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ATOMICS INTERNATIONAL <small>A Division of North American Aviation, Inc.</small>		TDR NO. 6670	APPROVED <i>[Signature]</i>
TECHNICAL DATA RECORD		PAGE 1 OF 18	<i>C. G. Bergdorf</i>
AUTHOR C. G. Bergdorf	DEPT & GROUP NO 793-36	DATE 8/30/61	
		GO NO 7580	
TITLE Performance Tests of SNAP 10A Thermoelectric Elements		S/A NO 2194	RECOMMENDED FOR OUTSIDE DISTRIBUTION ☐ YES ☐ NO
		TWR	
PROGRAM	SUBACCOUNT TITLE Thermoelectric Generator Development - Testing and Quality Control		SIGNATURE
DISTRIBUTION USE AN ASTERISK (*) TO INDICATE THOSE WHO ARE TO RECEIVE COMPLETE COPIES	STATEMENT OF PROBLEM The design and operation of thermoelectric element performance test apparatus simulating the operating conditions of the SNAP 10A Thermoelectric Generator.		
R. Balent* S. Bain* C. G. Bergdorf* M. H. Binstock* R. E. Burdick* D. J. Cockeram* J. C. Cooper* H. M. Dieckamp* E. G. Forster* S. H. Fitch* E. E. Garrett* J. J. Gill* C. A. Guderjahn* I. J. Groce* N. H. Katz* A. B. Martin* D. E. McKenzie* R. V. McCamy* H. D. MacNary* N. C. Miller* J. W. Morris* H. Pearlman* E. L. Reed* S. R. Rocklin* A. J. Saur* E. D. Stellmacher* A. W. Thiele* J. B. Vetrano* J. W. Walter* B. M. Watson* E. J. Westerveller* R. E. Wilkinson* R. L. Wilson*	ABSTRACT: Apparatus for the performance testing of SNAP 10A thermoelectric elements has been designed, constructed, and is now in operation. Elements may be tested for any desired length of time up to 1400°F and in a vacuum of 1×10^{-5} mm of Hg. The equipment used for these tests may also be utilized for measuring Seebeck coefficient and resistance as a function of temperature. Element performance is derived from the data on voltages and temperatures. The performance variables which are reported in graphic form are as follows: A. Loaded output voltage at any desired ΔT . B. Open circuit output voltage at any desired ΔT . C. Power output under optimum load conditions. D. Current produced under matched load conditions. E. Internal resistance of the element.		

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I. Test Requirements

The test requirements are set by the operating conditions of the SNAP 10A Thermoelectric Generator. The requirements are:

A. Temperature

900°F hot junction with a 300°F ΔT .

B. Vacuum

As high a vacuum as possible without using environmental test chambers, but not to exceed a minimum of 1×10^{-4} mm of Hg.

C. Mechanical

The pressure applied to the element surfaces to be as small as possible.

D. Visual observation, while on test, preferred.

E. Measurements

Obtain all possible information of the electrical variables indicative of life expectancy.

II. Apparatus

A. To provide the hot and cold junction temperatures, 200 w heating elements are placed against each side of the PbTe element. The junction temperature is controlled by varying the input voltage to the heater. This is accomplished with an autotransformer connected to each heating unit. If higher temperatures are required the heaters may be replaced.

B. To obtain the vacuum required, a 4-inch diameter pumping station was necessary. The station contains a 1397 Welch forepump and a PMC 720 Consolidated Vacuum Corporation oil diffusion pump. Above the diffusion pump a C.V.C. liquid nitrogen cooled chevron type baffle is used. The

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vacuum system is connected to a 4-inch diameter manifold that allows operation of six separate tests simultaneously. Each test chamber is valved to the manifold to allow individual operation. Each test chamber may be, on test under vacuum, undergoing loading operations, or used on a special test as desired. A vent and back-pressure manifold is also valved into each test chamber. This second, smaller manifold is used to pump down the test chamber and prepare it to open into the 4-inch vacuum system. (Figure 2)

C. To provide visual observation, of the element on test, a transparent Pyrex cross is used as a test vessel.

D. Temperature instrumentation of the test consists of a stainless steel, sheathed, chromel-alumel thermocouple in contact with each end of the capped and encapsulated PbTe element. The thermocouple leads are brought out of the test vessel through insulated fittings in the top plate. (Figure 1) The temperatures are read out on a strip chart temperature recorder.

Provision for reading the element output voltage is provided by spot welding small (20 mil) iron wires to the side of the iron caps on the element. The iron wires are brought through insulated fittings in the top plate and then to a millivolt strip chart recorder.

(Figure 1)

The internal resistance of the element should be matched by the resistance of the load connected to it, to obtain maximum power output. This necessitates physically large, low resistance, current conductors and low contact resistances.

The current conductors are #6 gauge, 7-stranded copper wire and $\frac{1}{4}$ -inch diameter, solid copper rod. At the element end of the current lead, a copper disc, of the same diameter as the element, is used to

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provide contact to the entire element surface.

To keep the contact resistance low, a gold indium braze alloy is used between the element and the copper disc on the current lead.

(Figure 1)

The current leads are also brought out of the test vessel through insulated sealed fittings.

III. Procedures

A. Installation and brazing of the element in a test fixture.

Prior to installing the PbTe element in position to test, small iron wires are welded to the iron caps. The surfaces to be contacted are thoroughly cleaned to help assure low contact resistance. The braze alloy, gold indium-325 mesh powder, is mixed with a binder. The binder used is Microbraze cement which vaporizes and is removed by the pump as the temperature of the element is raised. The mixture of cement and gold indium forms a paste which is spread thinly on the element's flat surfaces. The element is placed between the copper discs. The iron wires from the caps of the element are spot welded to the iron wires that lead through the top plate.

The plate, which now is part of the test fixture, (Figure 1), is placed on the Pyrex cross against an O-ring. Tightening the flanges seals the test vessel.

The roughing pump (Figure 2) is used to withdraw the air from the vessel.

When the vessel reaches $<10^{-6}$ microns, the heating elements are turned on. The temperature recorder is observed as the voltage applied to the heaters is increased. Braze temperature is 1000°F and

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once it has been reached the braze alloy can be seen, through the Pyrex, in a molten condition. The temperatures are now set, by adjusting the Variacs controlling the heater voltages, at 900°F on the hot junction side and 600°F on the cold junction side. The 4-inch diameter manifold and pumping station is now used to maintain a vacuum of 1×10^{-5} mm of Hg.

B. Matching the Load to the Element

An element is tested at maximum power output if its applied load resistance is equal to its internal resistance. To accomplish this, the current electrode resistance plus an additional adjustable resistance is set at a value equal to the internal element resistance. The small additional adjustable resistance, or part of it, serves as the ammeter in the circuit. The exact method of loading the element and calculating the current flow therein is described below and shown in Appendix B, figure 4.

1. Set test operating temperatures.
2. Apply 5 amps A.C. to the exposed current leads.
3. Measure the A.C. IR drop across the element from the Fe wires that are welded to the element caps.
4. Divide the IR drop (measured in 3) by the 5 amps A.C. applied (2). Ohms law is used here to give the element internal resistance - ($R = E/I$). This is the resistance the rest of the circuit must equal.
5. Measure the IR drop of each current lead. This measurement is made from the copper electrode exposed end to the iron wire on the element.
6. Divide the measured IR drops by the 5 amps A.C. applied. This gives the lead resistance on each side of the element.

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These leads are part of the load resistance.

7. Add the two (2) lead resistances obtained in step 6 and subtract their sum from the calculated internal resistance. (Step 4)

The remainder is the value of resistance that must be added to obtain matched load conditions.

8. The added resistance, or a part of it is that portion which becomes the ammeter in the circuit as mentioned previously. Remove the applied 5 amps A.C., record the produced D.C. volts. This is the open circuited output voltage. This voltage is obtained from the Fe wires.

9. Connect the extra resistance, calculated in step 7, between the current leads. Record the element output voltage again. If this is now one-half ($\frac{1}{2}$) the value measured in step 8 it indicates a matched load. The added resistance (8) is trimmed to provide the required element output voltage.

10. To calculate the element's output current, divide the measured IR drop, across the added external resistance (step 8) by the added resistance value. Ohms law is used again, $I = E/R$. This IR drop is monitored. It is now serving as an ammeter in our circuit.

C. Other information is obtained once the element is in place in its test unit.

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These are: high temperature resistance curves and Seebeck coefficient curves. They are derived as described below:

1. High Temperature resistance curves.

After the element is brazed between the current leads, 5 amps a.c. is applied and the IR drop is read from the Fe wires. This is the same as when the internal element resistance was calculated. Points for use in drawing the resistance curve are obtained by making this measurement repeatedly at different isothermal temperatures. These temperature settings are easily obtained by controlling the heaters from their associated Variacs and monitoring the temperature at each end of the element.

2. Seebeck coefficient curves.

The points for use in making these curves are obtained as the high temperature resistance points are recorded. A small ΔT (20 to 30°F) is established and the output voltage (d.c.) is recorded. This voltage is obtained from the Fe wires. The a.c. source used is removed to get the necessary reading. The source is reapplied as the temperatures are again adjusted to obtain the next required points. Voltages for Seebeck and resistance curves are recorded from 300°F to 900°F at 100°F intervals.

D. Performance Testing and Reporting Method

The element is now ready to undergo its performance test. The monitored or recorded data are:

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1. Hot junction temperature
 - a. Calibrated chromel-alumel thermocouples. The maximum possible error in the thermocouple is $\pm 2^{\circ}\text{F}$ in the operating range.
 - b. The temperature recorder, also calibrated, has an accuracy of $\pm 2^{\circ}\text{F}$ in the operating range.
2. Cold junction temperature
 - a. Same accuracies as listed under hot junction temperature.
3. Element voltage (from the iron wires)
 - a. The millivolt recorder (calibrated) is accurate to $\pm .1$ millivolts from 3 to 48 millivolts. Measurements above 48 millivolts or below 3 millivolts are made with a Rubicon Potentiometer and accurate to $\pm .01$ millivolts.
4. IR drop on the known resistance or current resistor is the same as that stated in item 3 above.

The reported data enumerated in the Abstract appears weekly in the project task log. In addition, a time vs. performance graph, like that described, is constantly maintained and distributed when an element has been removed from test. (Reference 1)

Any recommended changes or improvements are reported to the Responsible Engineer of the Sub-Account in an IOL.

IV. Post Test Data and Element Distribution

At the completion of the performance test, the unit is disassembled and the element, along with any deposit formed inside the test vessel, is submitted for chemical and metallurgical analysis.

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Copies of data produced in curve form are distributed.

V. Conclusions

The Appendices contain a mathematical analysis of the method used to calculate the elements internal resistance while on test (Appendix A). This method has been checked against the a.c. resistance technique described in part III-B-2 of this record. The average difference between a.c. and d.c. measurements is 2 percent. Either method is therefore considered valid. (Reference 2)

It has also been noted that when the element is adjusted to proper operating temperatures, the a.c. resistance and the open circuit voltage measured, the power output under matched load conditions can be predicted. (Reference 3)

REFERENCES AND APPENDICES

- Appendix A.....Calculation of Elements Internal Resistance Using D.C. by P. F. MacDoran
- Appendix B.....Techniques of Performance Testing by P. F. MacDoran
- Figure 1.....Single Element Test Unit
- Figure 2.....Six Station Performance Test Apparatus
- Reference 1 - IOL..Performance Test Identification and Reporting to Those Listed from C. G. Bergdorf and S. R. Rocklin, July 13, 1961
- Reference 2 - IOL..Measurement of Element Resistance. P. F. MacDoran to B. M. Watson, August 16, 1961
- Reference 3 - IOL..Performance Test Procedure Suggested Changes. C. G. Bergdorf to B. M. Watson, August 11, 1961
- Reference 4 - IOL..Improved Testing Techniques. P. F. MacDoran to B. M. Watson, August 2, 1961 (Appendix B)

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Figure 1. Single Element Performance Test Unit

Figure 2. Six Station Test Apparatus

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Figure 3a. Six Station Test Apparatus Schematic

Figure 3b. Typical Single Test Station Schematic

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APPENDIX A

by

P. F. MacDoran

The following operation shows how it is possible to determine the internal resistance of a thermoelectric pellet while on life test:

Circuit Diagram:

Let P be any given thermoelectric pellet with a temperature gradient. E is the e.m.f. generated and r is the internal resistance of the pellet. R is the load applied to the pellet output voltage. i is the conventional current flowing in the circuit.

From Ohm's Law and Kirchoff's Theorem,

$$E - ir - iR = 0 \quad r = \frac{E - iR}{i}$$

but iR is just the voltage drop across the load. The internal resistance of the pellet is therefore:

$$r = \frac{E - V_R}{i}$$

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APPENDIX B

Techniques of Performance Testing

by

P. F. MacDoran

The previous procedure was to read the voltage drop across the entire load (see Figure 4) from the points where the load was actually soldered to the copper electrodes from the element. When one side of the load was unsoldered for open circuit voltage measurement, this of course, disconnected one of the leads that read the voltage drop. When the load and voltage drop lead was resoldered, the possibility of the wires not being in their previous positions was present.

In the current calculation, $i = \frac{V}{R}$ where i is current, V is voltage drop across load resistor, and R is the load resistor calibrated before installation. The value of R must be held to its calibrated value to make the current calculation correct since during life testing only V is measured. Soldering and resoldering the voltage drop wires offers possibilities of changing the value of R which would therefore make i wrong.

New Method

There are two ranges of load values, one for "N" type and the other for "P" type elements. The load value for "N" elements is about 200 $\mu\Omega$ while the load for "P" elements is about 4000 $\mu\Omega$. Figure 1 shows the physical placement of the load on the performance test unit. To make the current calculation more accurate, a fixed portion of the load is used to calculate the current flow. In Figure 4, this portion of the load is from A to B.

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Consider, for example, an "N" type element that requires a 200 $\mu\Omega$ load. This load is made from a flattened piece of $\frac{1}{8}$ inch copper tubing. (See Figure 5(a)) The resistance from A to B is made some convenient value, say 100 $\mu\Omega$. Permanent probes are now attached to points A and B by means of screws and nuts which are then soldered to the load to assure good electrical contact. If the probes were fastened to the load and then soldered the resistance would probably be found less than the desired 100 $\mu\Omega$ due to the soldering. The resistance between A and B can be restored to the desired 100 $\mu\Omega$ by filing some of the copper away from between points A and B. However, the resistance can be increased only by about 30 $\mu\Omega$. Any more filing will weaken the resistor mechanically.

The 4000 $\mu\Omega$ load for "P" type elements is obtained by using #14 standard copper wire (Figure 5 (b)). Once again, two points, A and B, are selected to have a convenient resistance, say 2000 $\mu\Omega$. It is well to remember that solder flowing between the copper strands decreases the resistance and for that reason an adjustment must be made. The probes should be moved farther apart so as to have a little more than 2000 $\mu\Omega$ resistance. When the solder flows between the probes on the load, the resistance will decrease to something a little greater than 2000 $\mu\Omega$. To trim the resistance right to 2000 $\mu\Omega$, flow a little more solder on the copper strands between A and B.

Improved Load Resistance Integrity

When a load is removed from its element and then returned to the element, there has not been, to date, any mechanical assurances that the load was resoldered in the same position. It is very important to

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keep the load at its calibrated value, particularly if the internal resistance and open circuit is to be calculated. (See IOL to B. M. Watson from P. F. MacDoran, 2 August 1961.)

Slots are now being cut in the top of the copper electrodes which come from the element. The slots are cut $3/16$ inches deep and $3/32$ inches wide (Figure 6 (a)). The slots are cut with a hacksaw using two blades together to achieve the $3/32$ -inch width.

The end of the load even with the opposite end of the electrode (Figure 6 (b)) provides a convenient reference point that can be easily repeated in soldering operations.

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* THE A TO B PORTION OF LOAD IS USED TO FIND THE CURRENT FLOW

Figure 4. (Appendix B)

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Figure 5. (Appendix B)

Figure 6. (Appendix B)