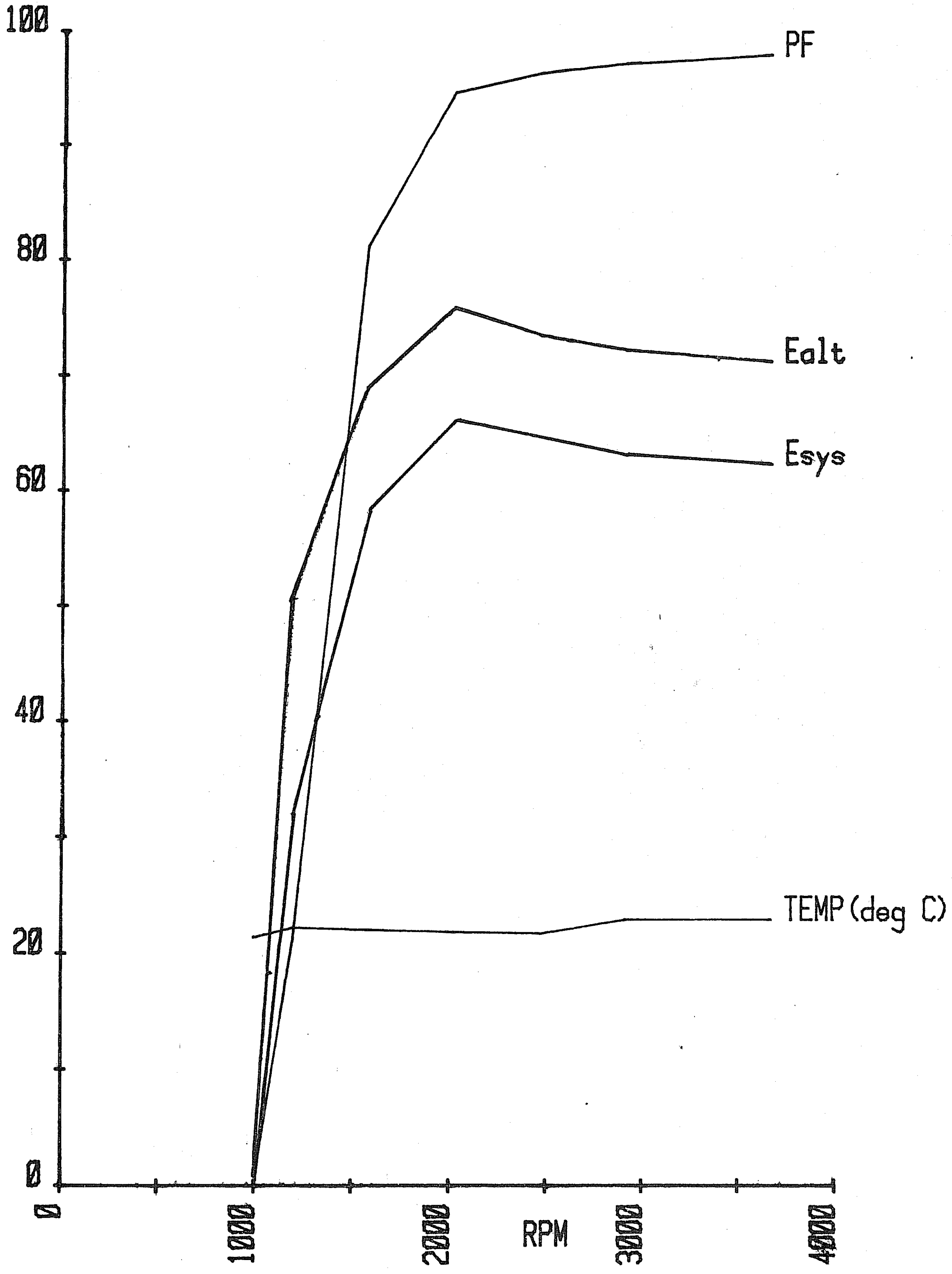


Table II

Tabulated Dynamometer Test Results
Float Regulated (27.5V)
25V Load Cut-IN

ASI/PINSON HR #1(ALT)

Amb Temp(C) 22

Volts	RPM	Torq in-lbs	Amps	Watts DC	PF(%)	I(fld)	Wfld	Eff(%)	Wac	Temp-C
23.3	1000	1	0.10	0	0	0.10	0	1	0	22.0
24.2	1118	5	7.20	16	9	1.09	19	61	52	21.8
25.6	1525	20	16.00	252	61	1.44	34	83	325	21.8
26.4	1881	45	30.24	724	91	1.55	39	82	852	22.1
26.8	2348	40	33.68	808	90	0.89	13	82	916	22.5
27.1	2784	40	38.80	988	94	0.86	12	84	1113	23.0
27.4	3206	40	43.60	1132	95	0.84	12	83	1273	23.3
27.7	3995	40	50.20	1336	96	0.82	11	79	1503	23.4
27.0	2565	40	35.20	880	93	0.89	13	81	992	24.2
26.3	1863	35	23.20	504	83	0.97	16	74	581	24.7
25.7	1524	25	17.28	252	57	1.20	24	66	313	24.9
25.1	1182	10	8.80	32	15	1.12	21	44	70	25.3

Figure 7

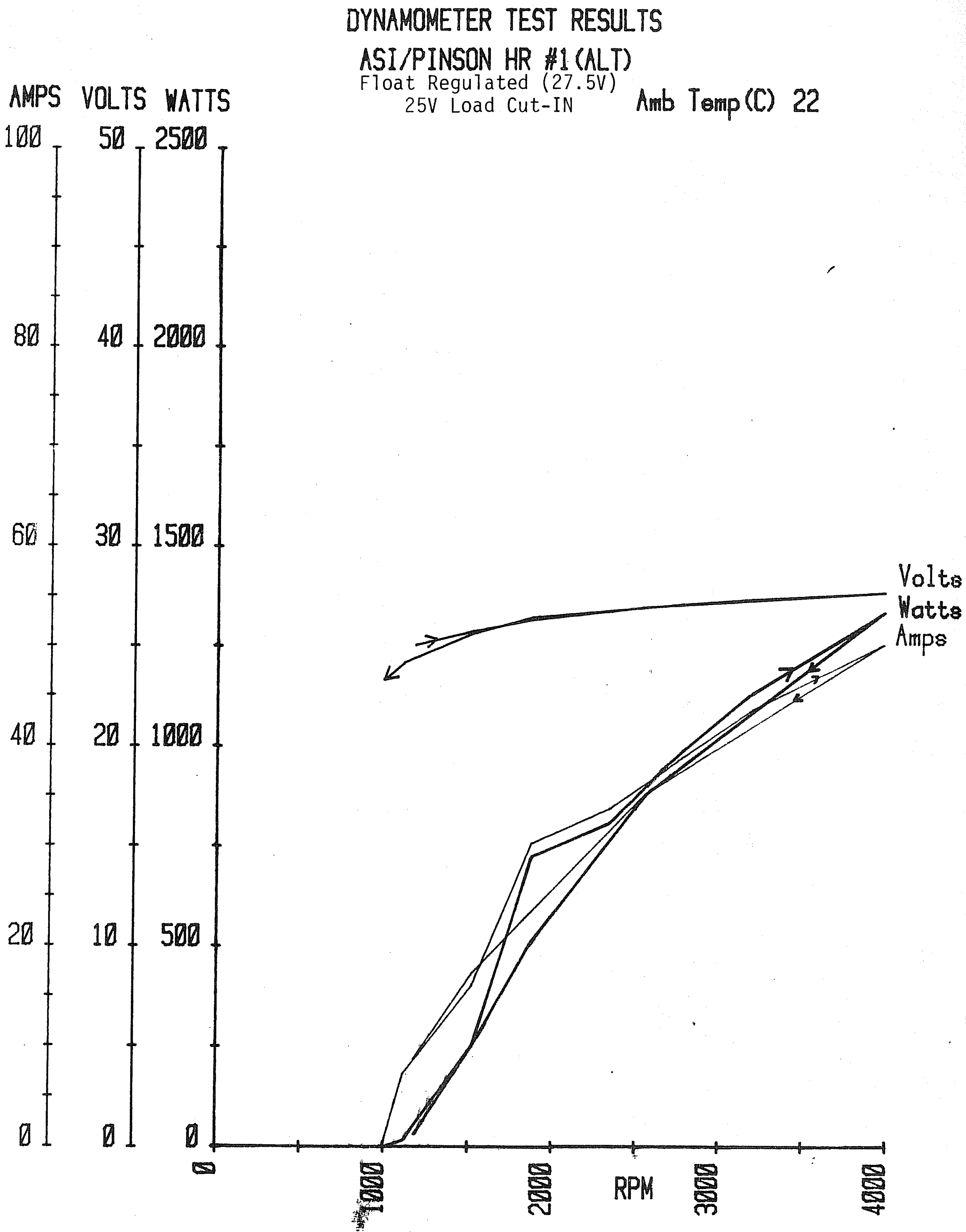

DYNAMOMETER TEST RESULTS
ASI/PINSON HR #1 (ALT)
Float Regulated (27.5V)
25V Load Cut-IN
Amb Temp (C) 22
AMPS VOLTS WATTS
100 50 2500
80 40 2000
60 30 1500
40 20 1000
20 10 500
0 0 0
0
1000
2000
RPM
3000
4000
Volts
Watts
Amps

Figure 8

DYNAMOMETER TEST RESULTS

ASI/PINSON HR #1 (ALT)

Float Regulated (27.5V)

25V Load Cut-In

Amb Temp (C) 22

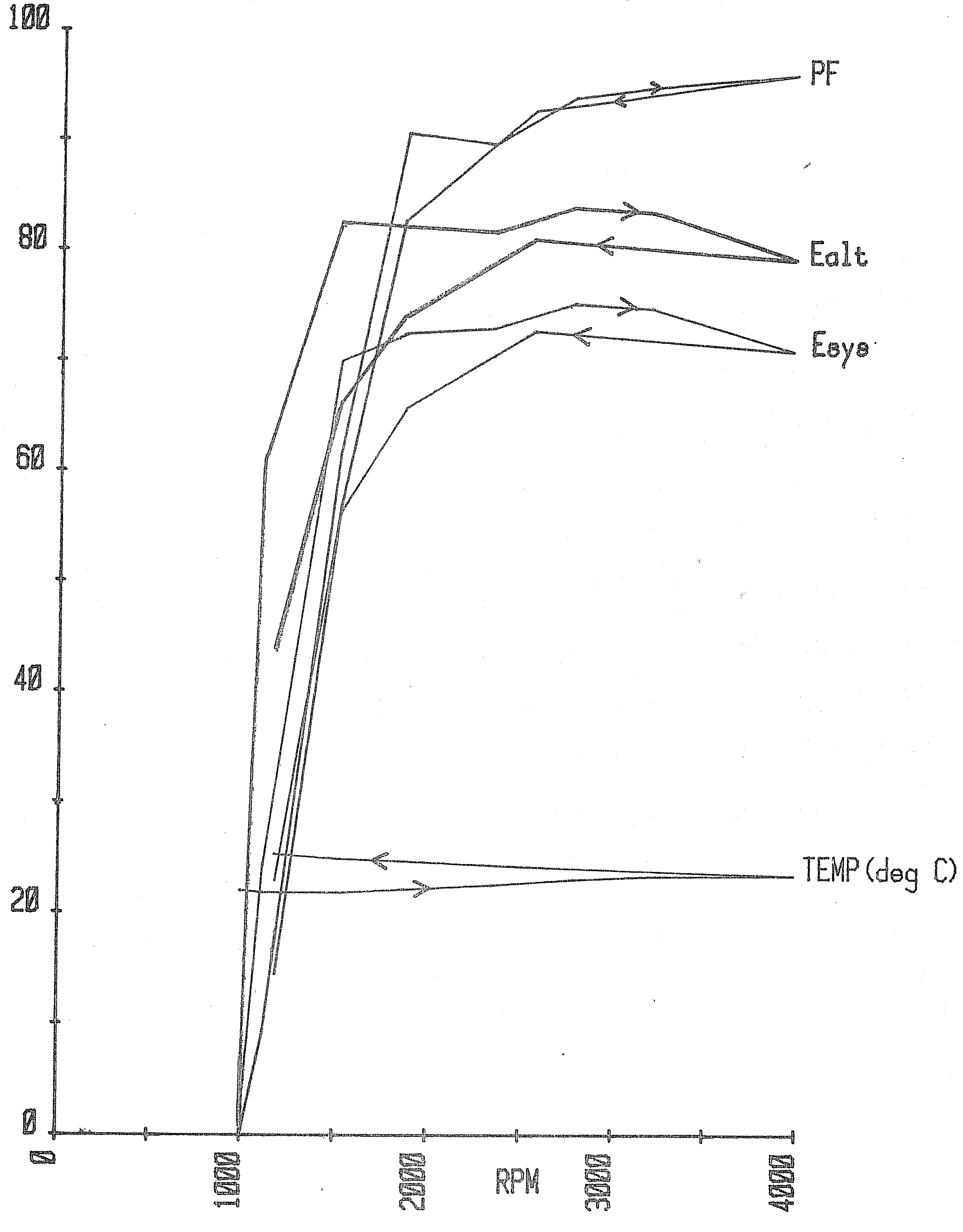


Table III

Tabulated Dynamometer Test Results
Float Regulated (27.5V)
26V Load Cut-IN

ASI/PINSON HR #1(ALT)

Amb Temp(C) 18

Volts	RPM	Torq in-lbs	Amps	Watts DC	PF(%)	I(fld)	Wfld	Eff(%)	Wac	Temp-C
23.2	1000	1	0.10	0	0	0.10	0	0	0	19.0
23.7	1060	10	6.40	4	3	1.05	17	26	37	18.4
26.1	1401	20	15.36	132	33	1.34	30	53	192	20.3
27.1	1897	50	28.60	708	91	1.55	41	72	833	20.6
27.5	2243	50	36.80	944	93	1.11	19	80	1072	20.7
27.6	2753	45	38.04	980	93	0.88	11	75	1101	20.9
27.7	3309	40	38.56	1004	94	0.75	7	72	1123	21.2
27.8	4009	40	40.00	1032	93	0.67	5	61	1152	21.1
27.7	2840	45	34.16	852	90	0.78	10	63	960	21.8
27.3	2391	40	28.32	676	87	0.81	11	67	765	22.5
26.4	1618	30	17.80	264	56	0.97	16	54	320	23.2
25.7	1152	20	6.00	12	8	1.10	20	16	48	23.9

Figure 9

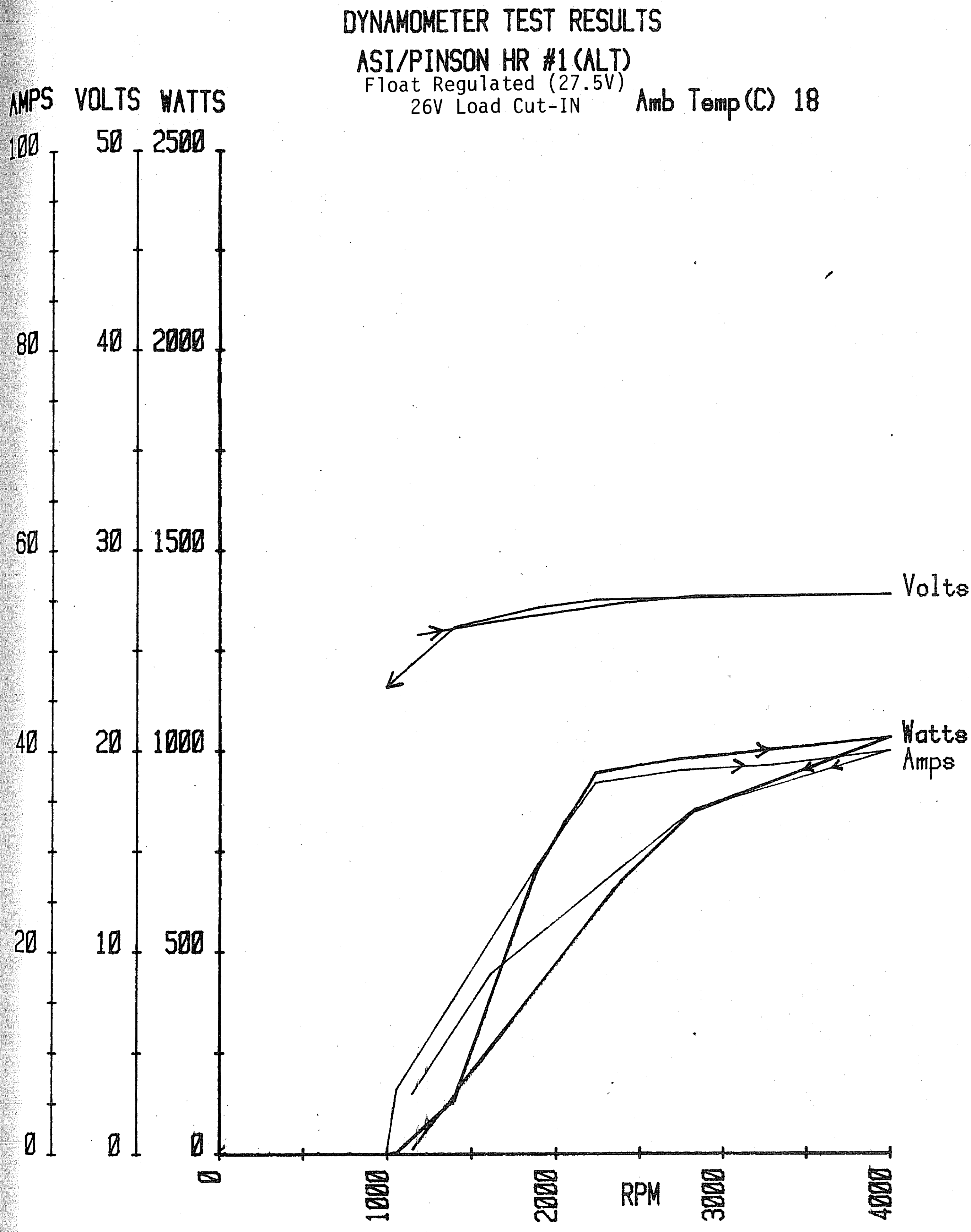

DYNAMOMETER TEST RESULTS
ASI/PINSON HR #1 (ALT)
Float Regulated (27.5V)
26V Load Cut-IN
Amb Temp (C) 18
AMPS VOLTS WATTS
100 50 2500
80 40 2000
60 30 1500
40 20 1000
20 10 500
0 0 0
0
1000
2000
RPM
3000
4000
Volts
Watts
Amps

Figure 10

DYNAMOMETER TEST RESULTS

ASI/PINSON HR #1 (ALT)

Float Regulated (27.5V)
26V Load Cut-IN

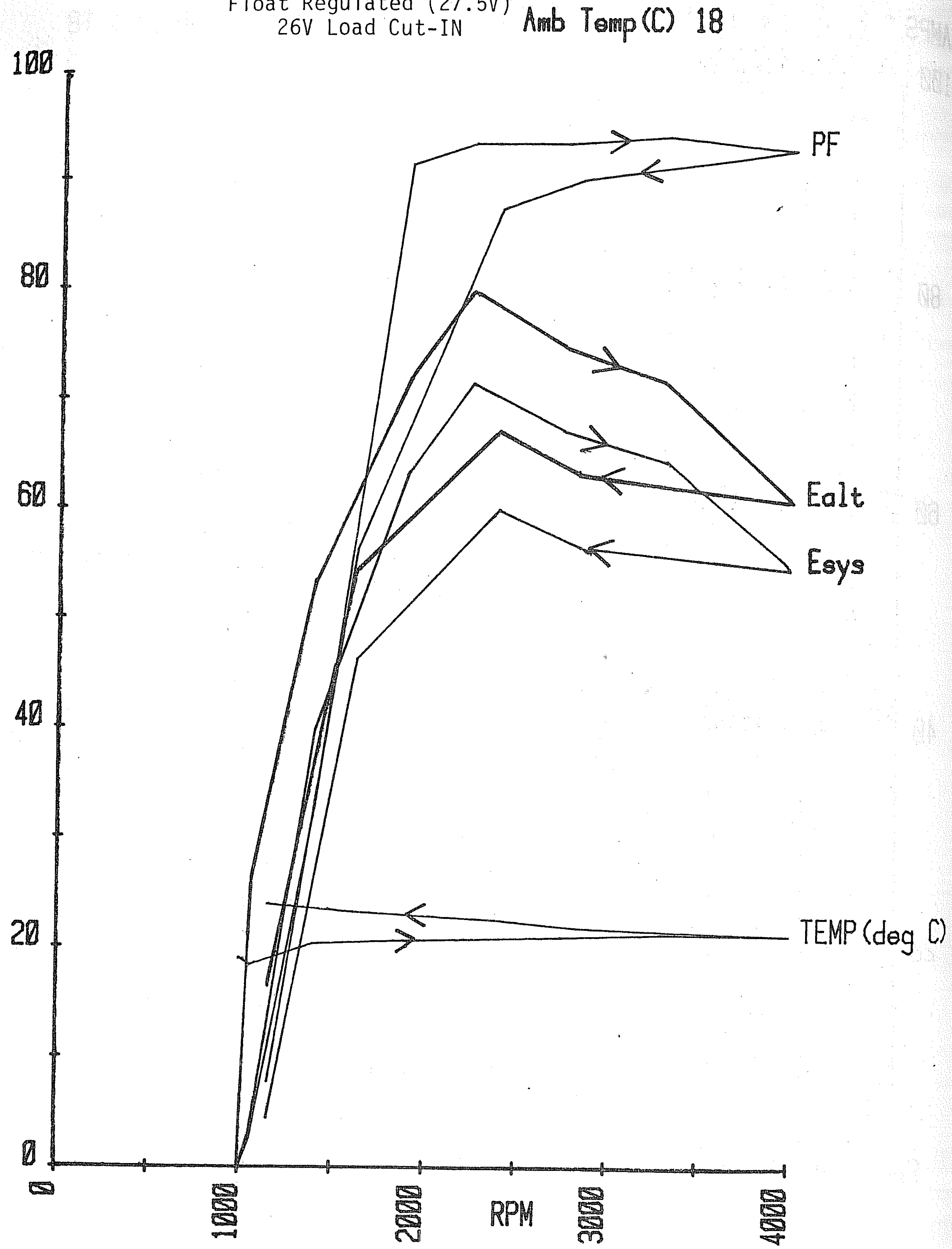


Table IV

Tabulated Dynamometer Test Results
Equalize Regulated (28.5V)
25V Load Cut-In

ASI/PINSON HR #1(ALT)

Amb Temp(C) 23

Volts	RPM	Torq in-lbs	Amps	Watts DC	PF(%)	I(fld)	Wfld	Eff(%)	Wac	Temp-C
23.4	1000	1	0.10	0	0	0.10	0	1	0	27.3
23.9	1102	10	6.40	20	13	1.05	18	31	46	24.7
25.1	1352	15	14.84	136	36	1.29	28	69	184	24.0
25.4	1523	25	17.20	272	62	1.39	32	71	340	24.0
25.7	1713	35	21.72	472	84	1.47	37	76	569	23.9
26.3	2007	40	31.04	728	89	1.07	20	87	838	23.9
26.8	2461	45	40.20	1016	94	1.04	18	87	1157	23.9
27.1	2893	50	46.72	1216	96	1.00	17	80	1376	24.1
27.5	3412	50	52.72	1404	97	0.96	16	78	1587	24.2
27.8	4088	50	57.72	1560	97	0.95	15	72	1757	24.6
27.1	2733	50	44.20	1124	94	1.01	17	78	1264	25.2
26.7	2282	50	36.72	912	93	1.07	19	76	1033	25.7
25.6	1573	30	18.32	316	67	1.39	33	66	391	26.3
25.0	1236	15	10.80	68	25	1.15	23	43	105	26.8

Figure 11

DYNAMOMETER TEST RESULTS
ASI/PINSON HR #1 (ALT)

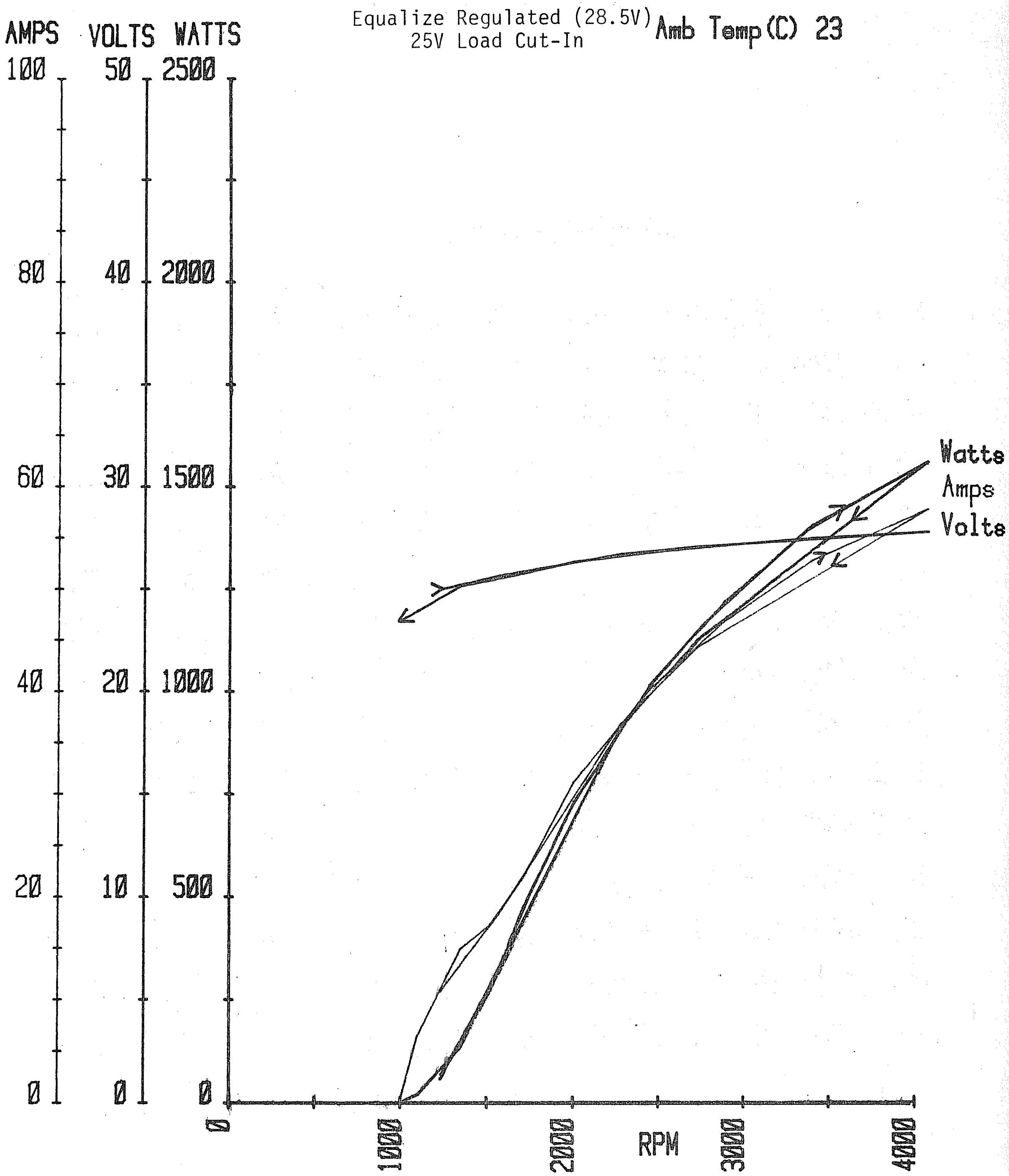


Figure 12

DYNAMOMETER TEST RESULTS
ASI/PINSON HR #1 (ALT)

Equalize Regulated (28.5V)
25V Load Cut-In

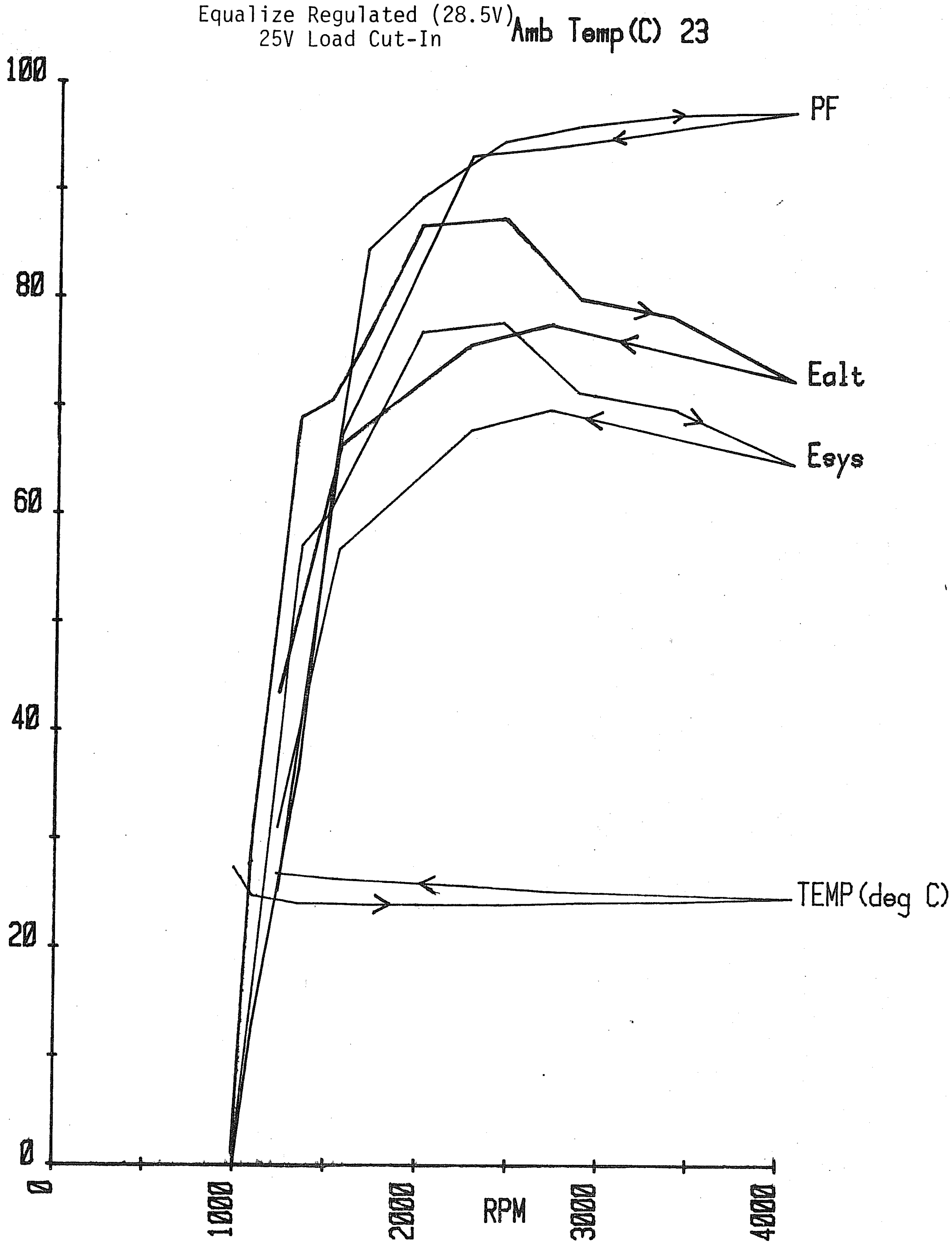


Table V

Tabulated Dynamometer Test Results
Equalize Regulated (28.5V)
26V Load Cut-In

ASI/PINSON HR #1(ALT)

Amb Temp(C) 19

Volts	RPM	Torq in-lbs	Amps	Watts DC	PF(%)	I(fld)	Wfld	Eff(%)	Wac	Temp-C
23.4	1000	1	0.10	0	0	0.10	0	1	0	22.8
24.0	1071	15	4.80	8	7	1.04	18	18	37	20.9
26.0	1367	20	14.08	112	31	1.33	29	47	166	20.8
26.7	1733	35	21.24	416	73	1.10	20	66	489	20.6
27.1	2030	45	27.52	640	86	0.96	16	68	742	20.7
27.6	2610	50	37.20	960	93	0.92	14	70	1081	20.6
28.0	3142	50	44.24	1176	95	0.89	13	71	1323	20.4
28.4	3745	55	50.04	1368	96	0.87	12	63	1531	21.0
28.5	4006	55	51.88	1420	96	0.86	12	61	1599	21.3
28.0	3072	50	42.84	1140	95	0.90	13	70	1277	21.9
27.5	2298	50	32.24	808	91	0.96	15	66	909	22.1
26.4	1541	30	17.08	256	57	1.33	29	55	318	22.7
25.7	1253	20	10.80	60	22	1.20	24	31	100	23.1

Figure 13

DYNAMOMETER TEST RESULTS

ASI/PINSON HR #1 (ALT)

Equalize Regulated (28.5V)
26V Load Cut-In

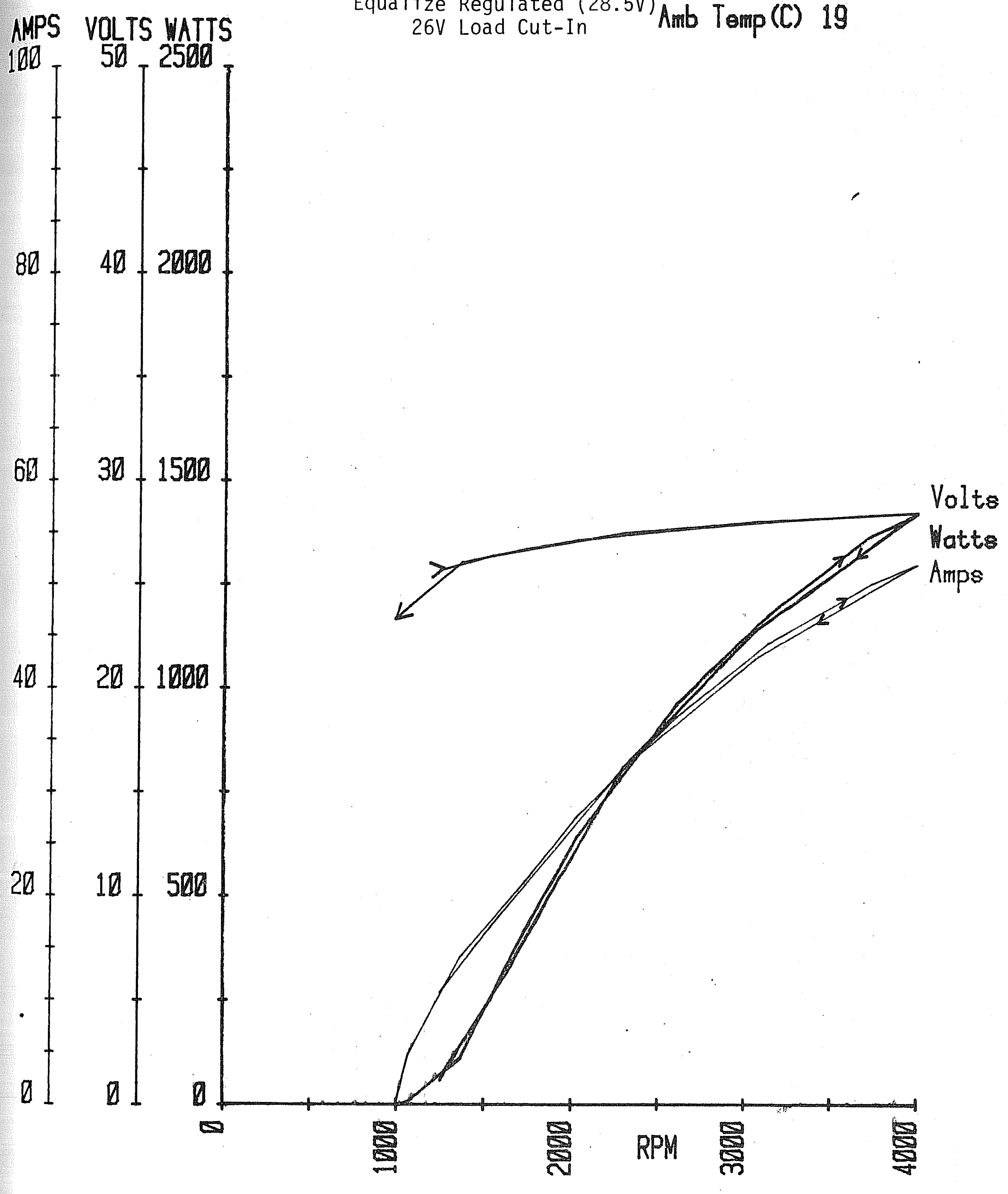
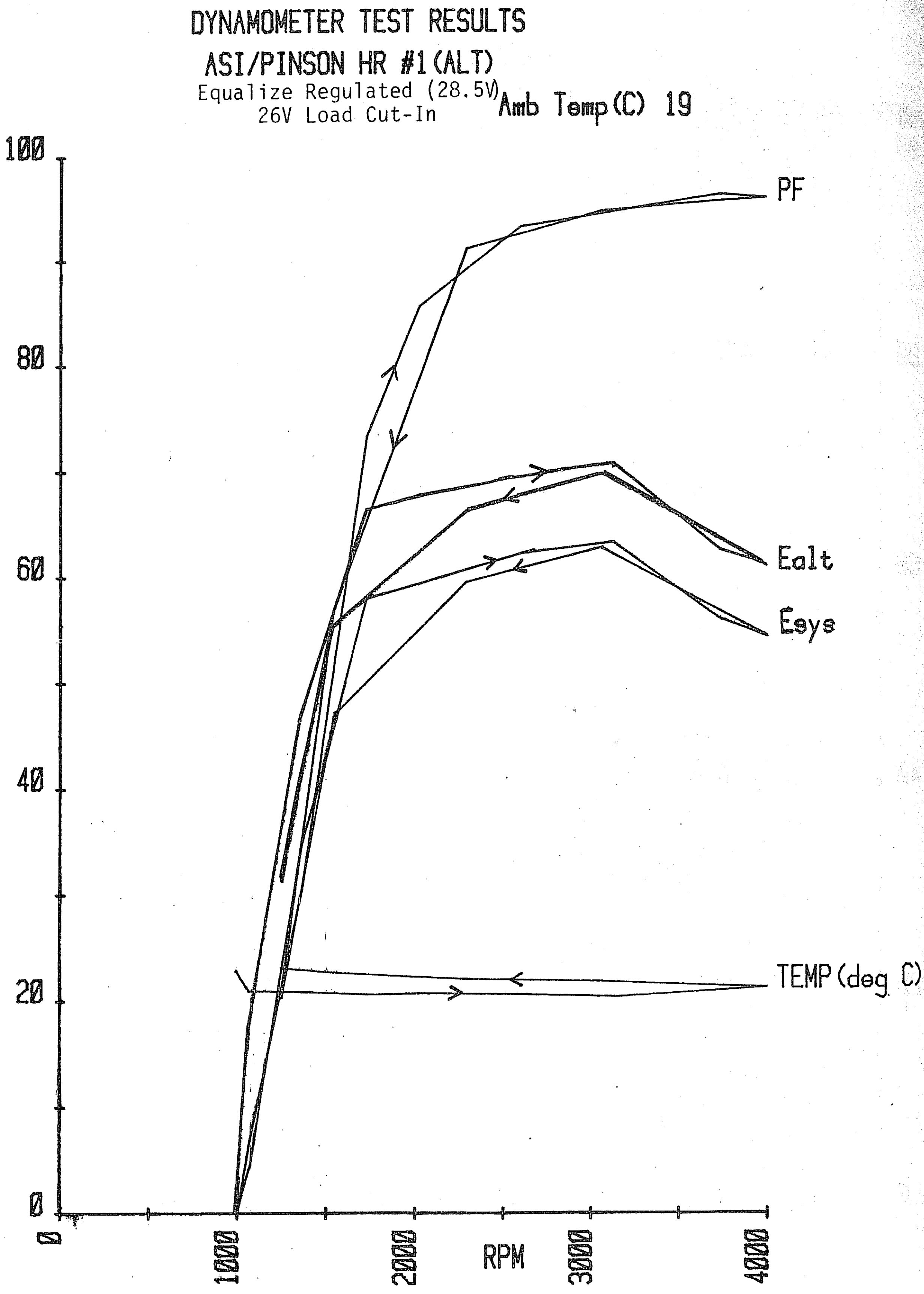


Figure 14



DYNAMOMETER TEST RESULTS
ASI/PINSON HR #1 (ALT)
Equalize Regulated (28.5V)
26V Load Cut-In
Amb Temp (C) 19
100
80
60
40
20
0
PF
Ealt
Esys
TEMP (deg C)
0
1000
2000
RPM
3000
4000

System efficiency (Esys = Eff(%) was plotted versus the alternator speed. Alternator efficiency (Ealt) was calculated and plotted as a percentage:

$$Ealt\ (\%) = 100*Wac/(Watt\ Input + Wfld)$$

Temperature was measured at each data point. Data were then plotted and tabulated in degrees centigrade. Time between data points was 1-2 minutes, and each test lasted approximately 20 minutes. As speed was increased and decreased in each test, a hysteresis loop formed (i.e., Figure 10). The lower generator output at decreasing speed appeared to be caused primarily by battery charge state - the battery bank had a small capacity - and not by winding heating. Alternator temperature remained below 30°C during all tests.

Conclusions/Recommendations:

Dynamometer testing of the ASI/Pinson showed good efficiency for both the alternator (up to 87%) and the overall system (between 70 and 80%). The alternator cut-in at 1000 rpm as specified and showed it was more than capable of satisfying the design requirement of a 1 kW output.

The method of setting the voltage regulator described in Section 8.5.2 of the manufacturer's Assembly, Operation and Maintenance Manual was found to be in error. The respective procedures for voltage regulator set-up in the float and equalize mode were reversed (i.e., method given for the float mode was in reality method for equalize mode). The manual should be amended to reflect the correct procedures for each mode.

The minimum float-charge voltage attainable was 27.5 volts. Since some load applications may require a lower voltage level, it would be convenient to be able to regulate at a lower voltage (i.e., 26 volts). A current limiting function, using a current shunt, should be incorporated to limit current output to 50 amperes. The clearing of a dc fuse would unload the WTG and force reliance on mechanical shutdown to control overspeeding. Also, if a dump load is being used on the dc output, it is important to carefully adjust the regulator cut-in voltages with the dump control cut-in voltage. Dump circuit cut-in voltage should be set well above the regulator settings to avoid undercharging the batteries.

LIST OF ABBREVIATIONS

A or amp	- ampere
ac	- alternating current
C	- centigrade
dc	- direct current
Ealt	- alternator efficiency
Esys	- system efficiency
HR	- High Reliability
Hz	- hertz
Ifld	- field current
kW	- kilowatt (1000 watts)
Mv	- millivolt
NBS	- National Bureau of Standards
PF	- power factor
PSSL	- programmable solid-state load
RMS	- root mean square
rpm	- revolutions per minute
SWECS	- small wind energy conversion systems
V	- volt
W	- watt
Wac	- alternator ac watt output
Wfld	- field power (watts)
WSTC	- Wind Systems Test Center
WTG	- wind turbine generator
o	- degrees