SNAP II POWER CONVERSION STATUS [1]

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Abstract

A review of the current development status of the combined rotating unit, the boiler superheater, and the load control is presented. The experimental performance characteristics of each of the components is discussed with respect to the expected influence on system operation. The critical development areas remaining for the power conversion system are presented.

Development of the SNAP II Power Conversion System at Thompson Ramo Wooldridge was initiated in October 1957. It is significant to note that this date coincides with the launching of Sputnik I which focused international attention on space systems. The subcontract for the SNAP II conversion system development was awarded by Atomics International under a prime contract with the aircraft reactors branch of the Atomic Energy Commission. Background experience with space oriented power conversion was available at Thompson Ramo Wooldridge from the SNAP I development which utilized a similar power conversion engine.[1]

Figure 1 schematically indicates the system with current cycle operating conditions noted. The major components of this system include a reactor heat source being developed by Atomics International, a NaK to mercury heat exchanger, a combined rotating unit, and the condenser. Two liquid metal loops are involved in the system. The primary loop, or NaK loop, removes the heat from the reactor and conducts it to the boiler

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for exchange with the second working fluid which is mercury. NaK from the reactor enters the heat exchanger at 1200°F and is rejected at 1000°F. The heat transferred is utilized to preheat, boil, and superheat the mercury to 1150°F.

The combined rotating unit, or CRU, contains on a single shaft the mercury vapor turbine, the alternator, the mercury pump, and the primary NaK pump.

The condenser-subcooler combination converts the mercury vapor back to liquid by radiating heat directly to space and then subcooling the liquid to 420°F for return to the mercury pump.

Each element of the power conversion system has undergone extensive development on both the SNAP I and SNAP II efforts over the past several years. The high temperature requirements of the metal working fluids plus the unprecedented reliability requirement associated with one year's unattended life, have resulted in stringent objectives for the component developments.

The mercury boiler is required to transfer approximately 50 kw of heat to preheat, boil, and superheat 18.6 lb/min of mercury. The through flow boiler shown in Figure 2 is required to produce dry superheated mercury vapor under environments of 1 g and zero g. To date, four boilers have been designed and tested to meet the boiler objectives, the latter two being capable of producing the necessary superheated mercury vapor. Average boiling heat fluxes of 10,000 Btu/hr. ft^2 were attained with the latest boiler configuration which consisted of 7 tubes containing mercury enclosed by a 2 inch pipe containing the NaK. This heat exchanger contains internal swirl devices for the mercury and is further wrapped into a helix to induce g forces in the flowing mercury that are large in comparison with the 1 g variation in environment. Assurance of operation in zero gravity as well as in one gravity is attained in this manner.

Figure 3 shows a cross sectional view of the combined rotating unit. To minimize the weight of this component, a 40,000 rpm shaft speed was selected as optimum to achieve the required 2,000 cycle per second output from the alternator. Each of the elements of this shaft has had a background component development program.

The mercury pump located at the end of the shaft consists of a 0.34 in. diameter centrifugal pump operating in combination with a jet booster pump. Four mercury pump designs were fabricated and tested to achieve desired performance for the combined rotating units currently in operation. The CRU pump provides 280 psi at 40 lb/min with an overall efficiency of 35%. The pump inlet pressure is remarkably low, being 6 psia or in pump terminology, only 1 foot of head.

Bearings for the combined rotating unit consist of a double-acting thrust bearing and two journal bearings. The bearings currently in use in the CRU have demonstrated a 50 pound radial load capacity and a 20 pound thrust load capacity, which is well beyond the loads imposed on the bearings during orbital operation. One hundred and thirty start-stop tests were conducted on this set of bearings in a separate bearing test rig. Start-stop operation associated with ground check-out is of particular concern inasmuch as both the thrust and the journal bearings are hydrodynamically lubricated.

The alternator of the SNAP II system consists of a six pole permanent magnet rotor and a two phase stator winding. The stator is hermetically sealed to prevent mercury from entering the stator. The alternator is required to operate at temperatures in the vicinity of 700°F in order to prevent condensation of mercury in the rotor area. Component alternator testing in a special high speed dynamometer has demonstrated an efficiency of 85% at 3 kw output with a voltage regulation of 5% between power factors of 0.8 and unity.

The turbine for the SNAP II application is a two stage axial flow machine. At present the turbine is capable of delivering 7 hp at 40,000 rpm with 115 psia mercury superheated to 1150°F. Development redesigns of the SNAP II turbine have improved output power and efficiency at design conditions. The turbine currently exhibits an overall efficiency of 48%.

The NaK pump for the system consists of a permanent magnet mounted in a rotor at the end of the combined rotating unit shaft, and a centrifugal pump type passage for the NaK. Rotation of the shaft induces a swirl of the NaK in the annular passage. The NaK swirl provides a pumping action similar to a centrifugal pump. Although the efficiency of this pump is only on the order of 2%, it was determined to be the lightest weight method for pumping NaK. Component tests for this pump have indicated a capability of pumping the design flow of 11.7 gpm of NaK at 1000°F with a 1.9 psi pressure rise.

Considerable testing has been conducted on the overall combined rotating unit. One of the most significant tests of this device was a 20 day test conducted in December.

The unit was operated during the test at 35,000 rpm with a power output of 2,127 watts. Turbine inlet pressure was held at 94.7 psia. Results were very encouraging in that the bearing flow and pressures remained constant throughout the test. There was no indication of deterioration or damage to any part of the system during the test. A similar endurance test on SNAP I power conversion machinery was operated for 2510 hours or 104 days. An evaluation of the test data and test hardware associated with these runs on SNAP I and SNAP II indicates that the one year life objective is entirely feasible. As a result of test experience, three combined rotating unit designs have evolved. Improvements in shaft critical speed, turbine design, bearing feed grooves, mercury pump design, the alternator rotor and stator have been factored into the advanced combined rotating unit designs. Figure 4 shows the second model of the combined rotating unit shaft following a 10 hour mercury run.

In addition to the performance testing, vibrational environmental tests of the first CRU have been performed. These tests were conducted over a frequency range of 5-3000 cycles with a maximum g loading of 25 g's. The unit was vibrated under dry non-rotating conditions which simulate the launch condition. The start of CRU operation is initiated after orbital conditions are achieved.

Development of the condenser for the SNAP II system has been directed towards establishing pressure drop, inventory, and two-phase flow stability criteria. In addition, several radiant type condensers have been fabricated for test rig operations. Zero g testing associated with condenser performance has been a particularly interesting aspect of the SNAP II program. Initial testing of single glass condenser tubes was conducted on board the Wright Air Development Division C-131 aircraft in zero gravity trajectories. More recently, a four-tube condenser was successfully tested aboard the KC-135 aircraft in 28 thirty second duration zero gravity tests. In addition to the condenser operation, performance of the principle elements of the power conversion system was also evaluated in zero gravity. The test rig consisted of an electrically heated through flow mercury boiler, a choked nozzle simulating the turbine of the combined rotating unit, the four tube condenser and a SNAP II mercury pump. Performance of this entire system was stable during the zero g trajectories, which include 1 g, 2 1/2 g and zero g operating conditions.

The control for the SNAP II system is a parasitic electrical load device which consists of a frequency discriminator designed to gate resistive load elements. The control has been tested with operating combined rotating units over a power range representing 0-3 kw net output power. The control is capable of maintaining the output frequency of the combined rotating unit at 2000 cycles ± 1%.

Development status of the power conversion system can be summarized by the table shown in Figure 5. In this table the original SNAP II objectives are compared with current test results indicating the development status of the various components. The efficiency improvements achieved in the alternator and mercury pump offset the current deficiencies of the NaK pump and turbine.

In summary, it may be stated that the two major feasibility questions associated with a mercury Rankine engine in space have now been answered. The 20 day and the 104 day tests of SNAP I and II power conversion systems indicate that long life operation of this system is attainable. The KC-135 tests indicate that stable system operation can be achieved in zero gravity environments. With delivery of a completed power conversion system that is hermetically sealed, Atomics International will conduct integrated reactor power conversion system tests at the Santa Susana test facility. This test will be a major milestone in the development of space nuclear power in a manner which has applications to not only the 3 kw power range but to the larger systems which will ultimately be required in space.

Reference

1. New Devices Laboratories, Engineering Report ER-4050, "SNAP I Power Conversion System Development", Thompson Ramo Wooldridge Inc., Cleveland, Ohio (20 June 1959).

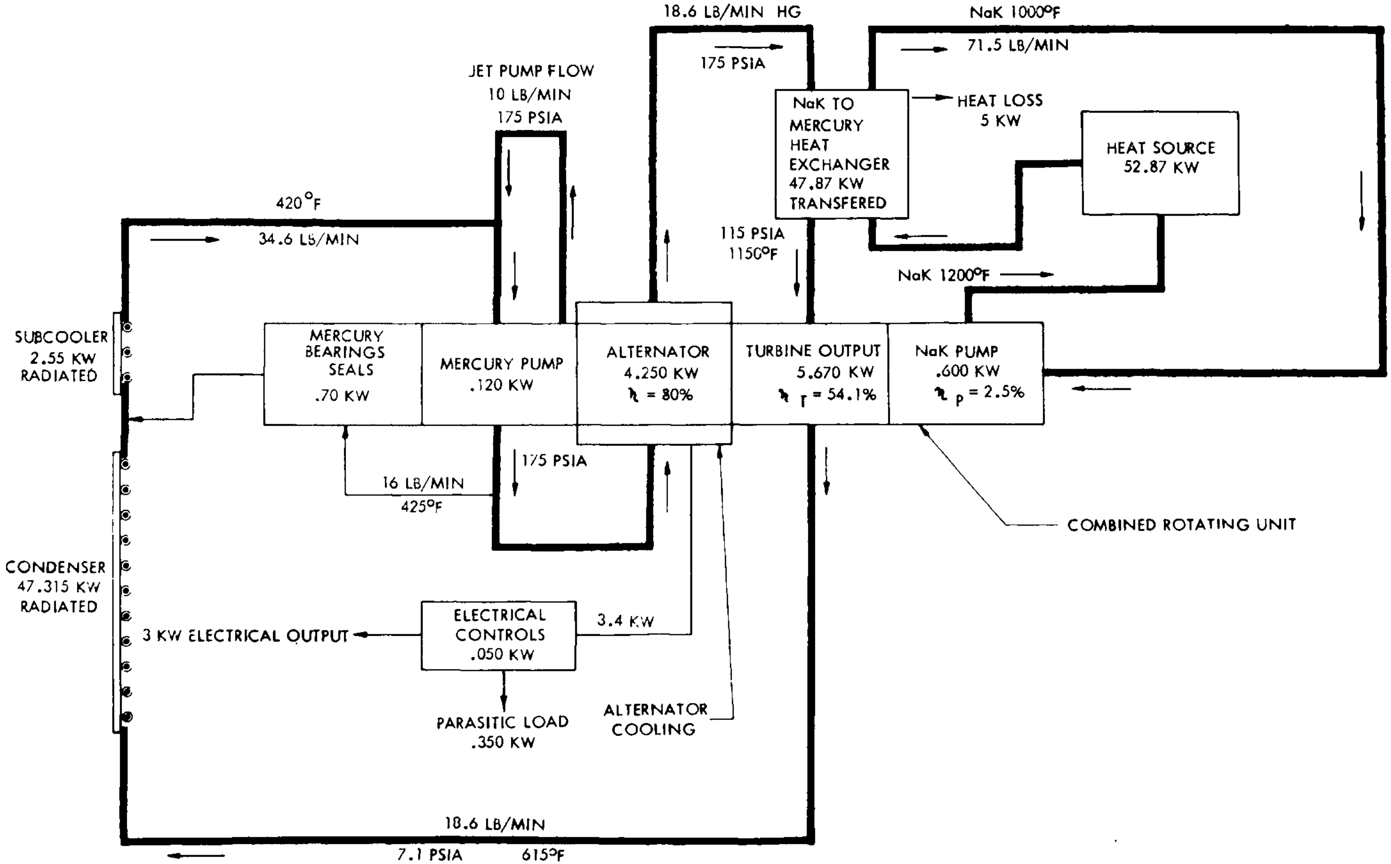

Figure 1. SNAP II Cycle Schematic.

<u>Figure 2.</u> SNAP II Boiler.

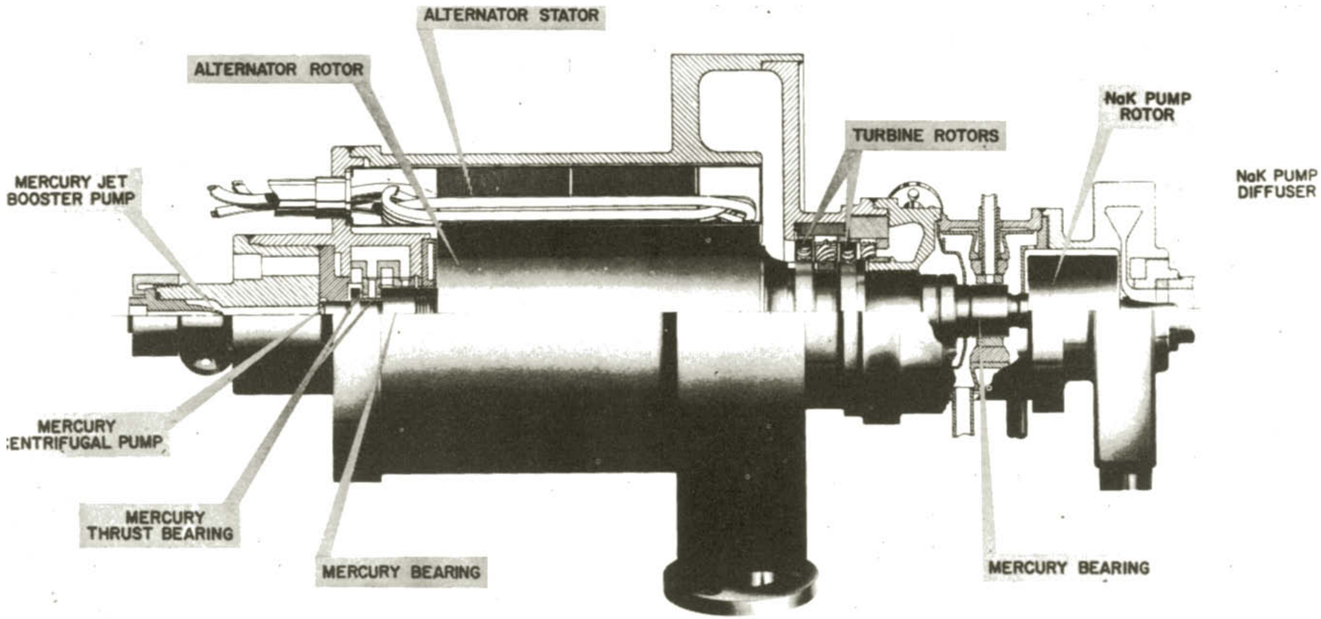

Figure 3. SNAP II Combined Rotating Unit.

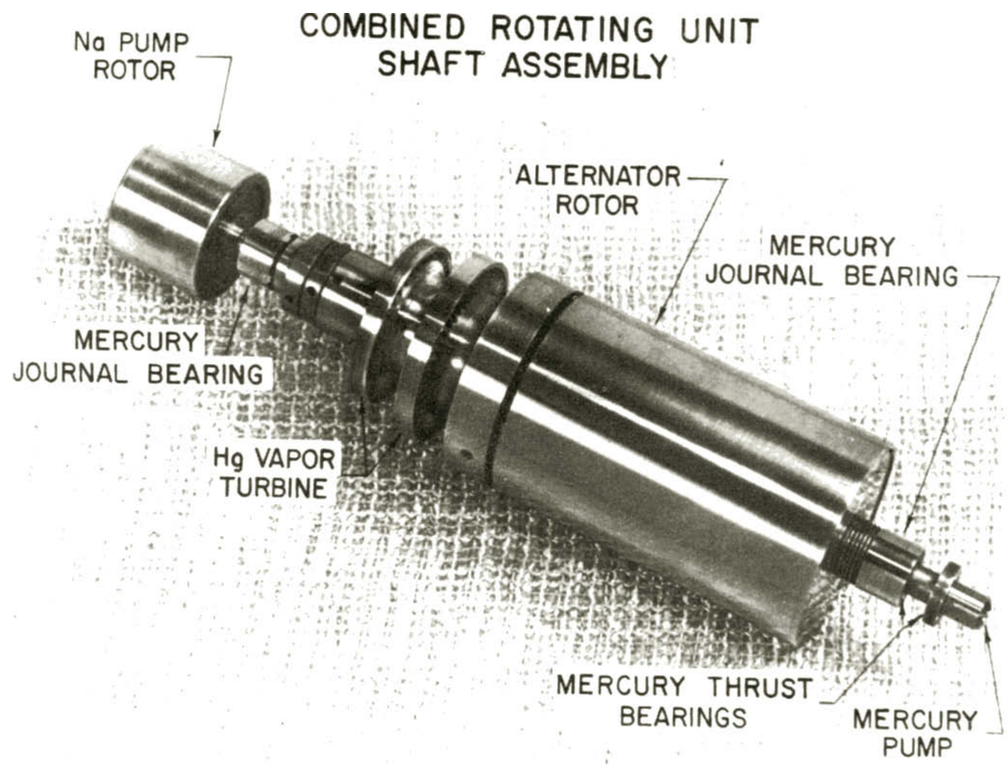

Figure 4. Combined Rotating Unit Shaft Assembly.

Figure 5
SNAP II COMPONENT PERFORMANCE STATUS

Component	Objective	Achieved
Boiler		
Flow rate (Hg)	18.6 #/min	20.0 #/min
Superheat	1150°F	1150°F
Hg Pump		
Efficiency	10%	35%
Flow Rate	37 #/min	40 #/min
Output Pressure	140 psia	280 psia
Hg Bearings		
Power consumption	600 watts	550 watts
Load Capacity (radial)	40 #	50 #
Alternator		
Efficiency	80%	88%
Output gross	3.1 KW	5.0 KW
Turbine		
Efficiency	55%	48%
Output Power	5.16 KW	5.16 KW
NaK Pump		
Efficiency	2.5%	1.2%
Flow rate	71.5#/min	71.5 #/min
Output Pressure	3 psi	1.9 psi

Figure 5. SNAP II Component Performance Status.