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SNAP-8 NaK-PUMP-MOTOR-ASSEMBLY
400 HERTZ START TESTS

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This information is being published in preliminary form in order to expedite its early release.

ABSTRACT

Two hermetically-sealed induction motor-driven centrifugal pumps were tested to determine their ability to start on 400 hertz power in NaK (eutectic sodium-potassium mixture) loops at 70 to 1300° F (294 to 976 K). The NaK flow resistance was preset by a flow control valve prior to each start and corresponded to NaK flow rates after pump start from zero to 40,000 lb/hr (18,160 kg/hr). The two pumps started successfully on 400 hertz power when the induction motor stator temperatures were 300 and 480° F (422 and 521 K) with NaK pump inlet temperatures of 115 and 1300° F (319 and 976 K), respectively. Both pumps experienced startup difficulties when the motor stator temperatures were 70 to 140° F (294 to 333 K) with NaK at the pump inlet at temperatures ranging from 70 to 600° F (294 to 588 K).

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SUMMARY

Two hermetically-sealed induction motor-driven centrifugal pumps were tested to determine their ability to start on 400 hertz power in NaK loops at 70° F to 1300° F (294 to 976 K). The NaK flow rate after start was preset from zero to 40,000 lb/hr (18,160 kg/hr) by a flow control valve prior to each start. The two pumps started successfully on 400 hertz power when the motor stator temperatures were 300 and 480° F (422 and 521 K) and the liquid NaK temperatures at the pump inlet were 115 and 1300° F (319 and 976 K). Both pumps experienced startup difficulties at low motor stator temperatures of 70 to 140° F (294 to 333 K) with NaK temperatures at the pump inlet of 70 to 600° F (294 to 588 K). The test results indicate that the SNAP-8 NaK pumps will start quickly and reliably on 400 hertz power provided the pump motor stator temperatures are maintained near the design operating value of 350° F (450 K).

INTRODUCTION

SNAP-8 is a 35 kilowatt nuclear-turboelectric power system being developed for use in space. The system operates on a Rankine cycle and uses a nuclear reactor as the heat source. Three liquid-metal loops are used for heat transfer. In the primary loop, heat is transferred from the reactor to a mercury boiler by an eutectic mixture of sodium and potassium called NaK. Mercury vapor drives the turbine alternator assembly in the two-phase power loop. Heat is transferred from the mercury condenser to a space radiator by the NaK heat rejection loop. All three loops use centrifugal circulating pumps driven by electric motors. During system operation, the electric power for the pump motors is provided by the turbine alternator assembly. During system startup, pump power is supplied by a variable frequency battery-driven inverter. Normal startup frequency of the NaK pumps is 45 hertz.

One system configuration being considered uses nonoperating backup pumps in the NaK loops. If an operating pump fails, the backup pump would be used, allowing full-power operation of the system to continue. Major system perturbation or shutdown and restart could be avoided if the redundant pump could be effectively started and accelerated rapidly

at the steady-state alternator frequency of 400 hertz. It was, therefore, considered necessary to experimentally establish the feasibility and reliability of starting a redundant pump unit on 400 hertz alternator power.

Start tests, therefore, were conducted with two SNAP-8 NaK pumps using 400 hertz power. The tests were part of an extensive system startup and shutdown test program in the SNAP-8 test facility at the Lewis Research Center. One of the NaK pumps was in the primary heat source loop and the other in the heat rejection loop of the SNAP-8 test system. The pump inlet NaK temperatures ranged from 70 to 1300^o F (294 to 976 K), and the pump motor stator temperatures ranged from 70 to 480^o F (294 to 521 K). For each pump, the NaK flow resistance was preset by a flow control valve prior to each start. By this method, the NaK flow rates attained after startup were varied from zero to 40,000 lb/hr (18,160 kg/hr).

DESCRIPTION OF SNAP-8 TEST FACILITY

The test facility in which the pumps were operated was designed for performance testing of an experimental SNAP-8 system that utilizes all of the major SNAP-8 components with the exception of the reactor, radiator, parasitic load resistor and fluid reservoirs. A computer-controlled electric heater was used to simulate the reactor, and air cooled heat exchangers were used to simulate the heat rejection radiator.

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.

PUMP DESCRIPTION

The NaK pump shown in Figure 2 and described in reference 2 is a hermetically-sealed unit incorporating on a single shaft a centrifugal pump, a "canned" 400 hertz 3-phase induction motor, NaK lubricated tilting-pad journal and thrust bearings, and an internal NaK lubricant-coolant recirculation pump. Two identically designed NaK pumps are used, one in the primary loop at an operating temperature of 1150^o F (895 K), while the second is used in the heat rejection loop at an operating temperature of 450^o F (505 K). The motors for both pumps at design conditions operate at 350^o F (450 K). Each pump weighs approximately 200 pounds (90 kg).

In this design no static or dynamic shaft seals were necessary. A unique feature of this pump is that the heat from the hot NaK is thermally isolated from the motor by minimizing the heat conduction paths between the two. This is done by providing the shaft and housing with a close clearance in the area between the pump impeller and the

motor. This close clearance annulus forms a nominal seal preventing any substantial interchange of the hot NaK being pumped with the cooler NaK in the motor cavity. This limited NaK oxide precipitation in the bearing area. Any oxides that do migrate into the bearing area are removed in the recirculation loop where cold trapping takes place.

The NaK pump has its own self-contained lubricant-coolant loop. The NaK recirculation loop cools the motor and supplies the bearings with oxide-free NaK. It consists of an internal NaK lubricant-coolant recirculation pump, an economizer, a heat exchanger cold trap, and a filter. The recirculation impeller pumps the NaK from the motor cavity through the recirculation loop. Oxides are precipitated out in the heat exchanger cold trap which is cooled by the oil coolant fluid. The economizer adds heat to the NaK leaving the cold trap to prevent oxide removal in the filter. The filter is used only to remove foreign particles.

INSTRUMENTATION

Instrumentation necessary to evaluate pump performance during starts consisted of: flowmeters; thermocouples; power, current and voltage transducers; and electromagnetic speed pickups. The primary NaK flow was measured by an electromagnetic (EM) flowmeter, while in the heat rejection loop, an EM flowmeter and a calibrated venturi were used. Description of the instrumentation, ranges, accuracies and methods of calibration are given in reference 3.

RESULTS AND DISCUSSION

The first pump startup test series was performed on the pumps with the primary NaK loop (PNL) temperatures at 1300° F (976 K) and the heat rejection loop temperature (HRL) at 115° F (319 K). The pump motor stator temperatures for the PNL and HRL pumps were 480° F (521 K) and 300° F (422 K) respectively. As shown in figure 1, each pump had a flow control valve (V115 and V314). Prior to each startup, the control valve was adjusted to allow the desired NaK flow at pump design speed of 5800 rpm at 400 hertz power. For this first test series, the tabulated startup data and the strip chart recorder traces for both pumps are shown in table I and figures 3 and 4. The time column in the table is the time required to reach design pump speed and is based on the time for attainment of steady-state motor current of approximately 18 amperes. The difference of about 3 amperes in steady-state current between the two pumps is due to differences in the design of the motor stators which resulted in the PNL pump requiring about one kilowatt greater power than the HRL pump (ref. 4).

All starts attempted in this first test series were successful. Each time, design speed was attained in a relatively short time. Since this test series covered a wide range of NaK temperatures (115 and 1300° F), it is believed that this variable is not of primary importance in pump starting. As shown in table I and figures 3 and 4, the acceleration times were affected somewhat by the NaK flow setting. For the primary pump, with a motor temperature of 480° F (521 K), the acceleration times ranged from 2.5 to 3.5 seconds as the equilibrium (or final) flow was increased from 10,000 to 40,000 lbs/hr (4,540 to 18,160 kg/hr). The heat rejection loop pump, with a motor temperature of 300° F (422 K), had an increase in acceleration time from 3 to 6 seconds as the final flow rate was increased from 10,000 to 40,000 lbs/hr (4,540 to 18,160 kg/hr).

For the second test series, the primary NaK temperature at the pump inlet varied from about 150 to 600° F (338 to 588 K) while the primary pump motor stator temperature varied from 100 to 140° F (311 to 333 K), due to a requirement of maintaining power to the primary NaK loop electric heater (reactor simulator). The heat rejection loop pump NaK and motor temperatures were maintained at 70° F (294 K). The tabulated and strip chart data for both pumps are shown in table II and figures 5, 6, 7, and 8.

The initial start of the primary pump on 400 hertz power at a pump inlet NaK temperatures of 150° F (338 K) was unsuccessful. The pump required a 60 hertz start followed by transfer to 400 hertz power. The remaining starts on 400 hertz power with NaK at the pump inlet at temperatures of 150° F (338 K) and higher were successful. Both pumps, however, experienced difficulty in attaining design current and speed at the preset flow conditions. The primary pump never attained the 40,000 lbs/hr (18,160 kg/hr) NaK flow rate while the HRL pump never attained the 30,000 and 40,000 lbs/hr (13,620 and 18,160 kg/hr) flow rate. During the tests, the pumps were not allowed to operate for extended periods of time at currents near the peak or starting current of 48 amperes. Continuous pump operation at the peak current could result in excessive motor stator temperatures and eventual motor damage. The acceleration times of the startups where the pumps attained the 5800 rpm design speed with low pump motor stator temperatures ranged from 9.8 to 31 seconds for the primary pump and from 9.5 to 45.2 seconds for the heat rejection loop pump.

CONCLUDING REMARKS

The tests that were made to investigate the startup characteristics of the SNAP-8 NaK pumps on 400 hertz power yielded the following results:

1. All of the pump starts at motor stator temperatures of 300 and 480° F (422 and 521 K) were successful. The pump design speed was attained in a relatively short time with a NaK temperature range of 115 to 1300° F (319 to 976 K) at the pump inlet.

2. The fastest accelerations for each NaK flow were attained with a motor stator temperature of 480° F (521 K) and a NaK temperature of 1300° F (976 K) at the pump inlet. At this temperature condition, acceleration times ranged from 2.5 to 3.5 seconds as NaK flow was increased from 10,000 to 40,000 lbs/hr (4,540 to 18,160 kg/hr).

3. At a motor stator temperature of 300° F (422 K) and a pump inlet NaK temperature of only 115° F (319 K) acceleration times ranged from 3 to 6 seconds as NaK flow was increased from 10,000 to 40,000 lbs/hr (4,540 to 18,160 kg/hr).

4. When the pump motor stator temperatures were in the range of 70 to 140° F (294 to 333 K), pump design speed of 5800 rpm was not attained in four of the ten startup attempts. In one start, the pump would not rotate at all on 400 hertz power. For these motor temperatures, the NaK temperature range was 70 to 600° F (294 to 588 K). When pump design speed of 5800 rpm was attained, the acceleration times varied from 9.5 to 45.2 seconds over a NaK flow range of zero to 30,000 lbs/hr (13,620 kg/hr).

The above results indicate that the SNAP-8 NaK pumps will start reliably and quickly on 400 hertz power provided the pump motor stator temperatures are maintained at approximately the design operating value of 350° F (450 K). This conjecture is supported by the fact that the starting torque of induction motors is proportional to rotor resistance which increases with temperature.

Further tests are required to obtain more complete pump-starting information. Also, additional start testing is required to determine the effect of fabrication tolerances.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 22, 1969
120-27

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TABLE I

NaK PMA START TESTS WITH MOTOR STATOR
TEMPERATURES OF 300 AND 480° F

PRIMARY NaK PMA									
Speed RPM	Flow x 10 ³		ΦA Current Ampere		Time Sec.	NaK		Motor Stator	
	PPH	KGPH	Peak	Steady State		°F	°K	°F	°K
0-5800	0-10	0- 4.54	43	17.5	2.5	1300	976	480	521
0-5800	0-20	0- 9.08	43	19.5	3.5	1300	976	480	521
0-5800	0-30	0-13.62	43	20.0	3.5	1300	976	480	521
0-5800	0-40	0-18.16	43	21.3	3.5	1300	976	480	521
HEAT REJECTION LOOP NaK PMA									
0-5800	0-10	0- 4.54	44.4	14.0	3.0	115	319	300	422
0-5800	0-20	0- 9.08	44.4	15.0	4.0	115	319	300	422
0-5800	0-30	0-13.62	44.4	17.5	4.5	115	319	300	422
0-5800	0-40	0-18.16	44.1	18.8	6.0	115	319	300	422

TABLE II

NaK PMA START TESTS WITH MOTOR STATOR
TEMPERATURES OF 70 AND 140° F

PRIMARY NaK PMA									
Speed RPM	Flow x10 ³		A Current Ampere		Time Sec.	NaK		Motor Stator	
	PPH	KGPH	Peak	Steady State		°F	°K	°F	°K
¹ 0-5800	0	0	47.6	19.0	9.8	150	338	100	311
0-5800	0-10	0- 4.54	47.6	25.0	13.5	300	422	110	316
0-5800	0-20	0- 9.08	47.6	22.5	30.0	400	477	120	322
0-5800	0-30	0-13.62	47.6	22.5	31.0	500	533	130	327
² 0-4400	0-40	0-18.16	47.6	46.0	30.5	600	588	140	333
<p>1 NaK PMA would not start initially on 400 hertz. Started on 60 hertz and transferred to 400 hertz.</p> <p>2 NaK PMA speed would not increase beyond 4400 rpm.</p>									
HEAT REJECTION LOOP NaK PMA									
0-5800	0	0	48.7	17.5	9.5	70	294	70	294
0-5800	0-10	0- 4.54	48.6	17.5	9.7	70	294	70	294
0-5800	0-20	0- 9.08	48.6	20.0	45.2	70	294	70	294
¹ 0-3700	0-30	0-13.62	48.6	45.8	69.8	70	294	70	294
¹ 0-3500	0-40	0-18.16	48.6	45.8	48.0	70	294	70	294
<p>1 NaK PMA speed would not increase beyond indicated speed.</p>									

LERC SNAP 8 SYSTEM LOOP

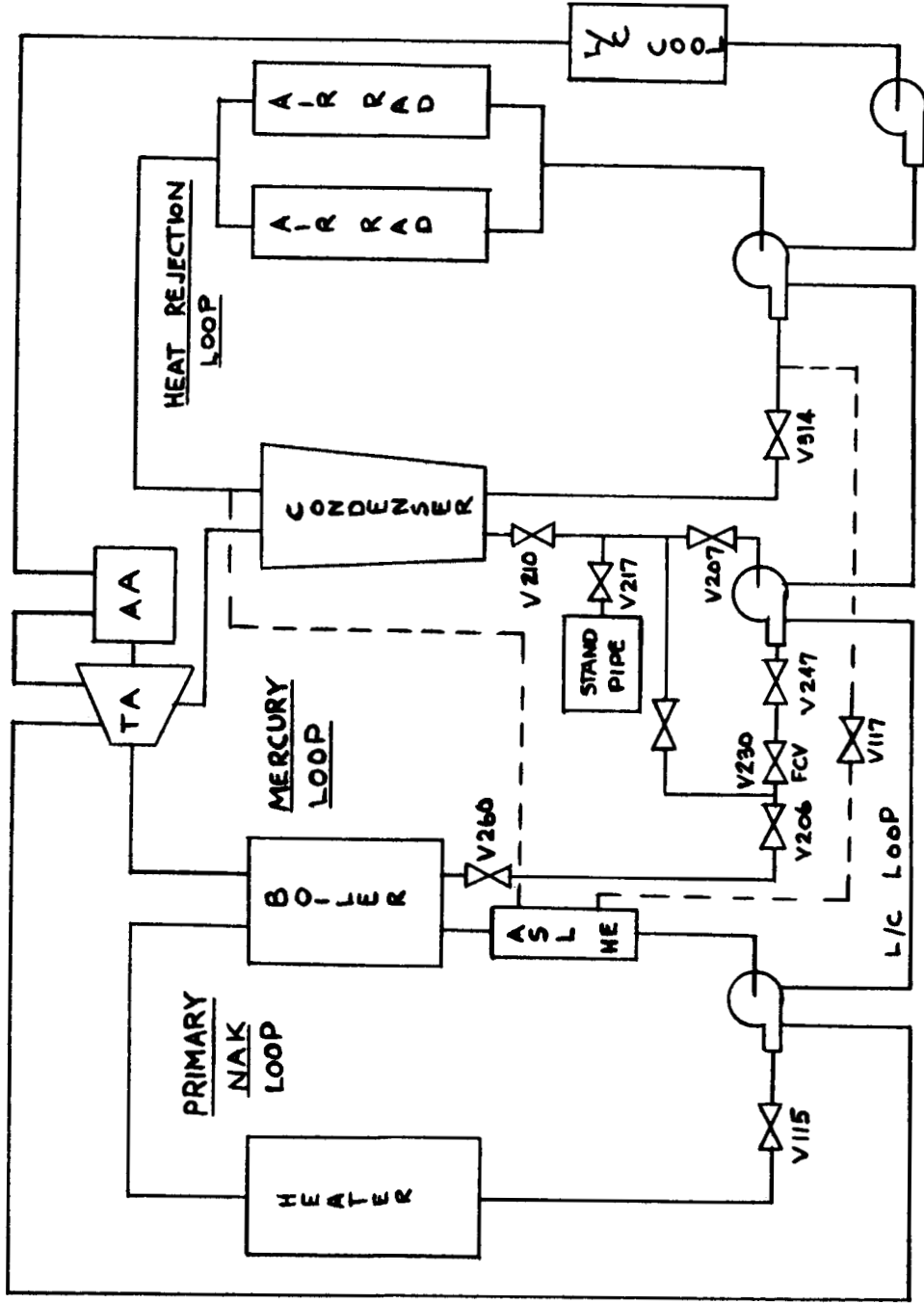
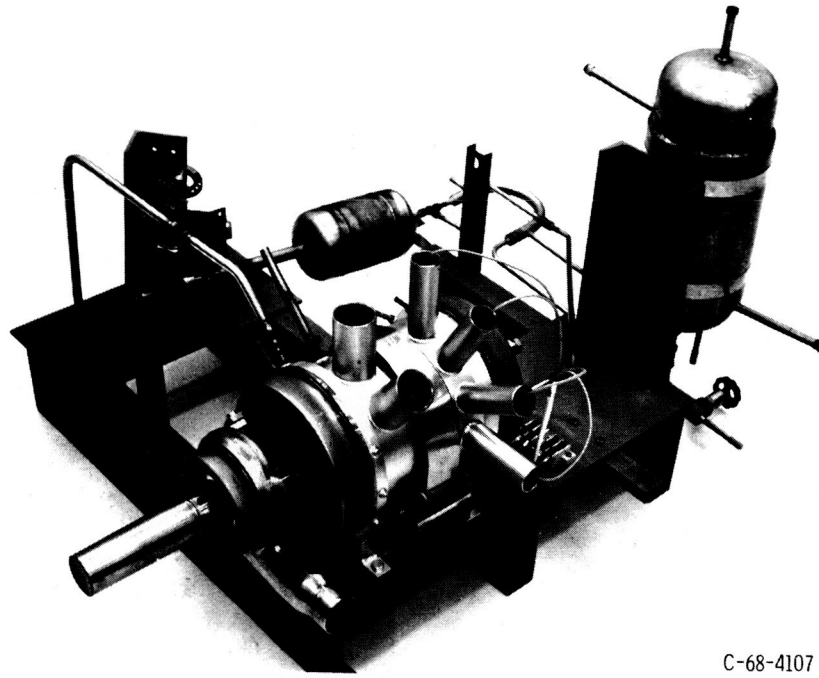
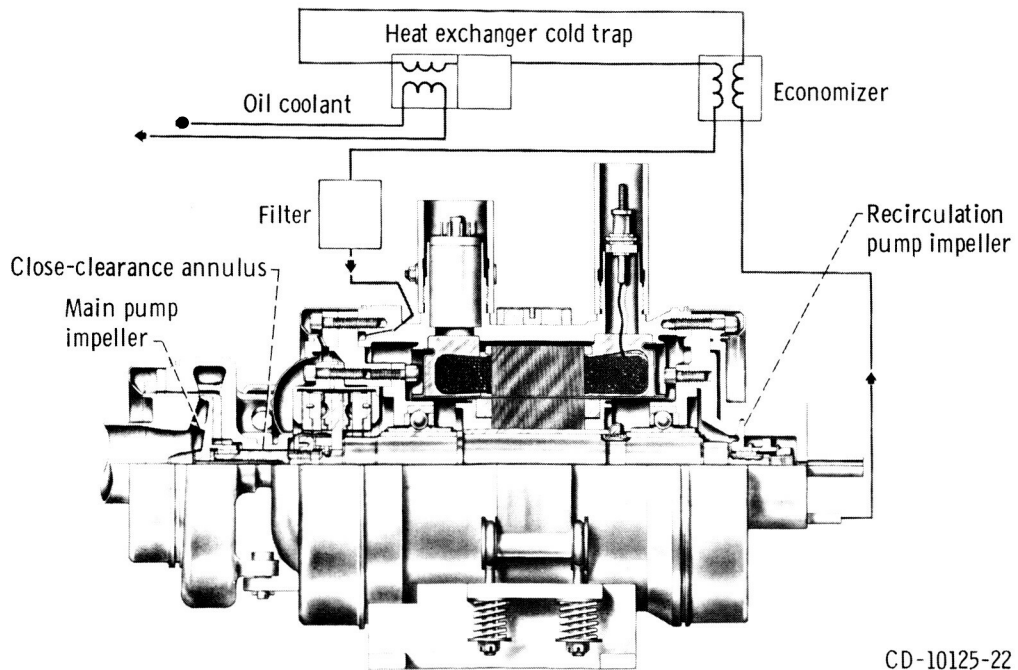


FIGURE 1 SNAP 8 TEST SYSTEM



NaK pump.

C-68-4107



NaK pump cross section.

CD-10125-22

Figure 2. - Views of SNAP-8 NaK pump.

FIGURE 3 PRIMARY NAK PMA START TEST
WITH MOTOR TEMPERATURE OF 480°F

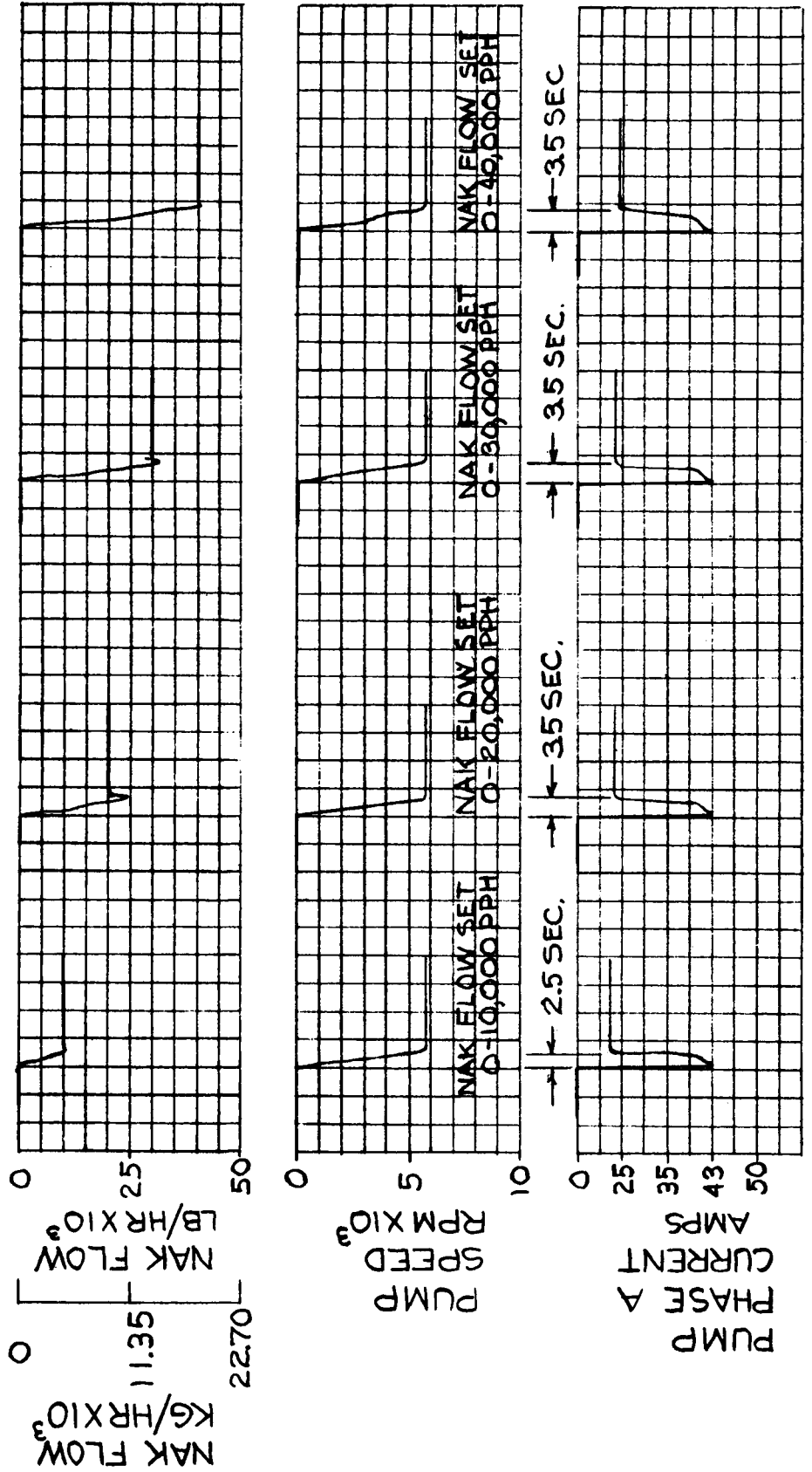


FIGURE 4 HEAT REJECTION LOOP NAK PMA
START TEST WITH MOTOR
TEMPERATURE OF 300°F

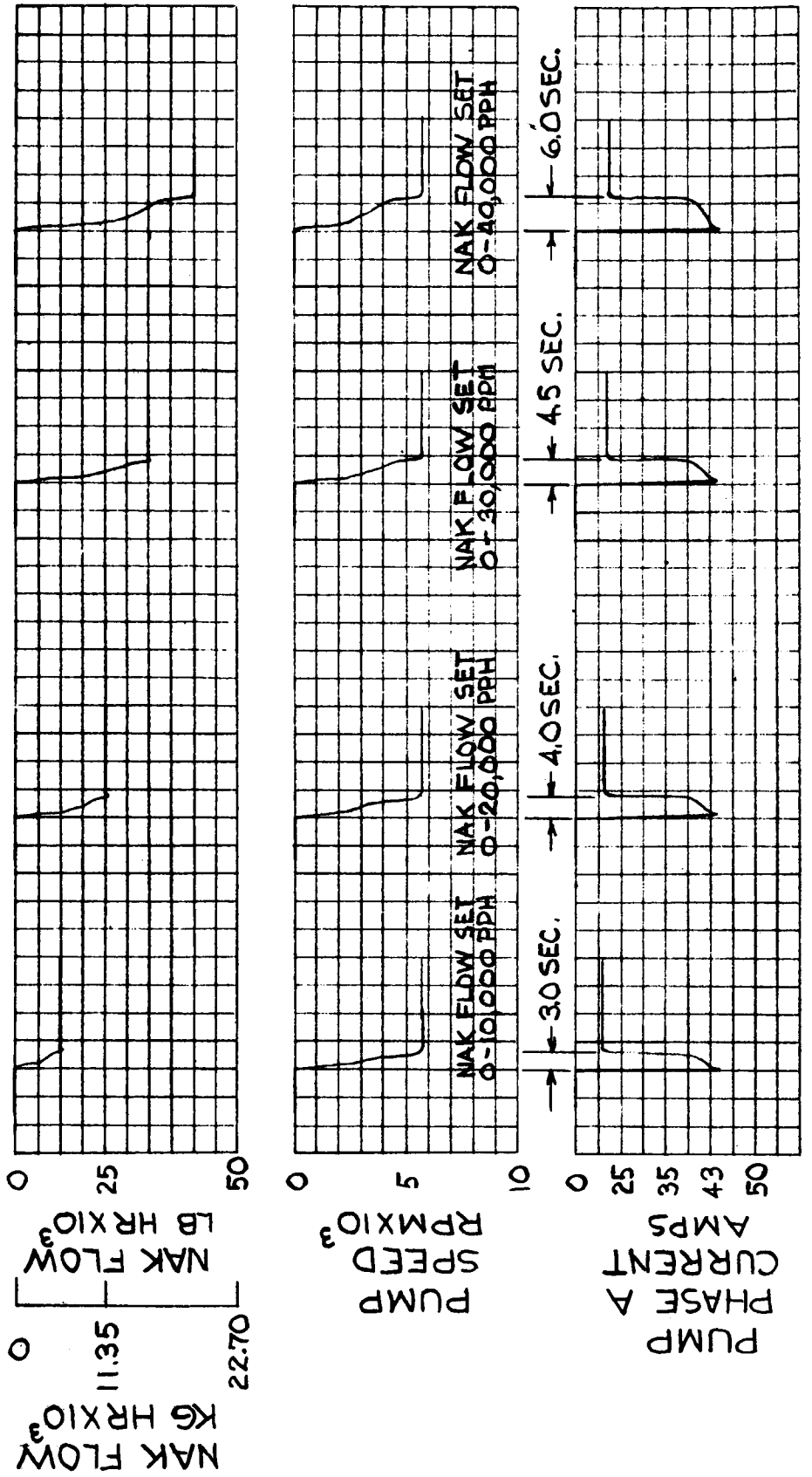


FIGURE 5 PRIMARY NAK PMA START TEST
WITH MOTOR TEMPERATURES OF 100 TO 120°F

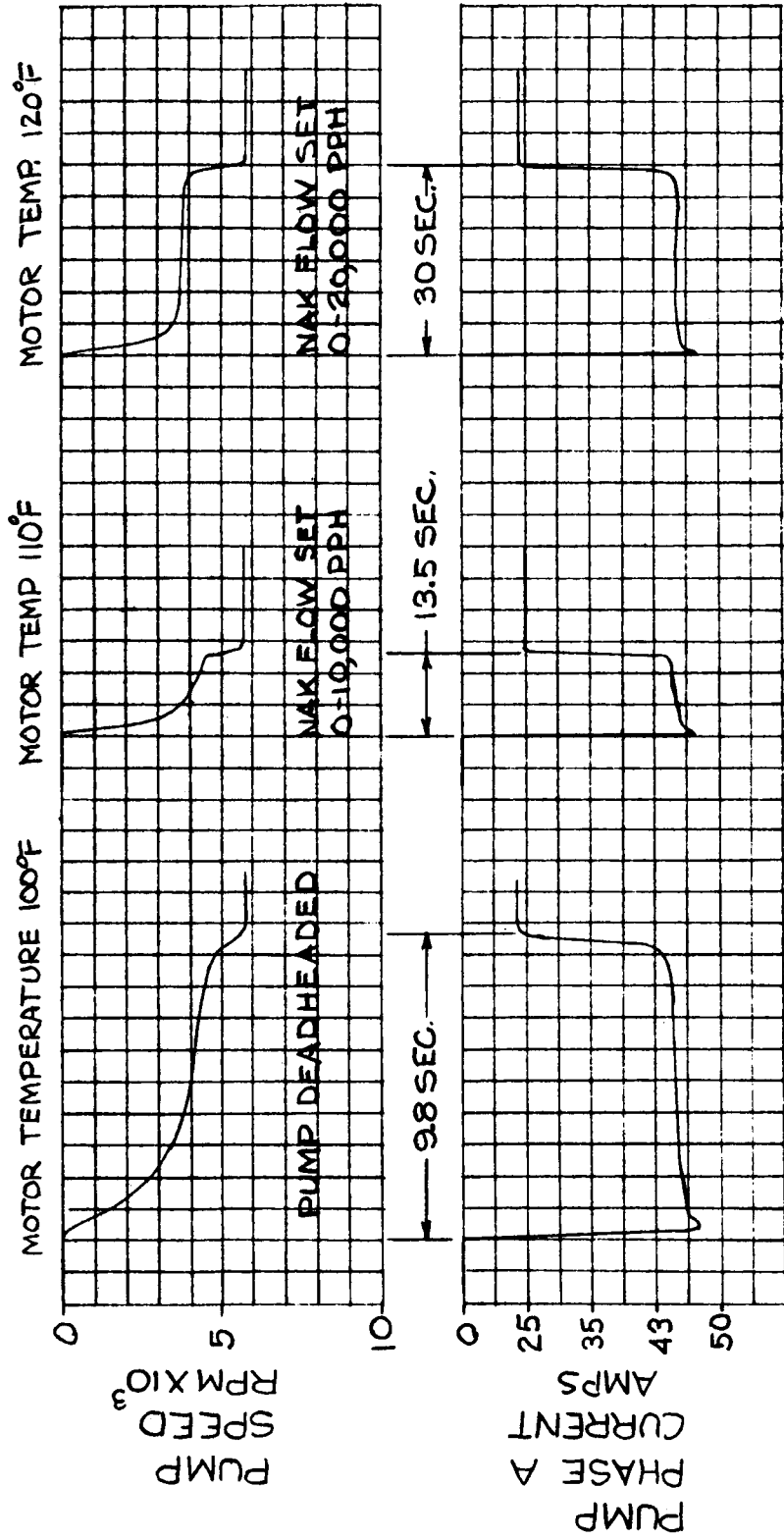


FIGURE 6 PRIMARY NAK PMA START TEST
WITH MOTOR TEMPERATURES OF 130°F & 140°F

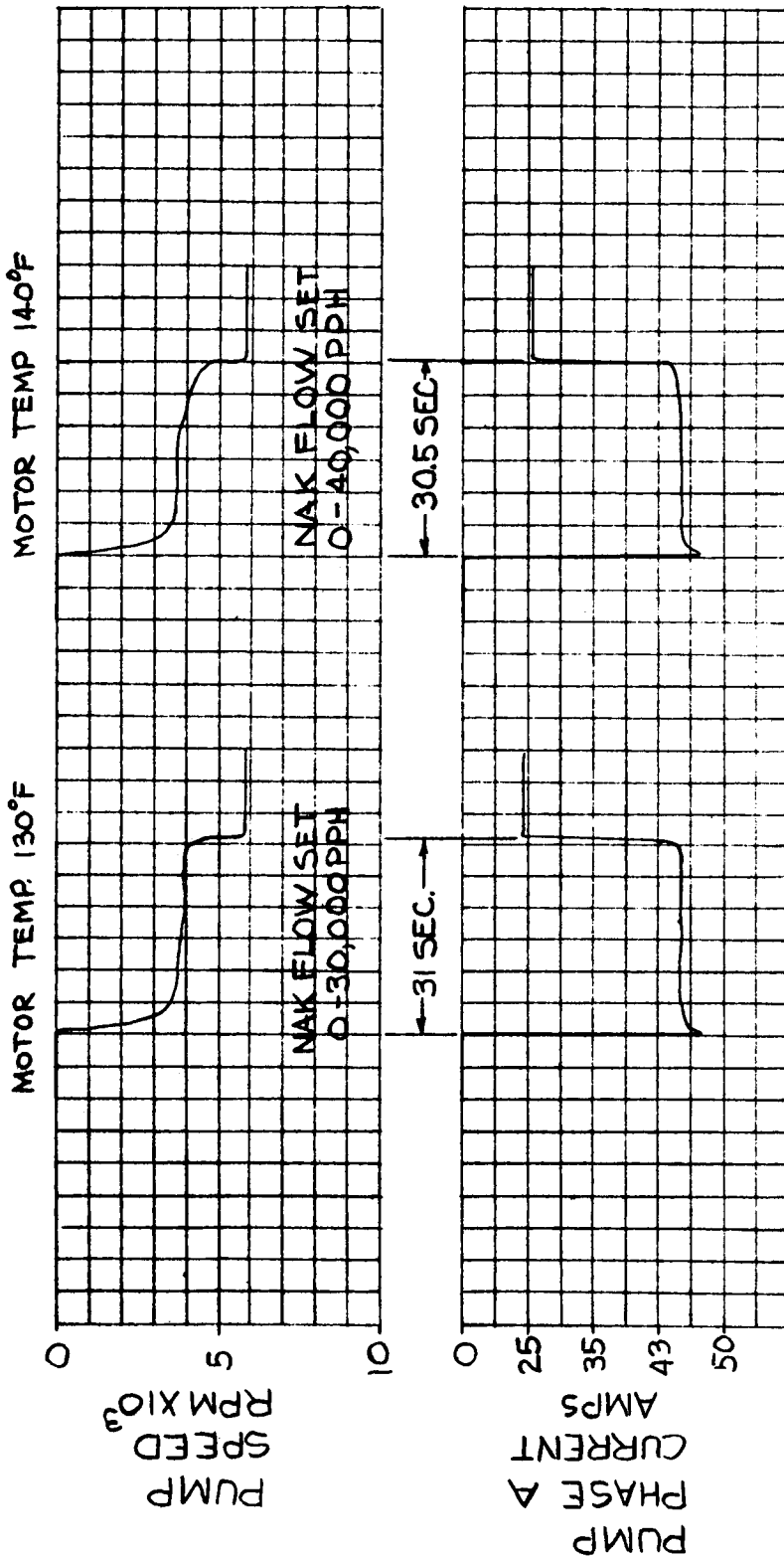


FIGURE 7 HEAT REJECTION LOOP NAK PMA
START TEST WITH MOTOR
TEMPERATURE OF 70°F

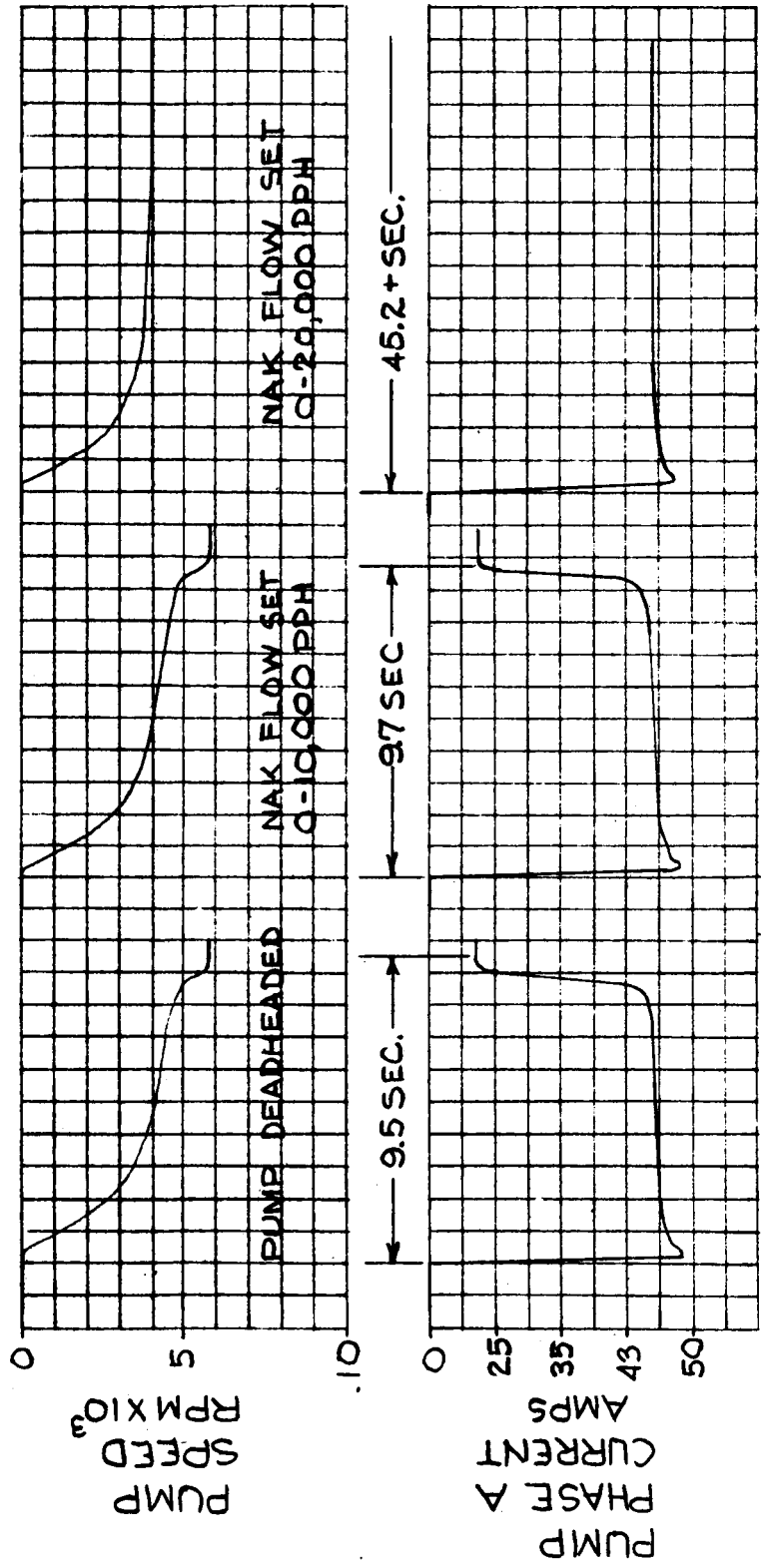


FIGURE 8 HEAT REJECTION LOOP NAK PMA
START TEST WITH MOTOR
TEMPERATURE OF 70°F

