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Abex Corporation ▪ Aerospace Division
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FINAL TECHNICAL REPORT
TO
NASA, L. B. JOHNSON SPACE CENTER
ON
SERVO CONTROLLED, VARIABLE PRESSURE
MODIFICATION TO
SPACE SHUTTLE HYDRAULIC PUMP

NASA CONTRACT
NAS 9-16622

AER-873
25 July 1983

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Staff Engineer

Approved by:

for

T. E. Sarphie
Director of Engineering

Aerospace Division

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INTRODUCTION

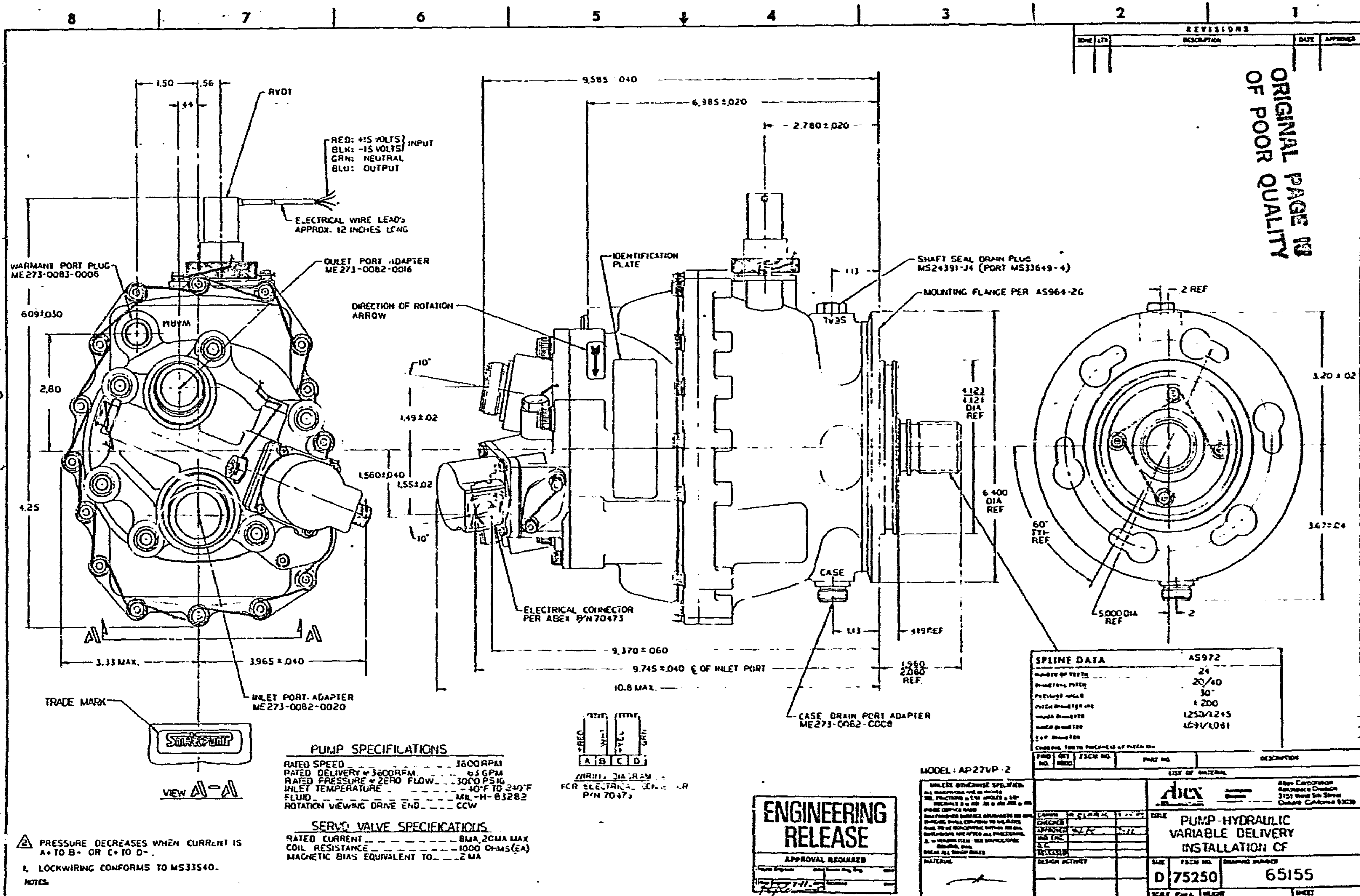
This report describes the modifications made to a standard model AP27V-7 (Abex P/N 65111) Space Shuttle hydraulic pump under contract NAS 9-16622 for the L. B. Johnson Space Center at Houston, Texas.

OBJECTIVE

The objective of the contract is to modify the constant pressure control of the model AP27V-7 hydraulic pump to an electrically controlled variable pressure setting compensator. In addition, the conversion is to include a hanger position indicator for continuously monitoring hanger angle. Also to be furnished is a simplex servo driver for controlling the pressure setting servovalve, as well as a support data package. Pump is then to be used to evaluate integrated performance on an "iron bird" flight control system application.

DESCRIPTION OF PUMP MODIFICATIONS

Drawing number 65155 shows the pertinent overall and installation dimensions of the model AP27VP-2 pump. All basic port dimensions are unchanged from the -7 model. The pump overall length has been increased to 10.8 inches and the vertical height from the pump center line has been increased to 6.09 inches to accommodate the RVDT unit. Other specifications remain unchanged.



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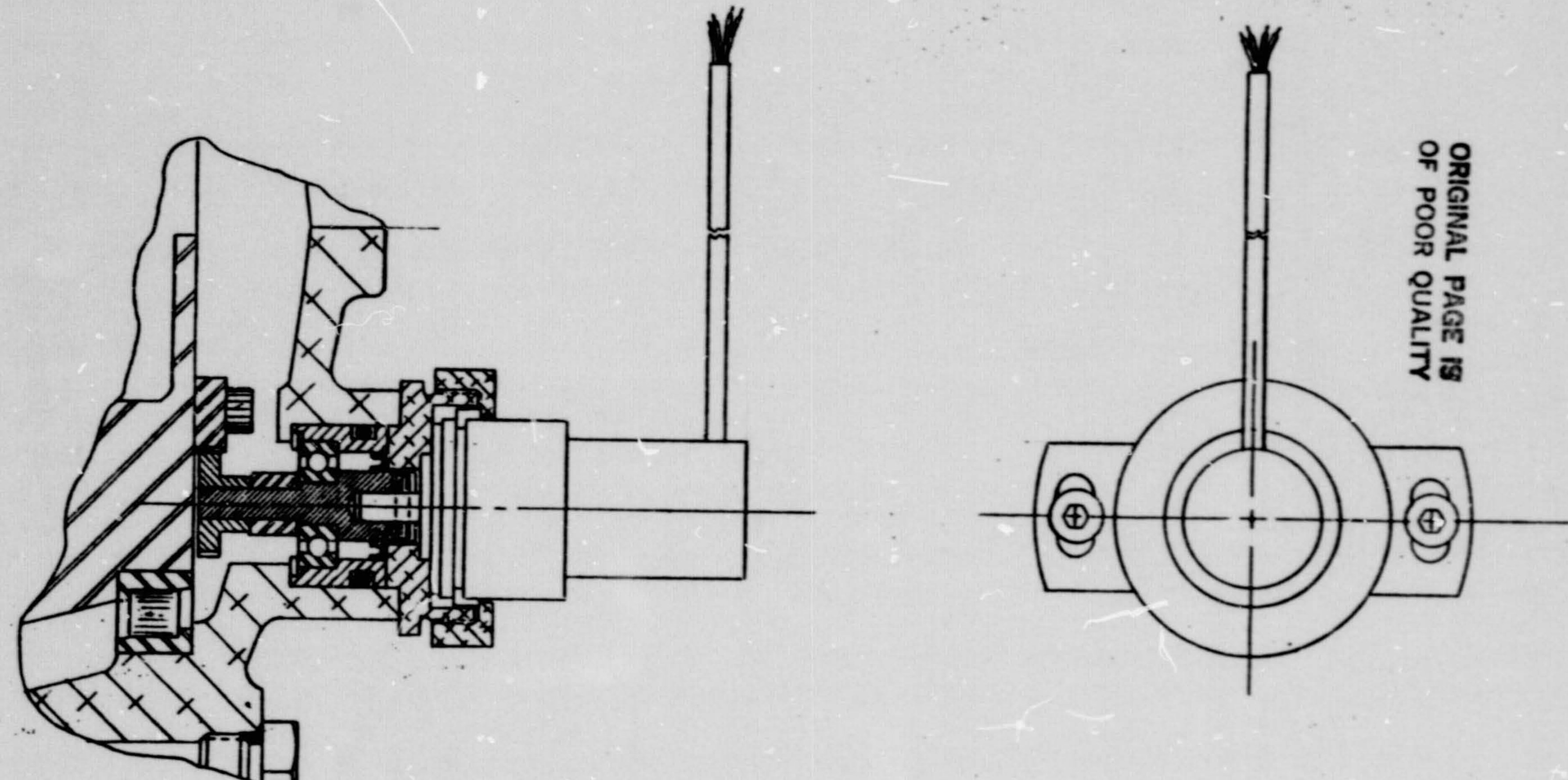
REVISIONS
ZONE LTR DESCRIPTION DATE APPROVED
RVDT
RED: +15 VOLTS
BLK: -15 VOLTS
INPUT
GRN: NEUTRAL
BLU: OUTPUT
ELECTRICAL WIRE LEADS APPROX. 12 INCHES LONG
WARMANT PORT PLUG ME273-0083-0006
OULET PORT ADAPTER ME273-0082-0016
INLET PORT ADAPTER ME273-0082-0020
TRADE MARK
VIEW A-A
IDENTIFICATION PLATE
DIRECTION OF ROTATION ARROW
ELECTRICAL CONNECTOR PER ABEX P/N 70473
SHAFT SEAL DRAIN PLUG MS24391-J4 (PORT MS33649-4)
MOUNTING FLANGE PER AS964-26
CASE DRAIN PORT ADAPTER ME273-0082-0008
CASE
SEAL
9.585 .040
6.985 ±.020
2.780 ±.020
9.370 ±.060
9.745 ±.040 ℄ OF INLET PORT
10.8 MAX.
3.33 MAX.
3.965 ±.040
6.400 DIA REF
4.121 4.124 DIA REF
5.000 DIA REF
60° TYP REF
3.20 ±.02
3.67 ±.04
1.960 2.060 REF
WIRING DIAGRAM FOR ELECTRICAL CONNECTOR P/N 70473
SPLINE DATA AS972
NUMBER OF TEETH 24
DIAMETRAL PITCH 20/40
PRESSURE ANGLE 30°
PITCH DIAMETER 1.200
1.250/1.245
1.091/1.081
PUMP SPECIFICATIONS
RATED SPEED 3600 RPM
RATED DELIVERY @ 3600 RPM 6.5 GPM
RATED PRESSURE @ ZERO FLOW 3000 PSIG
INLET TEMPERATURE -40°F TO 240°F
FLUID MIL-H-83282
ROTATION VIEWING DRIVE END CCW
SERVO VALVE SPECIFICATIONS
RATED CURRENT 8MA, 20MA MAX
COIL RESISTANCE 1000 OHMS (EA)
MAGNETIC BIAS EQUIVALENT TO 2 MA
MODEL: AP27VP-2
2 PRESSURE DECREASES WHEN CURRENT IS A+ TO B- OR C+ TO D-.
1. LOCKWIRING CONFORMS TO MS33540.
NOTES:
ENGINEERING RELEASE
APPROVAL REQUIRED
LIST OF MATERIAL
abex
PUMP-HYDRAULIC VARIABLE DELIVERY INSTALLATION CF
D 75250 65155

The basic unit furnished by NASA was a modified version of the standard Shuttle hydraulic pump (part number 65111, S/N 152294). The pump was disassembled and inspected for wear; all parts were found to be in excellent condition. The port plate was discarded, however, because it was a non-standard configuration (a result of an earlier special modification). A new port plate of standard configuration was substituted.

The pump mounting flange and hanger were then modified for adapting the RVDT (rotary variable displacement transducer) unit which is mounted on a special pad at the end of the mounting flange. Figure 1 is a partial cross section of the RVDT and mounting pad. The hanger angle position shaft is driven by a pinion gear which engages a segment gear at the end of the hanger. The resulting drive train ratio is 1:3. The other end of the position shaft is connected through a flexible coupling to the RVDT. The shaft is supported by a ball bearing and is sealed externally with a lip seal.

The pump front housing was modified by the addition of trunnion bearing stops which were welded and machined to form cradles above each bearing. These stops limit hanger lift under start up or adverse, no-load conditions to a maximum of .010 inches. This prevents disengagement of the hanger position indicator gears.

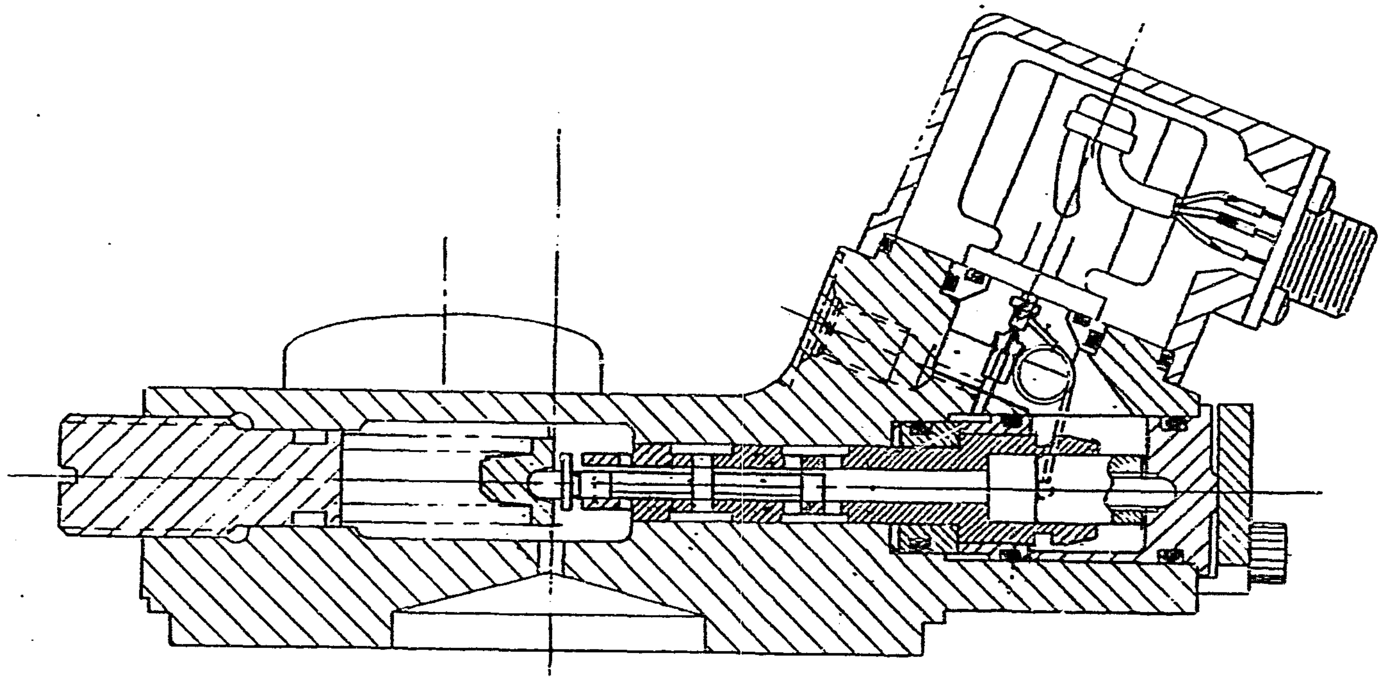


ROTARY VARIABLE DISPLACEMENT TRANSDUCER

Figure 1

A new port cap was designed and fabricated to give point to point inlet and outlet port locations and sizes per the AP27V-7 installation requirements and to accommodate the mounting of the servovalve. The design included the proven variable pressure control concept adapted from a similar size Abex pump.

Figure 2 is a schematic cross section of the pressure control mechanism and servovalve. The normally stationary sleeve of the compensator is now movable. The position of the sleeve, as shown, is in the maximum set pressure position. In this mode the compensator spool is load-adjustable with the normal adjusting screw-spring loading mechanism; maximum operating pressure is adjusted with the sleeve in this position. Fitted to the sleeve at the larger end is a floating piston grounded against the end cap. The net area of this piston is biased against the step area on the outside of the control sleeve. Pressure on the sleeve step area is controlled by the servovalve through the receiver. If the servovalve receives a command to reposition the sleeve to the right (lower pressure), the jet repositions to increase the receiver pressure and the sleeve moves to the right until rebalance is achieved between the floating piston of the sleeve and the step area of the sleeve. A position feedback spring between the sleeve and the servovalve jet pipe closes the command loop of the control system. Repositioning the



SERVO-CONTROLLED VARIABLE PRESSURE COMPENSATOR

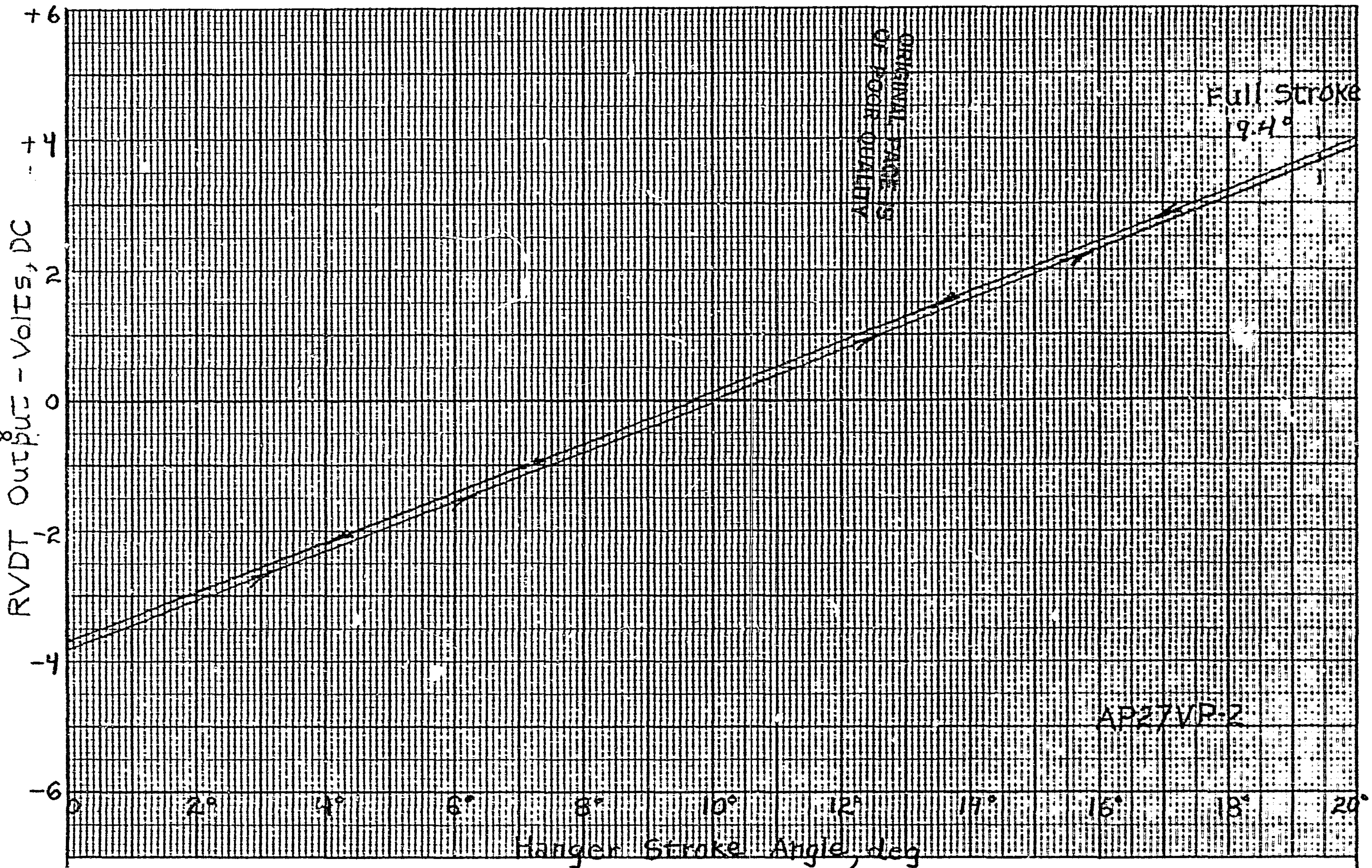
Figure 2

compensator sleeve to the right is equivalent to decreasing the spool spring load by unscrewing the adjustment screw an equivalent amount to the left. Basically, the compensator spool pressure, the floating piston pressure, and servovalve supply pressure are all equal to pump discharge pressure. The receiver pressure and the step area pressure are servovalve controlled.

The control concept is "fail safe" in that any interruption of electrical signal (zero amperage) or hydraulic supply pressure (plugged filter) to the servovalve results in a pressure bias on the compensator sleeve such that it immediately repositions against the stop to the left (high pressure setting).

RVDT CALIBRATION

Figure 3 is a calibration curve of the RVDT output voltage vs hanger angle of the pump. The voltage change is linear from the zero-stroke hanger angle to the maximum-stroke angle of 19.4 degrees. RVDT voltage outputs are - 3.8 volts and + 3.66 volts, respectively. At elevated pump temperatures, the maximum stroke angle of the hanger increases slightly ($0.1 - 0.2^{0}$), as will the voltage output of the RVDT.



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RVDT CALIBRATION

Figure 3

PUMP PERFORMANCE & RESPONSE CHARACTERISTICS

A series of pump calibration data were taken on the AP27VP2 unit at 3917 rpm and at inlet temperatures of 150 F and 225 F. Torque and hanger position voltages were recorded at discharge pressure levels of 3000, 2000, and 1000 psi and at flows from full flow to zero gpm in 25 percent intervals. The results of these data and pertinent calculations are shown by the calibration curves, Figures 4 through 9.

Performance of the unit at the 3000 psi level is essentially unchanged. Overall efficiency at 60 gpm is 87.5 percent, and heat rejection at 5 and 15 gpm is 380 btu/minute and 400 btu/minute, respectively, with an inlet temperature of 150 F. At the high inlet of 225 F, the efficiency at 60 gpm is 88 percent, and the heat rejection is 330 btu/minute and 332 btu/minute, respectively. At 225 F inlet, and 1000 psi discharge pressure, the comparable heat rejection at 5 and 15 gpm is 200 btu/minute and 240 btu/minute, respectively. This represents a 40 and 32 percent energy savings, respectively, at the lower pressure. Similar energy savings result throughout the complete flow range. Figures 10 and 11 are typical calibration curves of standard AP27V-7 Shuttle pump, included for comparison purposes.

The dynamic response of the pump output control circuit was determined by oscillograph traces of the discharge pressure as the electrical signal to the servovalve was interrupted

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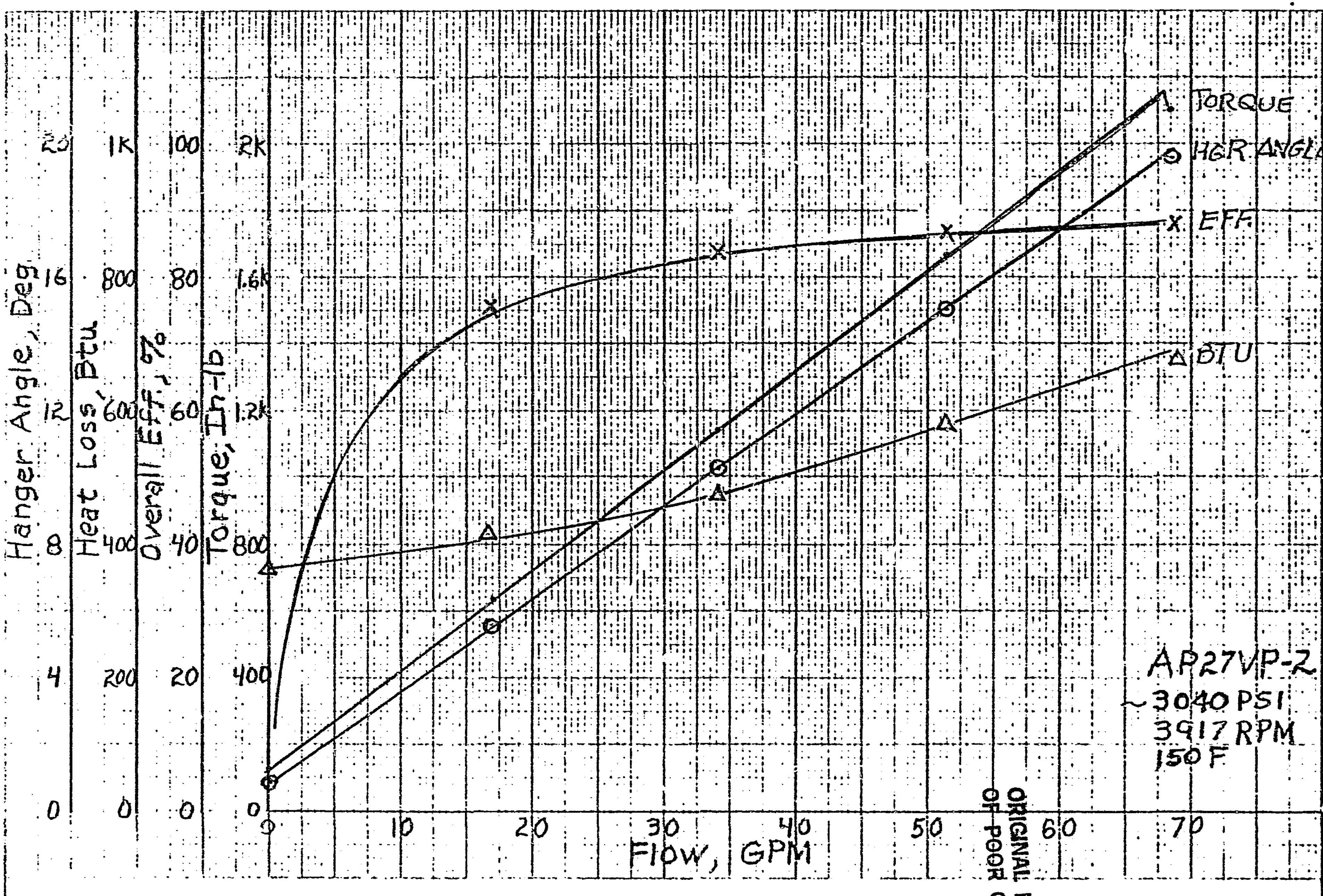

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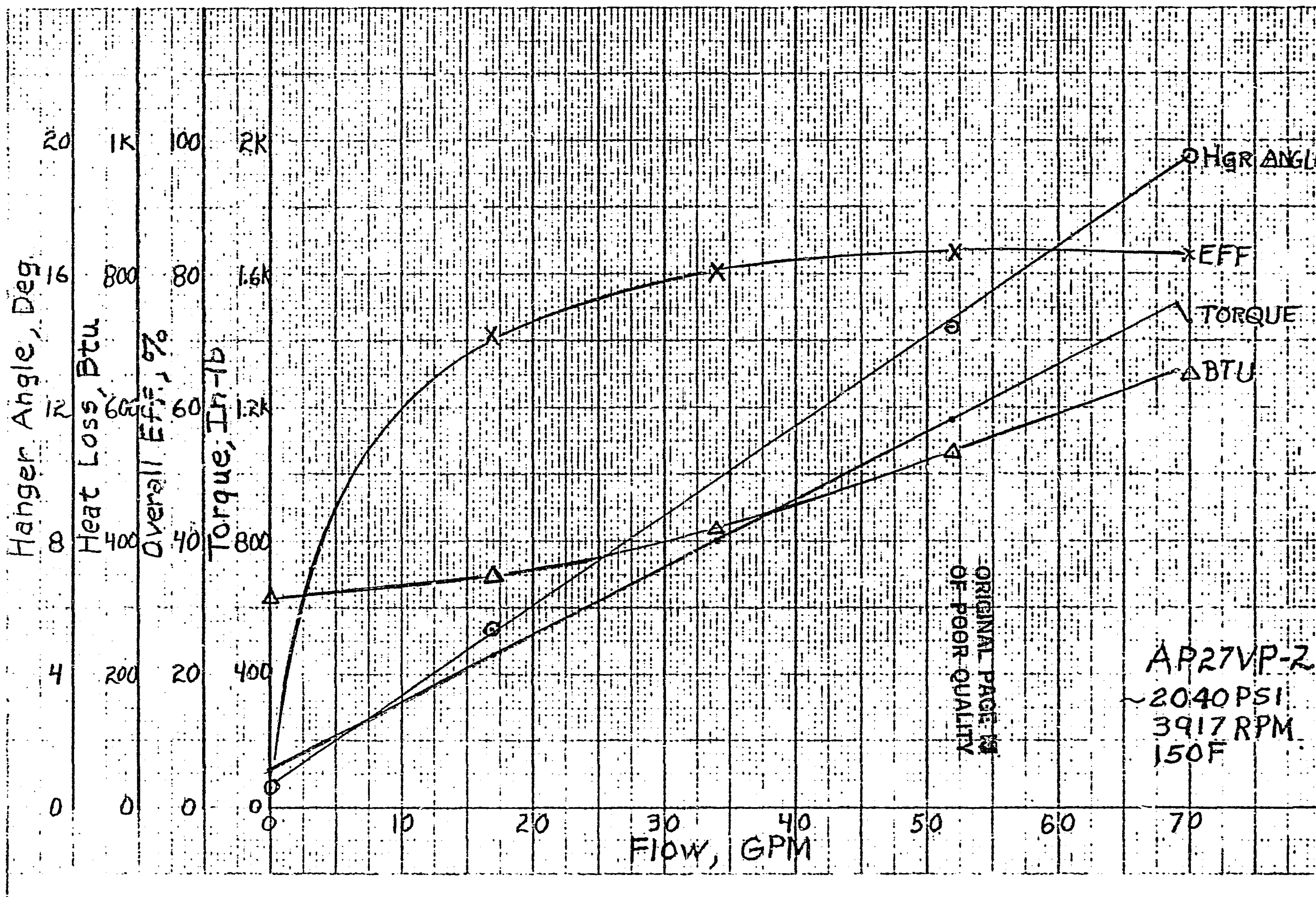
CALIBRATION ~ AP27VP-2

5-24-83 HK

FIGURE 4



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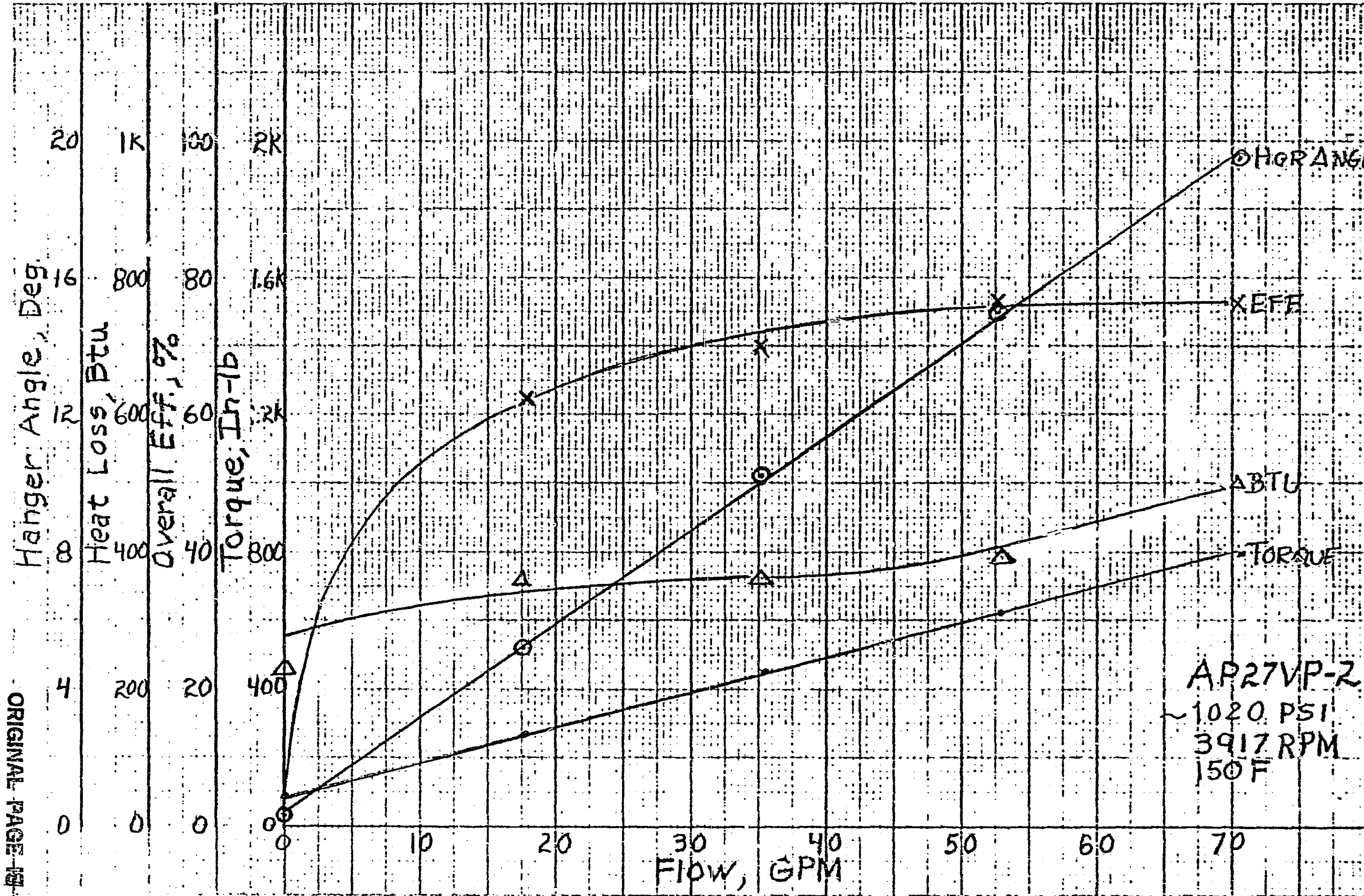
CALIBRATION ~ AP27VP-2

5-24-83 HK

FIGURE 5



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CALIBRATION ~ AP27VP-2

5-24-83 HK

FIGURE 6

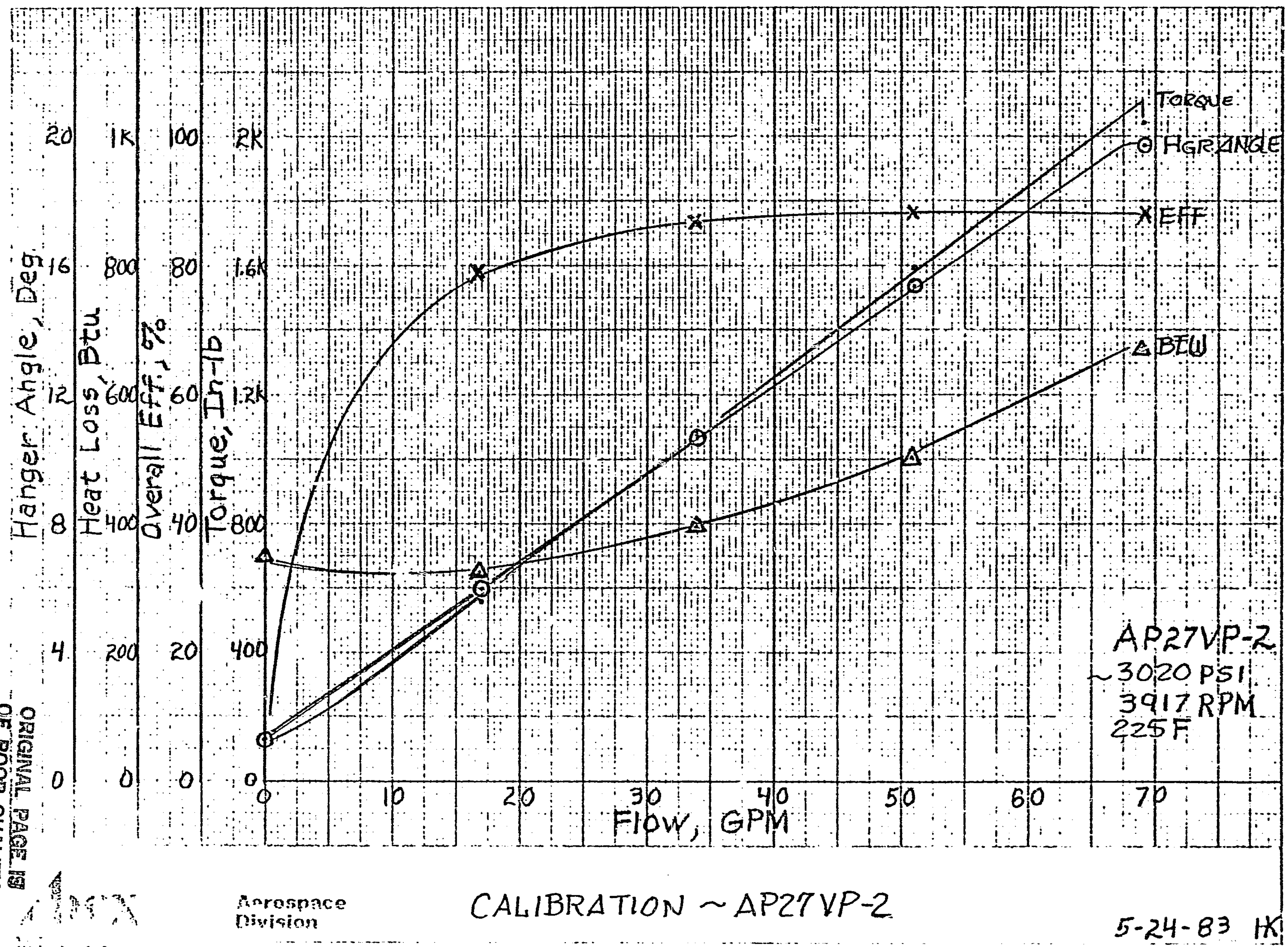

FIGURE 7

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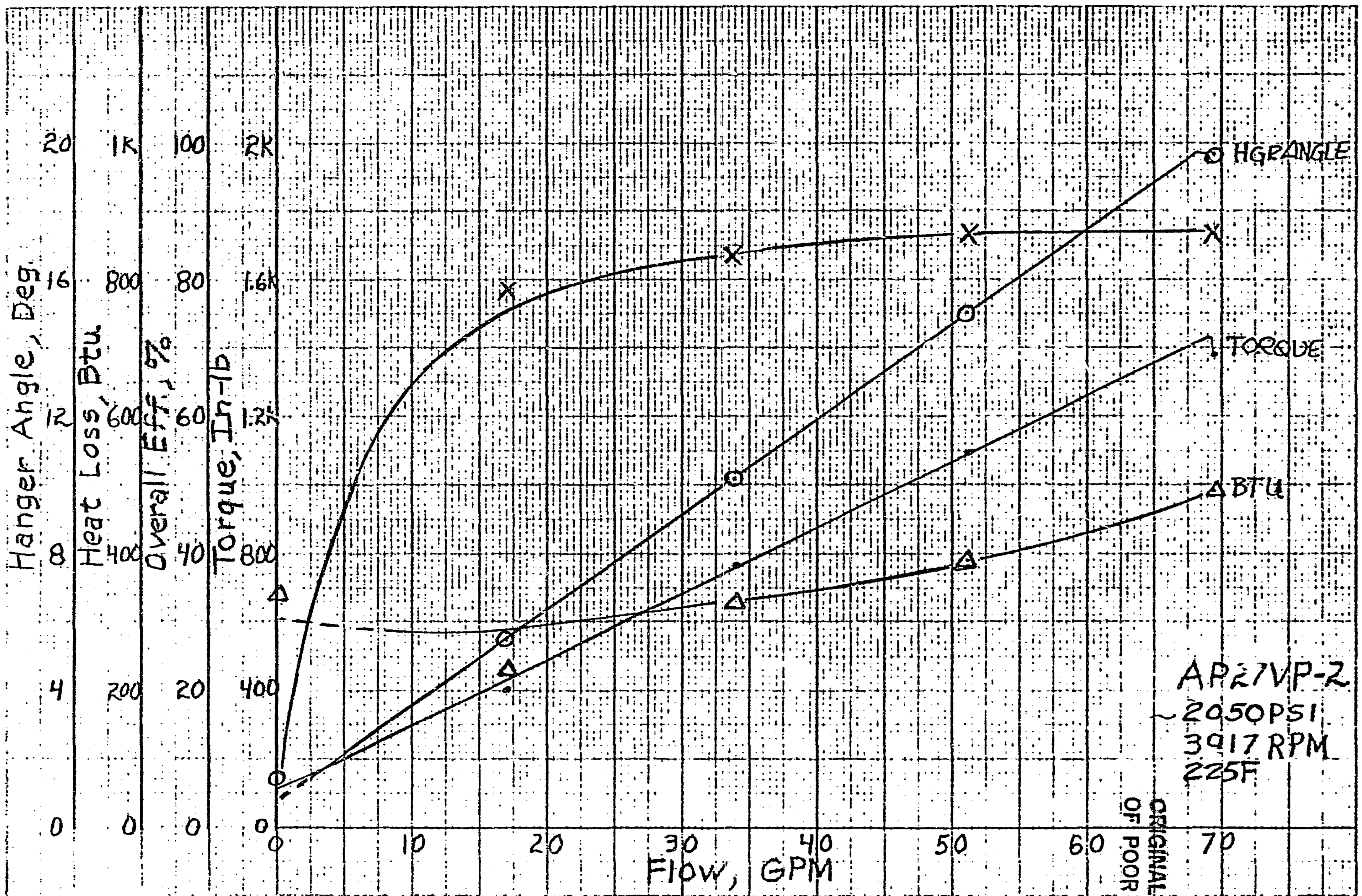

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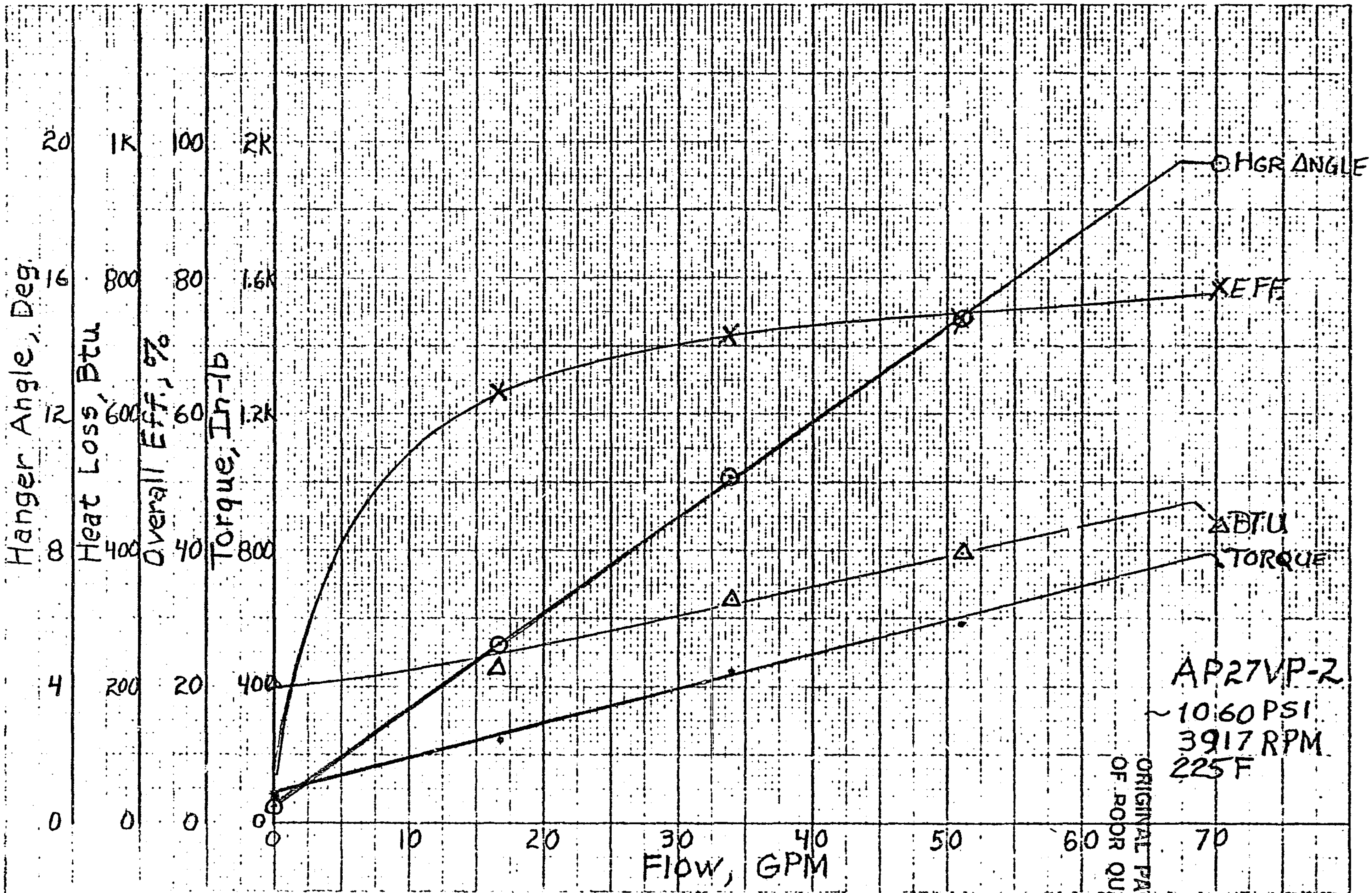
CALIBRATION ~AP27VP-2

5-24-83 HK

FIGURE 8



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CALIBRATION ~ AP27VP-2

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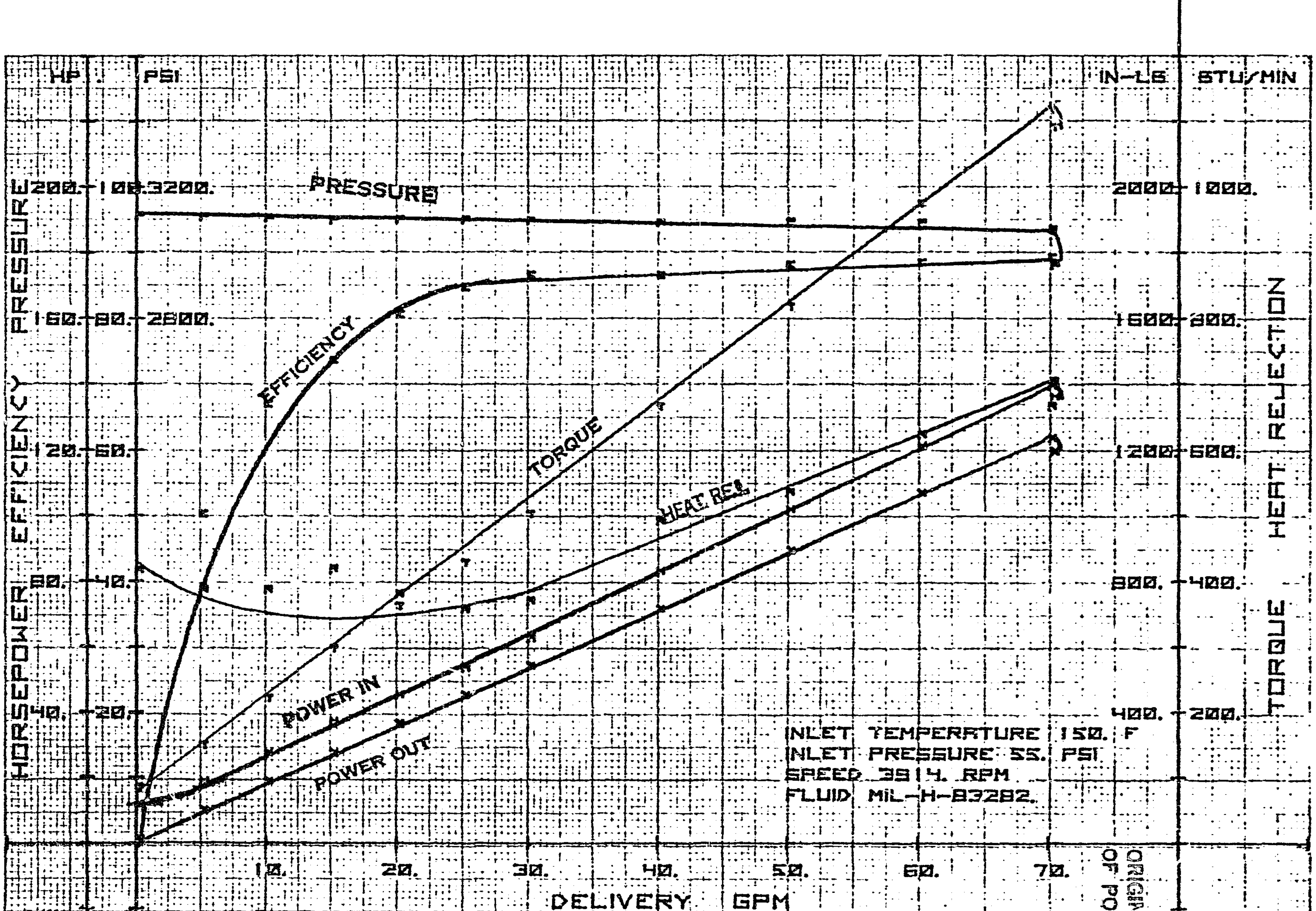
FIGURE 9



CALIBRATION AP27V-7

FIGURE 10

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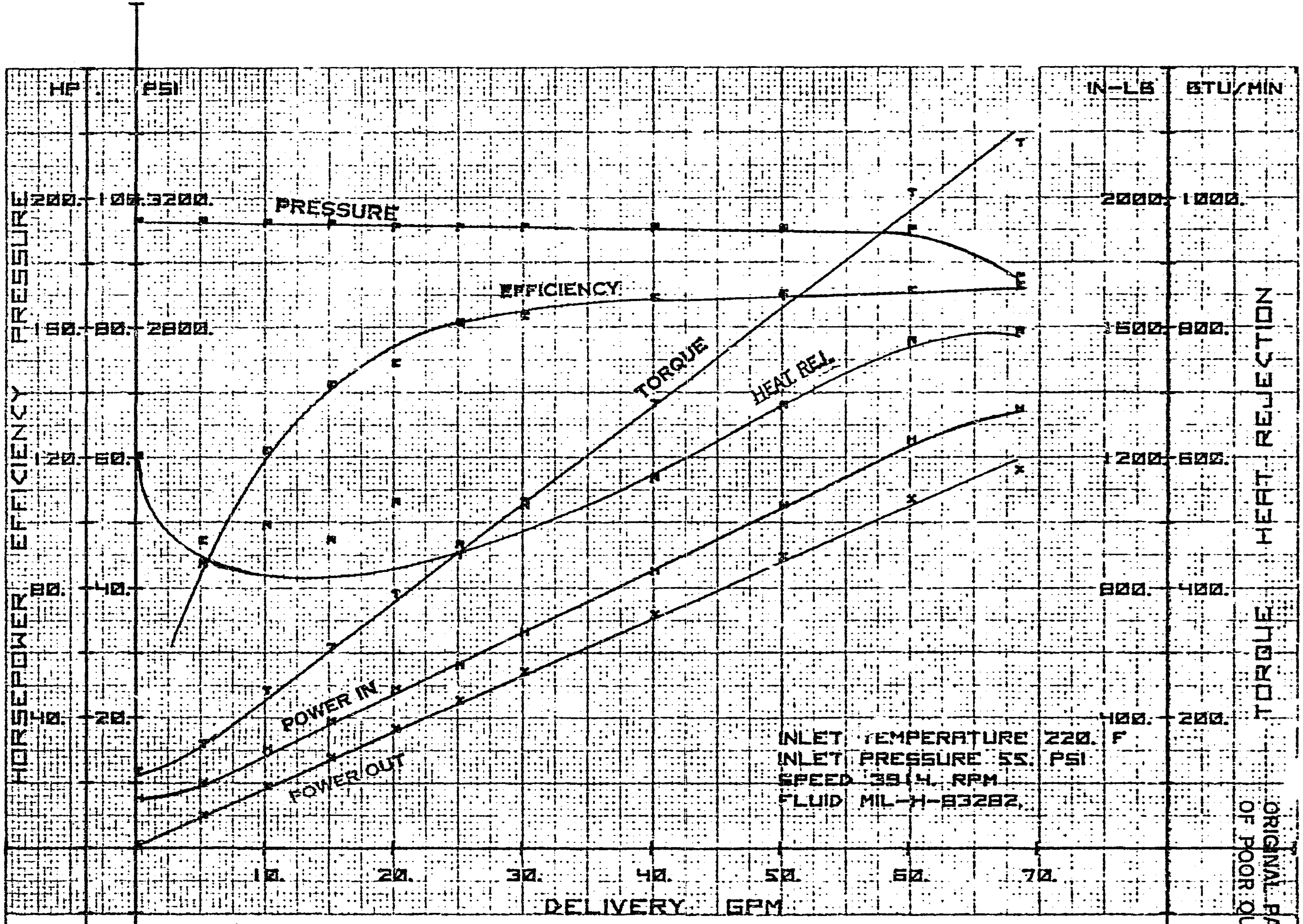


CALIBRATION AP27V-7

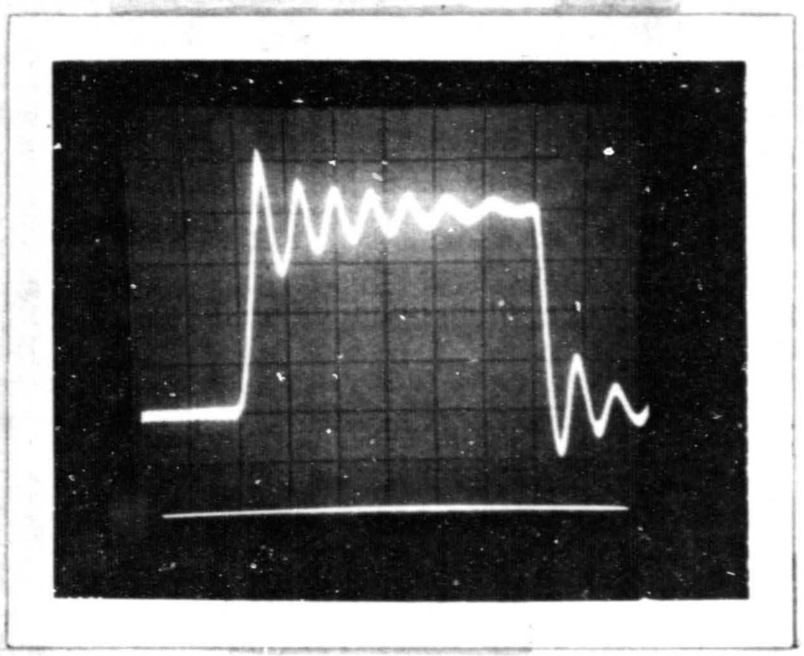
FIGURE 11

and then restored. Traces were obtained at pump flows of 5 and 15 gpm and speeds of 1800 and 4000 rpm in a system volume of approximately 150 in^3. Pressure recovery time (1000 psi to 3000 psi) varied from 47 ms (milliseconds) at the higher speed and lower flow to 107 ms at lower speed and the higher flow rate. Pressure stability was achieved well within the one second requirements of the military specification. Pressure decay times in most cases was approximately 70 ms (no requirement). Figures 12 and 13 are typical response traces photographs.

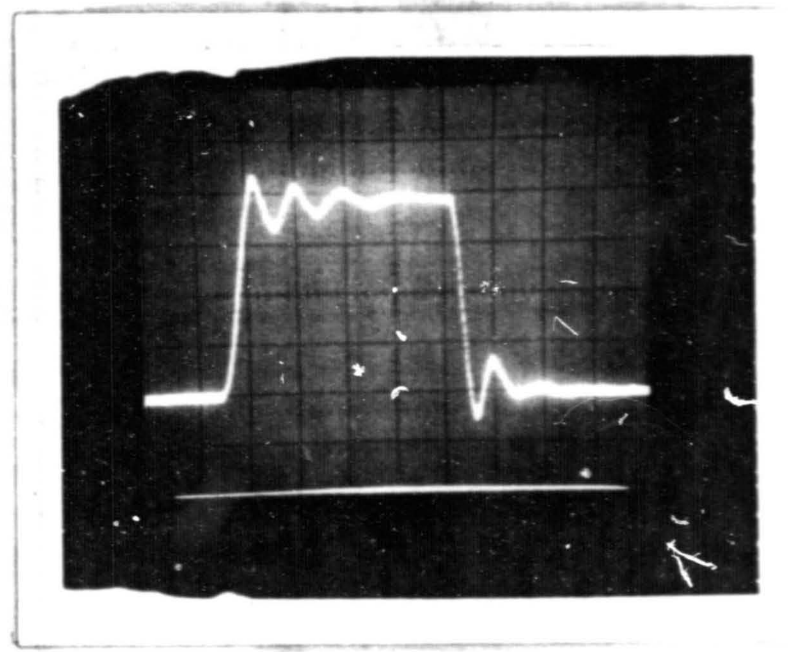
Pressure control hysteresis was determined at pump speeds of 1800 and 4000 rpm, with discharge flows of 5 and 15 gpm, and at an inlet temperature of 225 F. Control current hysteresis was generally less than 0.1 milliampere. Figures 14 through 17 are typical performance plots of the electronic pressure control hysteresis.

CONCLUSIONS

Test results and data analysis confirm that the modified AP27VP-2 hydraulic pump meets or exceeds all of the requirements and objectives as described in the NASA contract. Normal (3000 psi) pump performance parameteres are unchanged --output flow, overall efficiency, heat rejection, response, etc., are unaffected by the modifications. The expected



5 gpm, 1000-3000-1000 psi

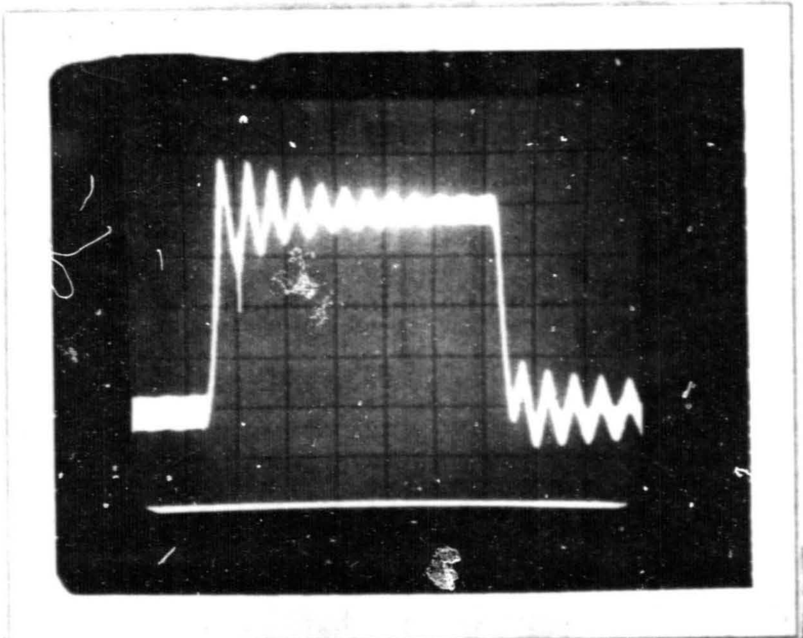


15 gpm, 1000-3000-1000 psi

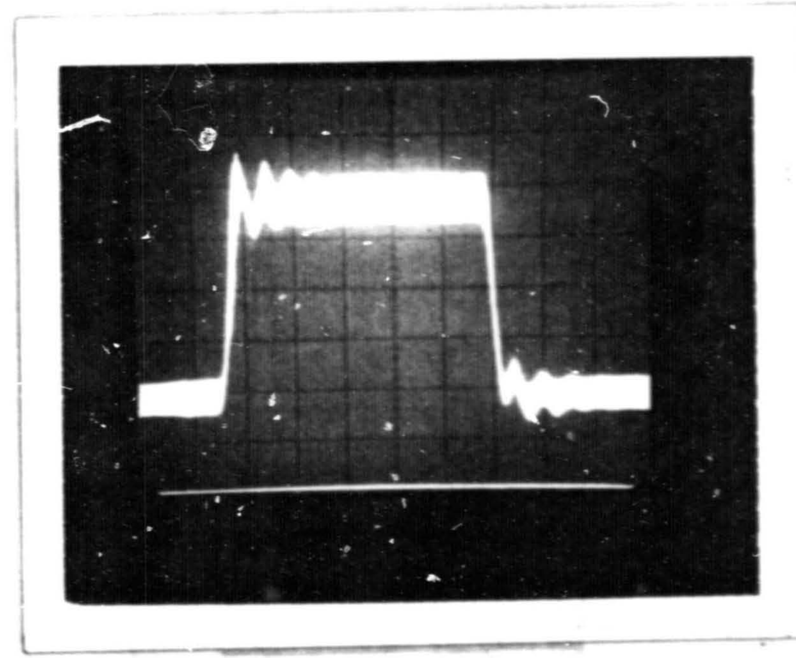
Speed ~ 1800 rpm
Sweep time ~ 200 ms/block
Pressure ~ 500 psi/block

RESPONSE TIME - AP27VP-2

Figure 12



5 gpm, 1000-3000-1000 psi

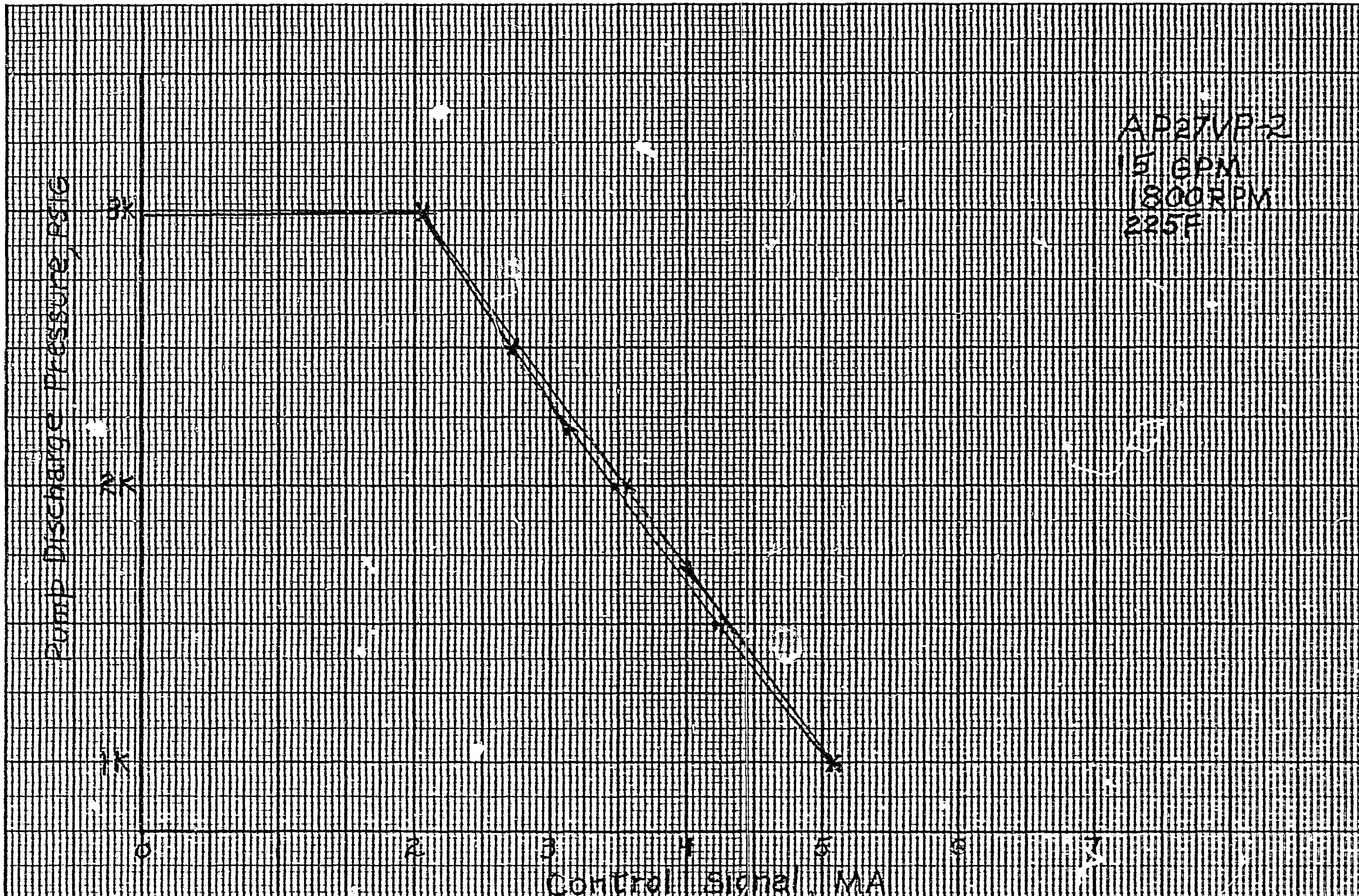


15 gpm, 1000-3000-1000 psi

Speed ~4000 rpm
Sweep time - 200 ms/block
Pressure ~ 500 psi/block

RESPONSE TIME - AP27VP-2

Figure 13



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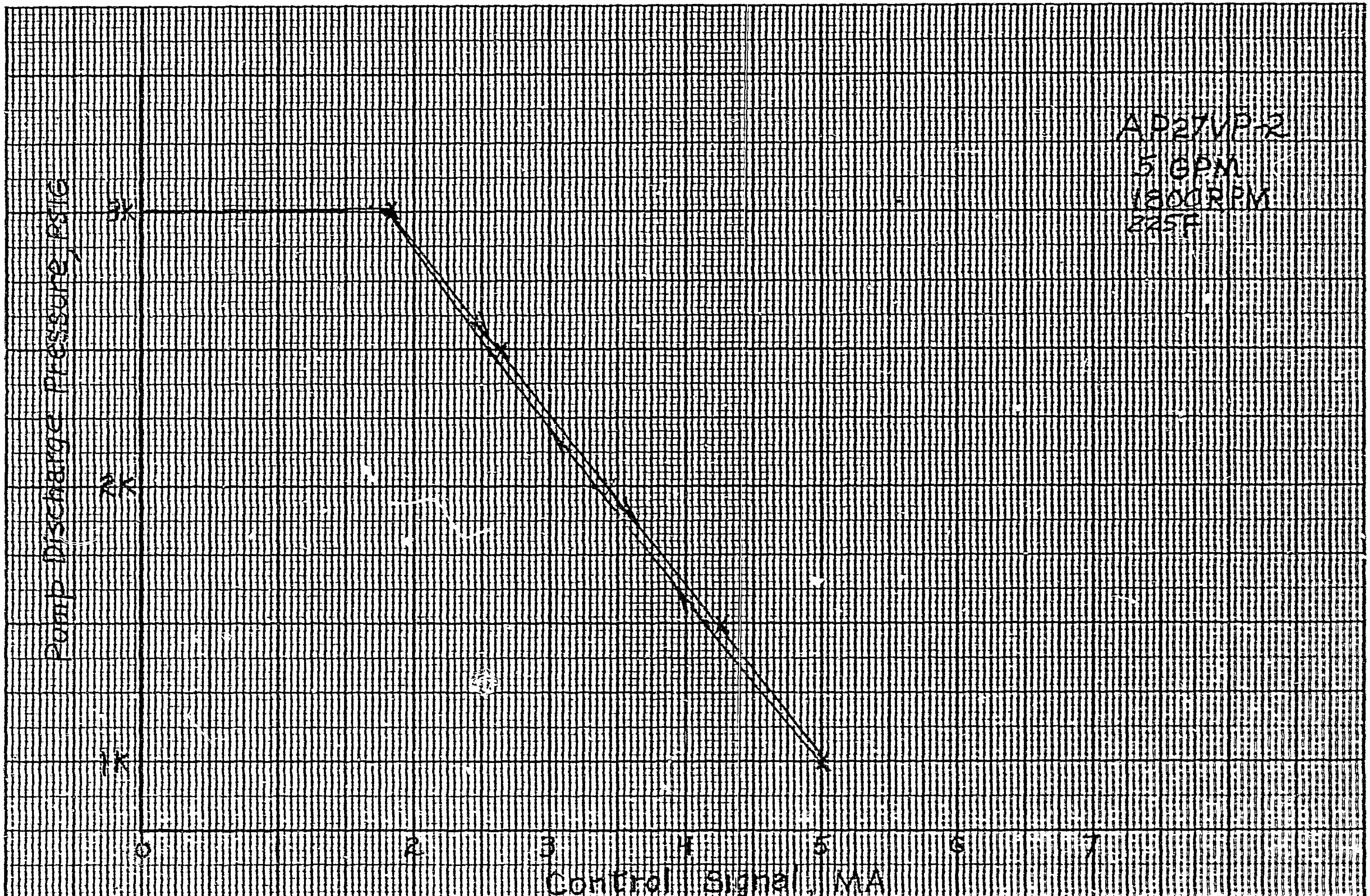
PRESSURE CONTROL HYSTERESIS

26 May 83 HK

Figure 14



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PRESSURE CONTROL HYSTERESIS

26 May 83 HK

Figure 15

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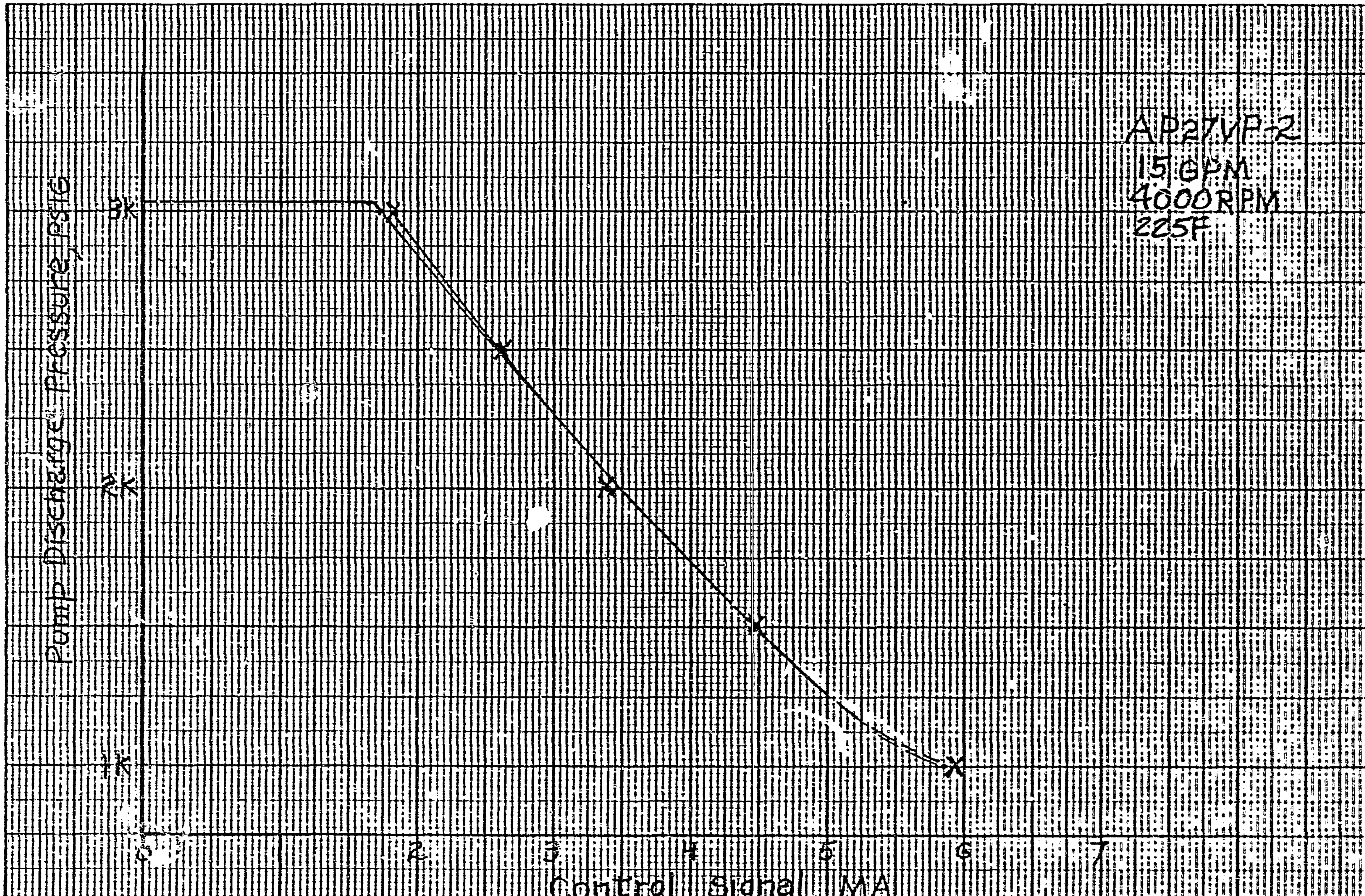

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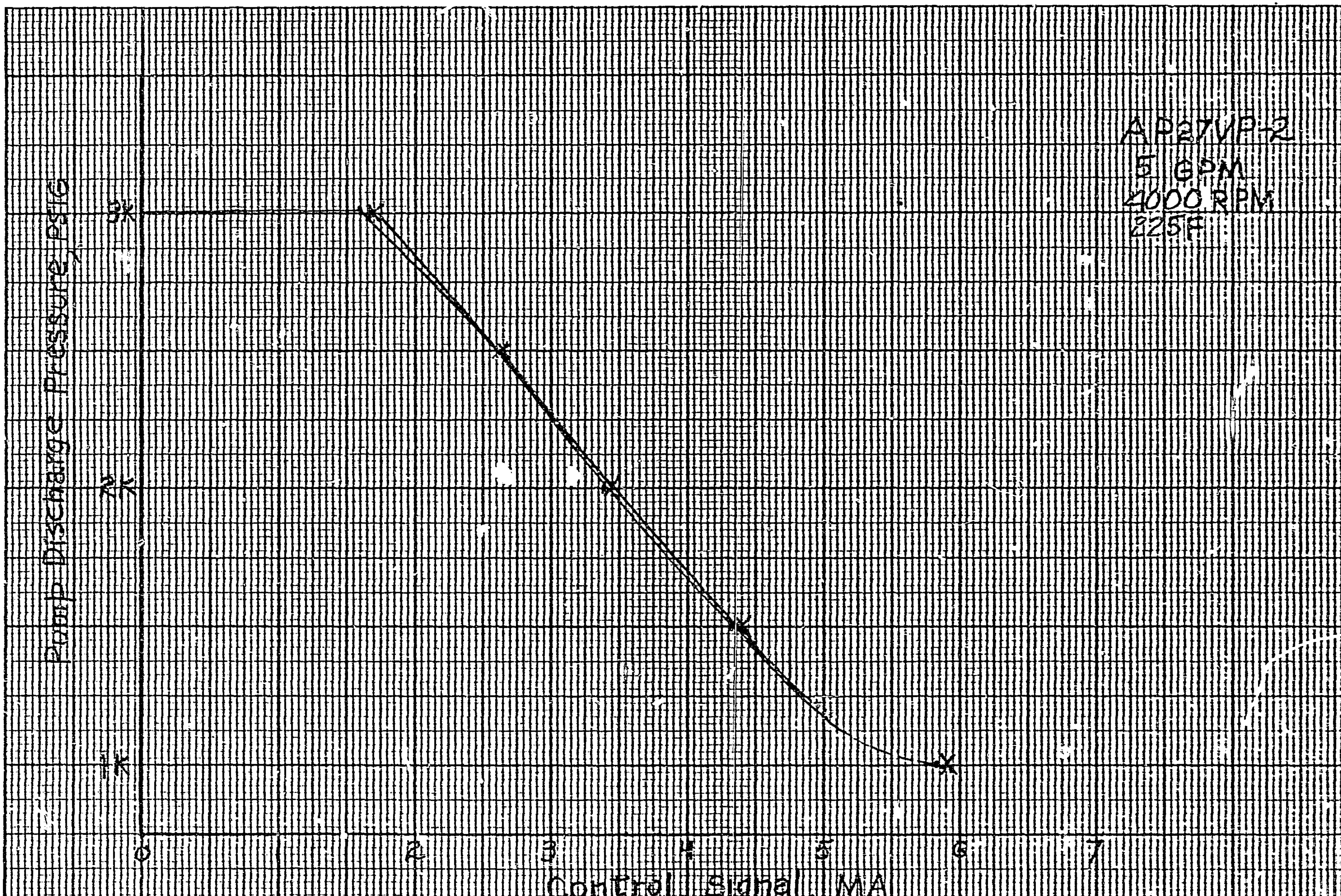
PRESSURE CONTROL HYSTERESIS

26 May 83 JK

Figure 16



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PRESSURE CONTROL HYSTERESIS

26 May 83 JK

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Figure 17

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savings in heat rejection (energy reduction) are confirmed at the lower pressure levels. The electronic pressure level control functions properly with little hysteresis and the RVDT accurately tracks hanger angles under all conditions.

A P P E N D I X

DATE	CONDUCTED BY	PURPOSE OF TEST	PAGE 1 OF
5.9.83	GS	CALIBRATION	UNIT TYPE AP27VP-2

TEST STAND NO.	TEST CONDITIONS	SERIAL NO.	LAB. NO.
#8	150°F ⟷ STATIC Hgr Volt +3.69	152294	5177

SPEED	INLET				OUTLET				DRAIN				TORQUE		MA.	O.Eff.	Volt.	Hgr	Loss	
	FLOW		PRESS	TEMP	FLOW		PRESS	TEMP	FLOW		PRESS	TEMP							Btu	
RPM	CPS	GPM		°F	CPS	GPM	PSIG	°F	CPS	GPM		°F	IN-LB					10°		
1 3917			60	155	120	69.1	2850		94	.49	105		2064		0	87.7	+3.76	19.5°	670	1
2 3918			60	150	900	51.5	3020		21	.11	90		1650		0	86.7	+1.97	15.0	577	2
3 3917			60	150	600	34.2	3030		118	.62	75		1134		0	84.1	+0.15	10.2°	475	3
4 3915			60	155	300	17.0	3040		205	1.07	70		634		0	75.1	-1.70	5.5°	417	4
5 3916			60	149		0	3050		282	1.45	66		138		0	0	-3.53	0.7°	363	5
6																				6
7																				7
8 3920			60	156	1223	70.1 ~~69~~	1900		133	.70	96		1460		3.05	82.9	+3.75	19.5°	656	8
9 3919			60	152	900	51.9	2060		29	.15	86		1176		3.05	82.9	+1.85	14.4	531	9
10 3919			60	149	600	34.2	2050		51	.27	76		798		3.05	80.1	+0.07	10.1	420	10
11 3917			60	149	300	17.0	2040		127	.66	67		446		3.05	70.8	-1.79	5.3	343	11
12 3917			60	155		0	2060		210	1.10	65		118		3.05	0	-3.62	0.5	311	12
13																				13
14																				14
15																				15

DATE	CONDUCTED BY	PURPOSE OF TEST	PAGE 2 OF
5-10-83	GS	CALIBRATION	UNIT TYPE: AP27VP-2
TEST STAND NO.	TEST CONDITIONS		SERIAL NO. / LAB. NO.
#8	150°F ↔ STATIC Hgr VOLT +3.70		152294 / 5177

	SPEED	INLET				OUTLET				DRAIN				TORQUE						LOSS	
		FLOW		PRESS	TEMP	FLOW		PRESS	TEMP	FLOW		PRESS	TEMP		Hgr				O.Eff	BTu	
	RPM	CPS	GPM		°F	CPS	GPM	PSIG	°F	CPS	GPM		°F	IN-LB	L	MA		VOLT			
1	3919			60	157	830	70.6	970		118	.62	106		792	19.5	5.50		+3.75	76.1	497	1
2	3918			60	157	622	52.9	1020		23	.12	90		626	15.0	5.50		+1.97	76.1	393	2
3	3918			60	158	415	35.3	1000		32	.17	75		448	10.2	5.50		+0.09	69.5	360	3
4	3918			60	149	207	17.6	1050		85	.44	70		262	5.2	5.50		-1.86	62.4	359	4
5	3916			60	149		0	1050		166	.87	66		86	0.3	5.50		-3.69	0	227	5
6																					6
7				225°F				STATIC		Hgr		VOLT —				+3.75					7
8	3920			60	224	803	68.3	2850		14	.07	95		2044	19.7	0		+3.80	87.5	672	8
9	3920			60	230	600	51.0	2990		95	.50	85		1594	15.4	0		+2.08	88.0	504	9
10	3916			60	220	400	34.0	3010		221	1.15	81		1090	10.7	0		+.29	86.4	391	10
11	3917			160	221	200	17.0	3020		326	1.67	70		596	6.0	0		-1.55	79.3	325	11
12	3917			60	225		0	3030		417	2.11	70		134	1.3	0		-3.27	0	353	12
13																					13
14																					14
15																					15

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OXNARD CALIFORNIA U S A

DATE	CONDUCTED BY	PURPOSE OF TEST	PAGE 3 OF
5-10-83	GS	CALIBRATION	UNIT TYPE AP27VP-2
TEST STAND NO. ±1 8	TEST CONDITIONS 225°F ←		SERIAL NO. 152294 / LAB. NO. 5177

SPEED		INLET				OUTLET				DRAIN				TORQUE	O. Eff		Hcr			Loss Btu	
		FLOW		PRESS	TEMP	FLOW		PRESS	TEMP	FLOW		PRESS	TEMP								
	RPM	CPS	GPM		°F	CPS	GPM	PSIG	°F	CPS	GPM		°F	IN-LB		MA.		VOLT			
1	3919			60	220	817	69.5	1900		61	.32	90		1386	86.6	3.48	19.7	+3.79		489	1
2	3919			60	219	600	51.0	2040		30	.16	86		1096	86.5	3.48	15.0	+1.93		390	2
3	3916			60	230	400	34.0	2060		133	.70	75		764	83.6	3.48	10.2	+0.17		331	3
4	3920			60	222	200	17.0	2040		224	1.16	70		402	78.6	3.48	5.5	-1.70		227	4
5	3920			60	224		0	2060		296	1.52	69		128	0	3.48	1.4	-3.23		337	5
6																					6
7																					7
8	3920			70	221	829	70.5	970		17	.09	95		762	78.2	5.78	19.4	+3.71		438	8
9	3922			70	218	600	51.0	970		33	.17	90		582	74.0	5.78	14.8	+1.89		398	9
10	3922			70	222	400	34.0	1070		82	.43	85		441	71.9	5.78	10.2	+0.12		329	10
11	3923			70	218	200	17.0	1050		137	.72	78		241	63.6	5.78	5.3	-1.83		236	11
12	3920			70	220		0	1060		220	1.15	75		78	0	5.78	0.5	-3.61		205	12
13																					13
14																					14
15																					15

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DATE	CONDUCTED BY	PURPOSE OF TEST	PAGE 7 OF
5-12-83	GS	CALIBRATION	UNIT TYPE: AP27VP-2

TEST STAND NO.	TEST CONDITIONS	SERIAL NO.	LAB. NO.
#8	225°F ← → HYSTERESIS	152294	5177

	SPEED	INLET				OUTLET				DRAIN				TORQUE			MA		VOLT			
		FLOW		PRESS	TEMP	FLOW		PRESS	TEMP	FLOW		PRESS	TEMP				↓	↑	↓	↑		
	RPM	CPS	GPM		°F	CPS	GPM	PSIG	°F	CPS	GPM		°F	IN-LB								
1	1805			60	220	59	5.0	3010		299	1.53	69		418	415		0	1.68	-2.09	-2.08		1
2	1804			60	220	59	5.0	3000		297	1.52	69		418	420		1.83	1.78	-2.08	-2.07	4.5	2
3	1804			60	219	59	5.0	2500		252	1.30	67		334	340		2.64	2.56	-2.16	-2.16		3
4	1804			60	218	59	5.0	2000		217	1.13	65		260	264		3.44	3.32	-2.25	-2.25	4.1	4
5	1804			60	216	59	5.0	1500		175	.92	65		190	194		4.27	4.15	-2.34	-2.34		5
6	1804			60	215	59	5.0	1000		134	.70	62		128	130		5.02	4.98	-2.41	-2.42	3.7	6
7																						7
8	1802			60	223	177	15.0	2990		208	1.09	68		1028	1034		0	2.06	+0.26	0.21	10.6	8
9	1801			60	221	177	15.0	2500		181	.95	67		850	858		2.71	2.68	+0.17	+0.18		9
10	1804			60	218	177	15.0	2000		147	.77	66		662	668		3.56	3.48	+0.06	+0.07	10.17	10
11	1804			60	223	177	15.0	1500		129	.67	66		492	496		4.27	4.20	-0.02	+0.01		11
12	1803			60	226	177	15.0	1000		98	.51	65		322	326		5.09	5.07	-0.07	-0.05	9.84	12
13																						13
14																						14
15																						15

DATE	CONDUCTED BY	PURPOSE OF TEST	PAGE 9 OF
5-12-83	GS	CALIBRATION	UNIT TYPE: AP27VP-2
TEST STAND NO. #8	TEST CONDITIONS: 225°F ← → HYSTERESIS		SERIAL NO. 152294 / LAB. NO. 5177

SPEED		INLET				OUTLET				DRAIN				TORQUE			MA		VOLT			
		FLOW		PRESS	TEMP	FLOW		PRESS	TEMP	FLOW		PRESS	TEMP				↓	↑	↓	↑		
	RPM	CPS	GPM		°F	CPS	GPM	PSIG	°F	CPS	GPM		°F	IN-LB								
1	4008			60	224	59	5	3020		393	2.00	69		256	256		0	1.58	2.92	2.92		1
2	4007			60	215	59	5	3000		368	1.87	68		252	254		1.70	1.68	2.94	2.92		2
3	4004			60	219	59	5	2500		333	1.70	65		212	214		2.64	2.64	2.97	2.97		3
4	4004			60	226	59	5	2000		284	1.46	65		172	174		3.43	3.39	3.04	3.04		4
5	4002			60	215	59	5	1500		214	1.12	65		144	146		4.40	4.31	3.12	3.13		5
6	4002			60	215	59	5	1000		200	1.05	63		122	122		5.92	5.80	3.17	3.17		6
7																						7
8	4001			60	216	177	15	3030		323	1.65	67		542	544		0	1.63	1.86	1.85		8
9	4001			60	229	177	15	3000		351	1.79	66		532	538		1.82	1.72	1.87	1.86		9
10	4000			60	224	177	15	2500		293	1.50	66		456	454		2.63	265	1.90	1.91		10
11	4004			60	216	177	15	2000		225	1.17	66		366	366		3.39	3.40	2.00	1.99		11
12	4008			60	225	177	15	1500		188	.98	65		290	288		4.47	4.46	2.05	2.06		12
13	4006			60	215	177	15	1000		156	.82	65		220	220		5.92	5.85	2.11	2.11		13
14																						14
15																						15

ORIGINAL PAGE IS OF POOR QUALITY