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DYNAMIC TESTING OF SNAP III RADIOISOTOPE THERMOELECTRIC GENERATOR

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SUMMARY

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A dynamic method of measuring the output power characteristics of a radioisotope thermoelectric generator (RTG) is reported. This method of measurement incorporates simulated operation of the RTG, reduces the time required to obtain I-V characteristic curves, and provides more complete I-V curves than static methods. The measurements were made using a modified SNAP III generator.

Author

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DYNAMIC TESTING OF SNAP III RADIOISOTOPE THERMOELECTRIC GENERATOR

INTRODUCTION

The SNAP III is a Radioisotope Thermoelectric Generator (RTG) designed to convert the thermal output of a radioisotope material such as Pu-238 or Po-210 into electric power. It was developed as a part of the Systems for Nuclear Auxiliary Power (SNAP) program[1]. A SNAP III generator, modified by substituting an electric heater for the radioisotope power source[2], was used in the tests reported here (Figure 1).

Previous methods of measuring the output characteristics of thermoelectric generators require thermal stabilization after each load resistance change. A long period of time is then required to obtain sufficient data to construct an output current versus output voltage (I-V) curve. In addition, the open circuit and short circuit values could not be measured, but had to be extrapolated from the measured I-V points for finite upper and lower load resistance values. The open circuit temperature measurement could not be made because the loss of Peltier cooling would result in hot shoe temperatures that exceed the semiconductor's operational limit. Truly short circuit measurements could not be made due to the finite resistance in leads, contacts, etc.

In actual operation the output power of an RTG is converted to a more useful voltage level (i.e., 3 v to 24 v) by chopping, inverting, transforming and then rectifying and filtering the initial low dc voltage output. The junction temperatures for this mode of operation can be expected to differ from those found in static measurements.

The method of measurement reported here has the following advantages over the static methods:

a. The output characteristics are measured with simulated operating conditions.

b. The measurement time for a complete characteristic I-V curve is reduced to a few minutes.

c. Provision is made for sweeping the output past both open and short circuit conditions to give actual measurements at those points.

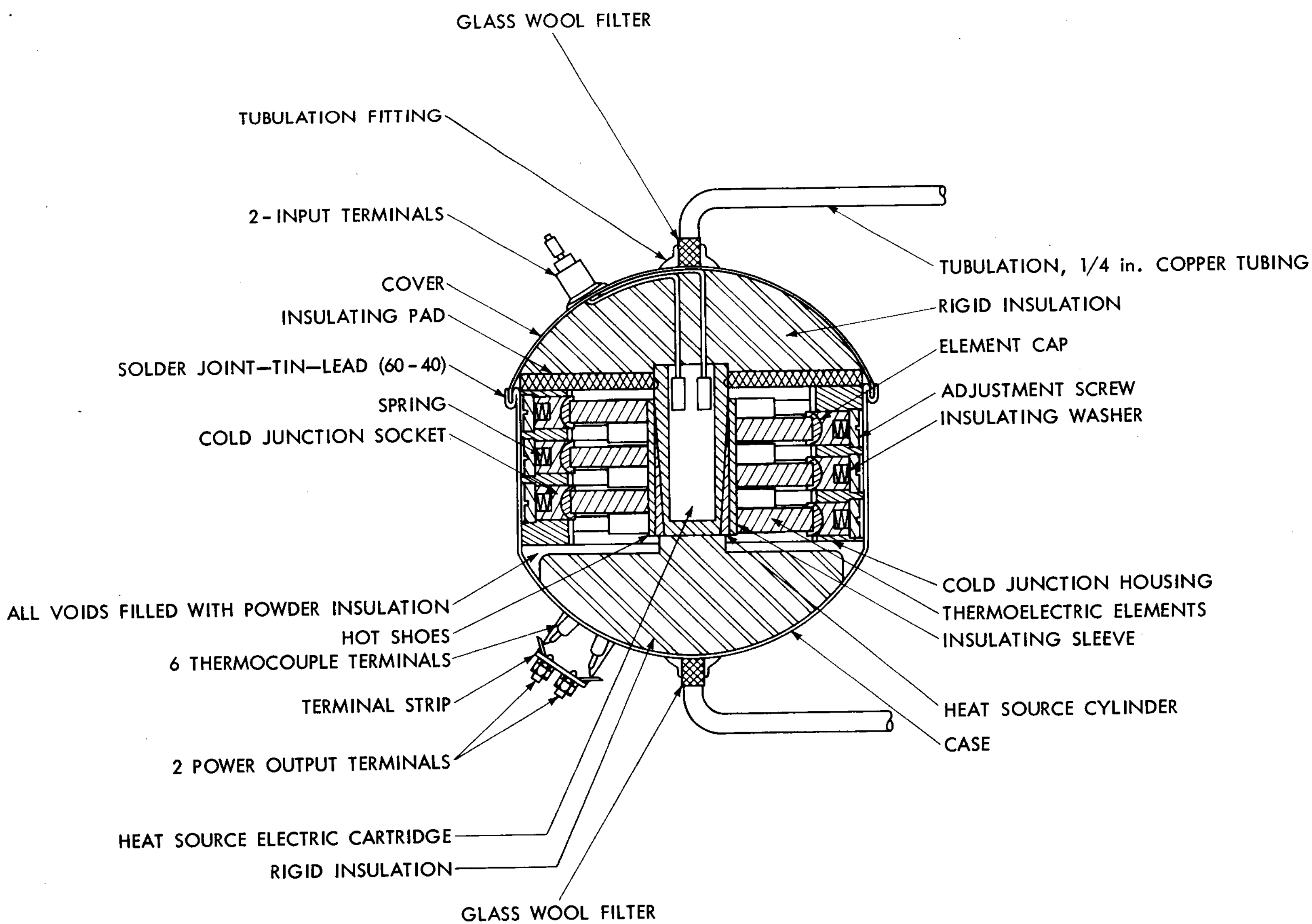
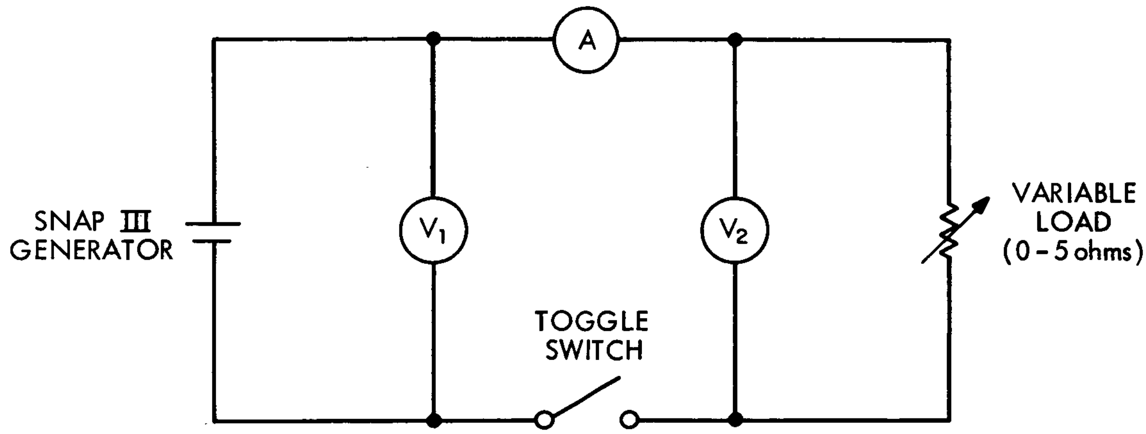


Figure 1. Cross-Sectional View of SNAP III

EXPERIMENT ARRANGEMENT AND PROCEDURES

Static Measurements

The input power to the electric heaters in the SNAP III test generator was supplied by a regulated dc power supply and monitored with a Weston wattmeter. The output circuit for the static measurements is shown in Figure 2. Losses ($I^2 R$) in the output circuit were monitored by measuring the voltage at the generator output terminals as well as across the load resistance. The output I-V curves (Figure 3) were determined by varying the input power and the load resistance.



A - OUTPUT CURRENT MEASURED ON WESTON DC AMMETER
V_1 - GENERATOR TERMINAL VOLTAGE MEASURED ON DYMEC DIGITAL VOLTMETER
V_2 - OUTPUT VOLTAGE MEASURED ON DYMEC DIGITAL VOLTMETER

Figure 2. Static Test Output Circuit

Temperatures within the generator were measured using calibrated (ice bath reference) type J iron-constantan thermocouples. Thermocouples were located at the heater, the hot shoe, and the cold shoe, all shown in Figure 1. For a fixed power input, the equilibrium temperature of the hot shoe was found to vary with load resistance as shown in Figure 4. Since the thermoelectric efficiency increases with hot shoe temperature, this variation in hot shoe temperature tends to increase the optimum load resistance.

Dynamic Measurements

The power input circuit for the generator in the dynamic tests was the same as described for the static tests. The output circuitry for the dynamic testing is shown in Figure 5. The function generator signal was amplified and used to

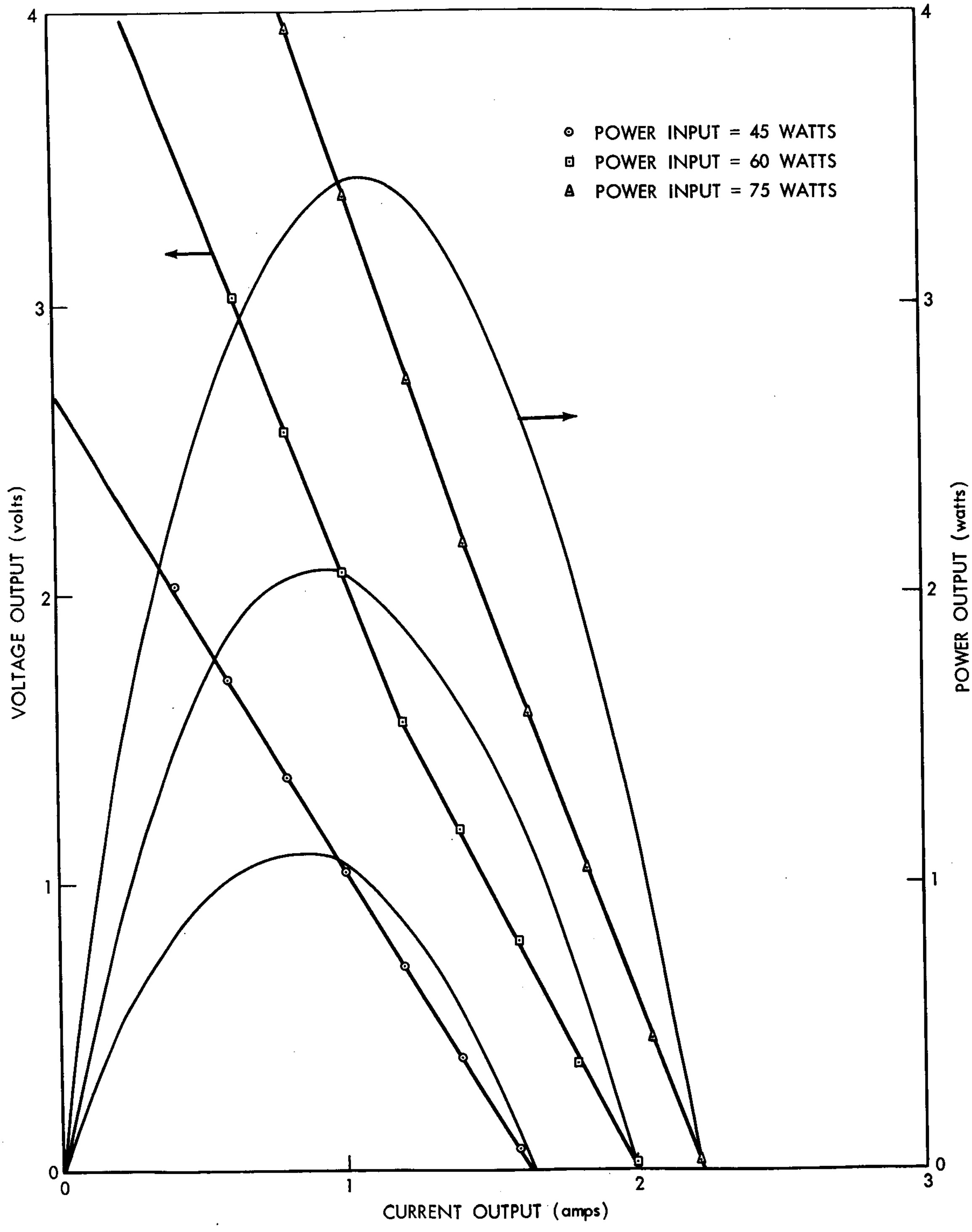


Figure 3. SNAP III - Static I-V Curves

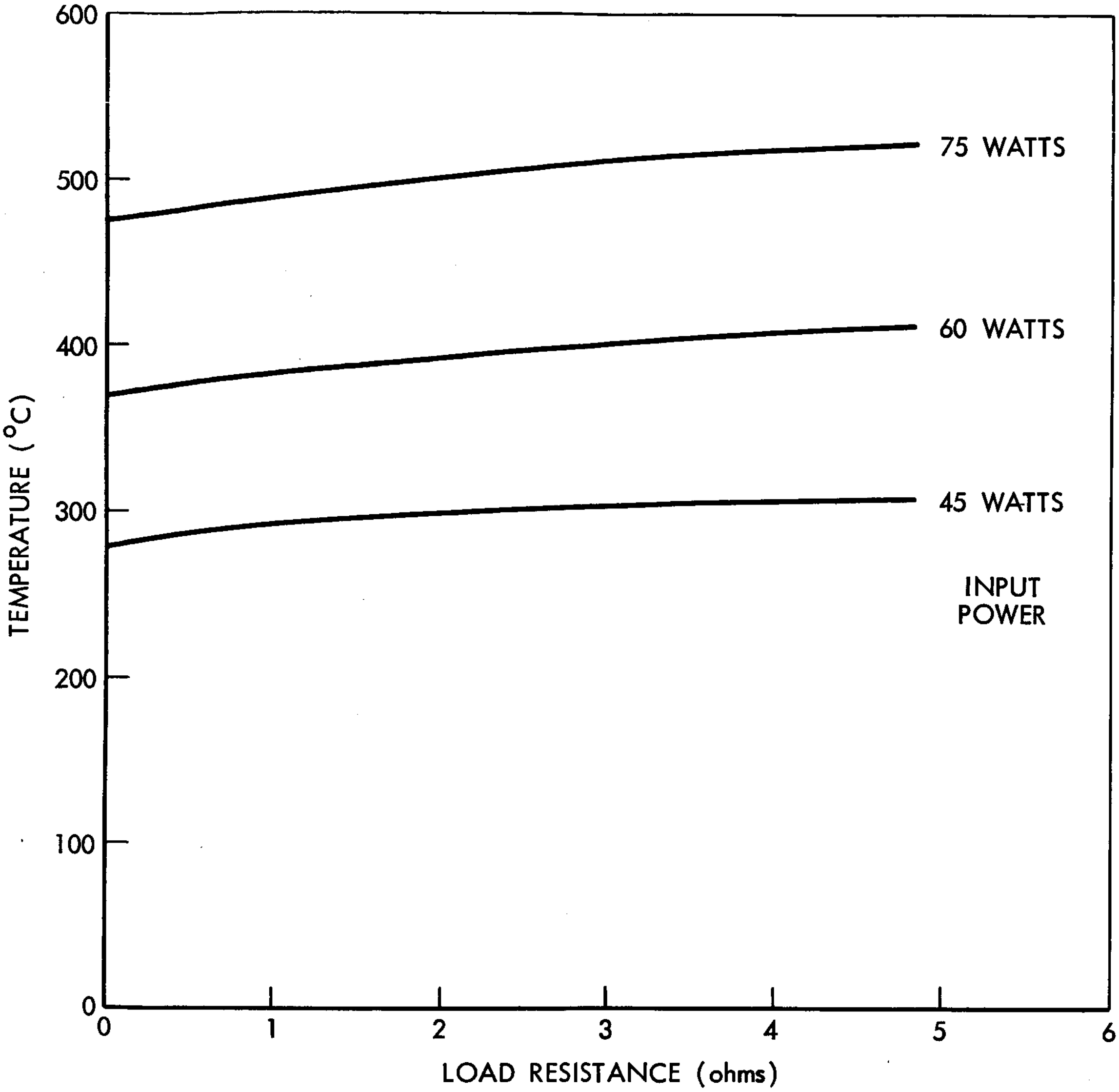


Figure 4. Variation of Hot Shoe Temperature with Load Resistance

provide a simulated chopped output impedance. The oscilloscope could be switched from X-Y operation, displaying the output I-V curve, to dual-beam time base display of the output current and voltage. The function generator provided a variety of wave shapes for the oscillated load, at frequencies up to 10kHz.

At each of the desired input power levels, a display of the output I-V curve in the power quadrant was obtained by appropriate adjustment of the power amplifier gain and the auxiliary load resistance. A triangle wave oscillated load with a frequency of 700 to 900 Hz was used to give a constant temperature I-V curve on the oscilloscope display. A square wave oscillated load, simulating

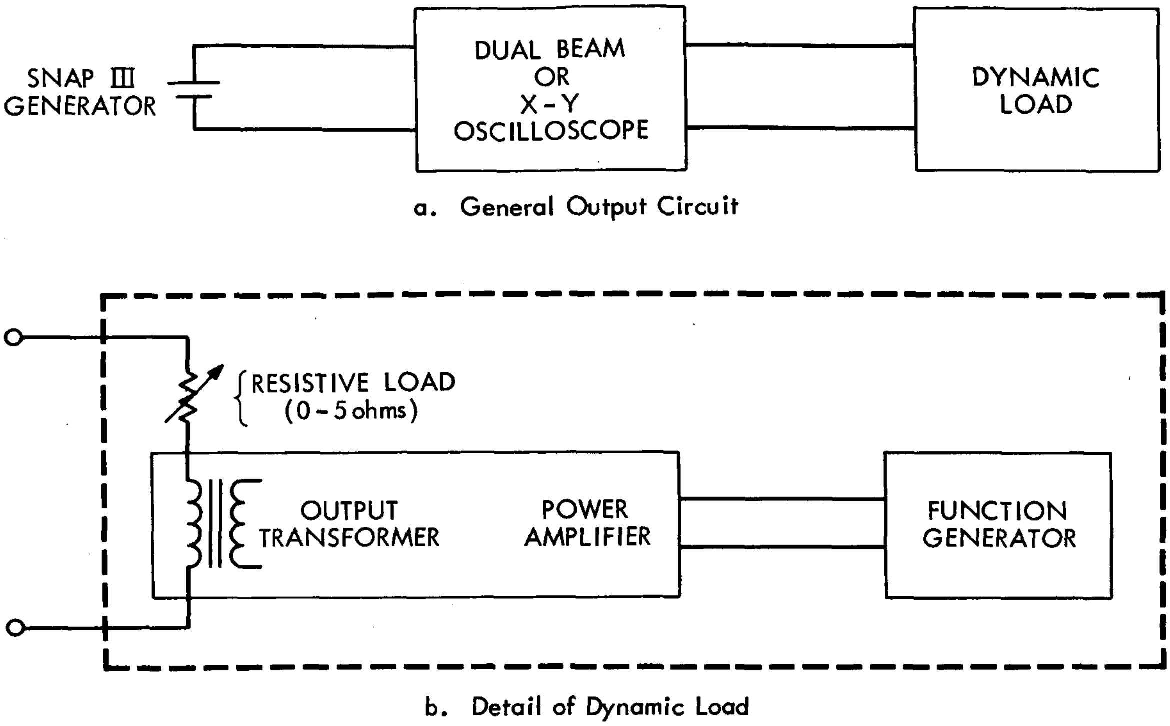


Figure 5. Dynamic Test Output Circuit

chopped output, provided for operation alternating between two points on the I-V curve. For approximately 95% of the operating cycle, the output was at one or the other of these two points, and for 5% of the cycle the output was in transient between the points. The average power output during a cycle was determined from the current-voltage versus time display with a square wave oscillated load.

SUMMARY OF RESULTS

The results of the static tests were similar to those of Huffman and Gross[1]. The present measurements differ in that they were conducted under room ambient rather than vacuum conditions and the radioisotope fuel was simulated with an electric heater. The earlier measurements, conducted in a bell jar environment, showed the operating temperatures to be considerably higher than those observed in the present room ambient tests at the same power input. The higher operating temperatures, due to the absence of convective heat transfer in the bell jar, resulted in the higher efficiency operation during the earlier tests.

The static and dynamic output characteristics are compared in Figures 6 and 7. Figure 6 shows the static and dynamic I-V and I-P (current output versus power output) curves for a power input of 75 watts. Figure 7 gives a comparison

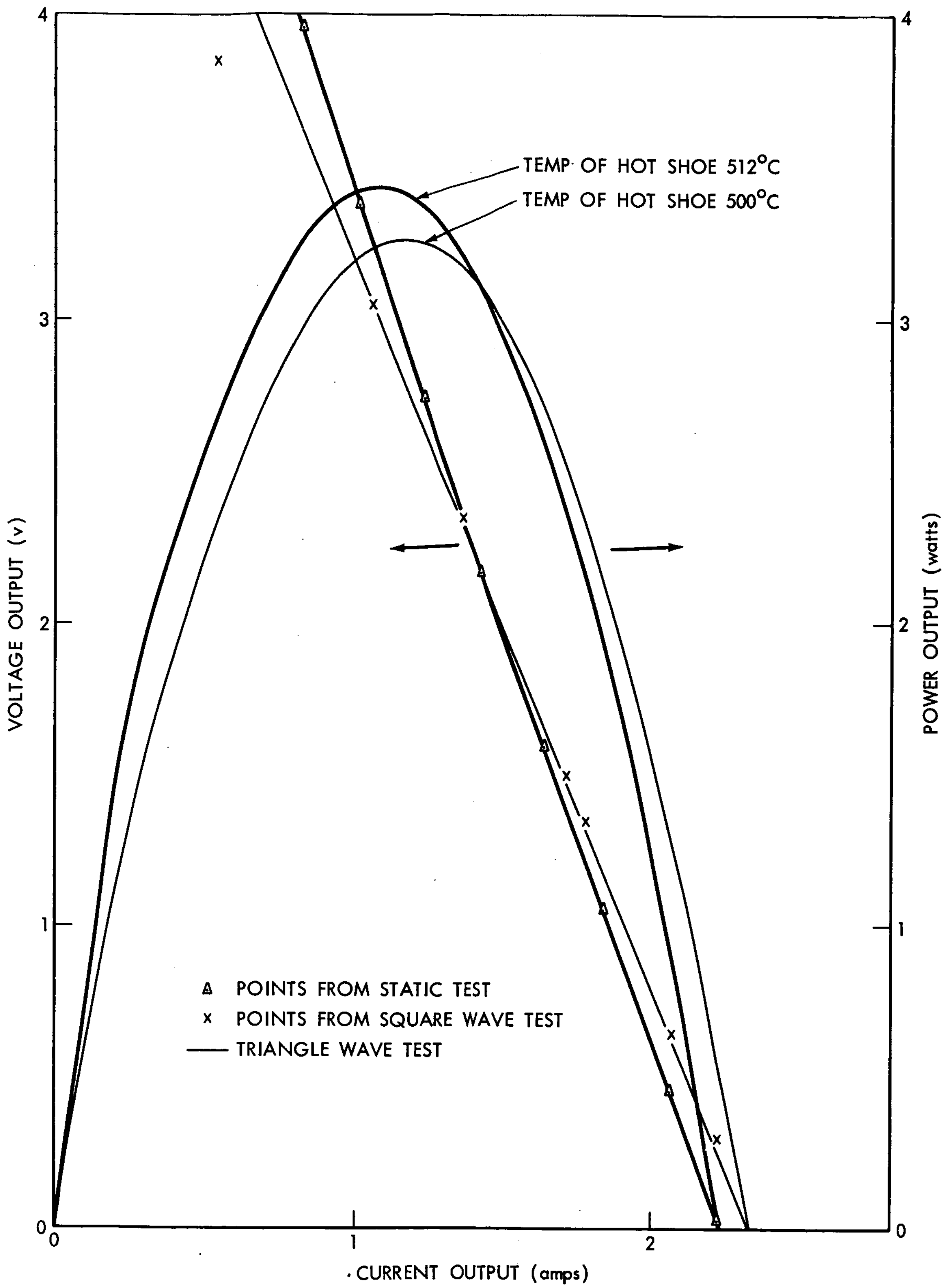


Figure 6. SNAP III - Static and Dynamic Comparison (75w Input)

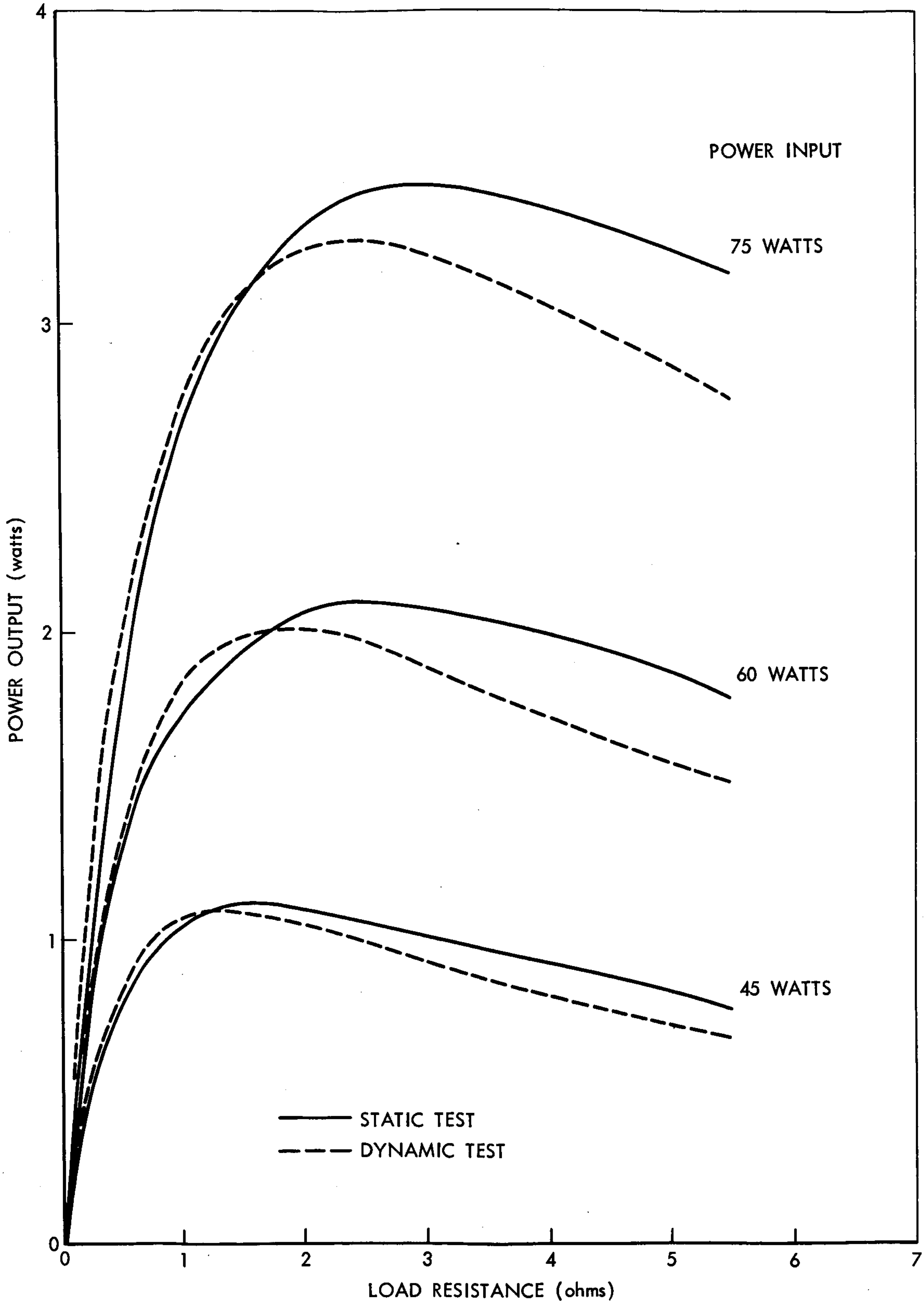


Figure 7. SNAP III - Power Out vs Load

of static to dynamic power output versus load resistance. From these curves it is seen that the peak power output in dynamic operation is always less than the optimum static power output at a given input power level. This difference is due to the fact that RTG's have lower efficiencies at lower operating temperatures and dynamic operation results in a lower effective operating temperature. The hot shoe temperature is seen to be 12°C lower during dynamic operation than at the optimum static point for the case of 75 watts input power (Figure 6).

The average power output over a cycle during square wave oscillated output falls below the optimum static power output at the same input power level. This is illustrated in Figure 8, which shows the power output versus time from which

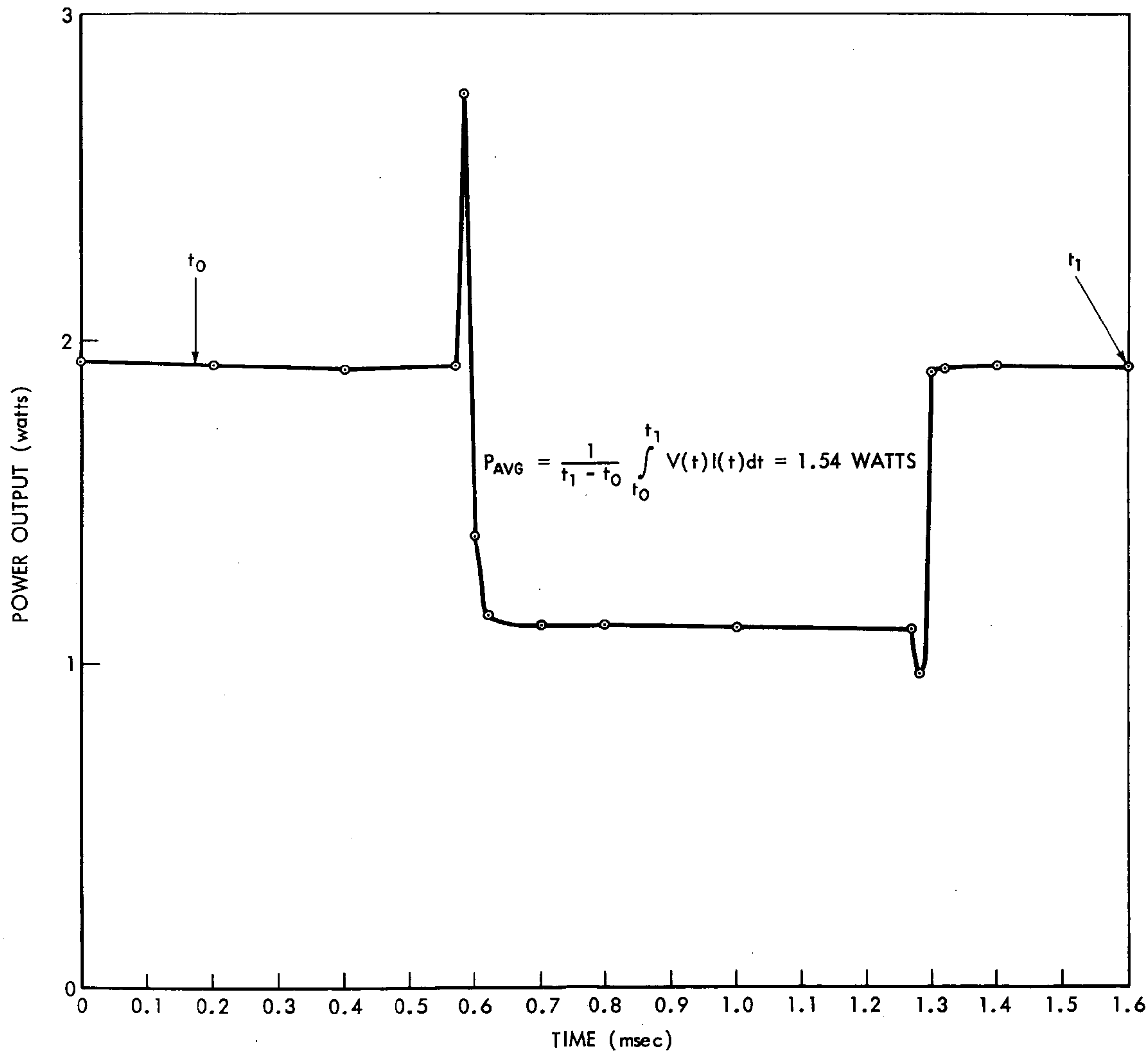


Figure 8. Dynamic Power Output with 700 Hz Square Wave Oscillated Load

the time-average power output was calculated. The average power output is lower than the optimum static output since the maximum dynamic power output is only obtained for part of the cycle. In practical applications, the fraction of operating time at optimum load will be increased by chopping as shown in Figure 9. This pattern of chopping is expected to give higher average power output than measured in the present tests.

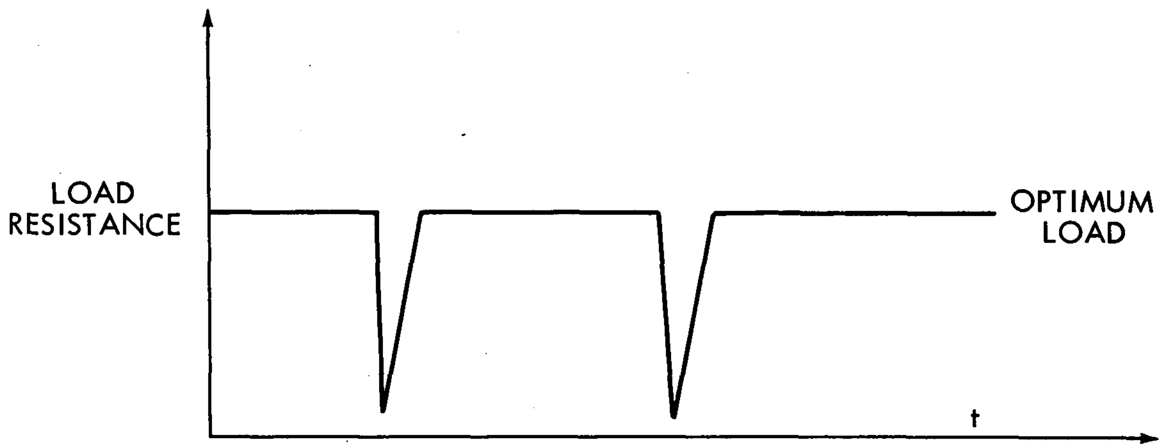


Figure 9. Practical Chopped Output

The peak and dip in the power output curve of Figure 8 were found to be caused by the lagging of the output current behind the output voltage. This current lag arises from the inductive load used to chop the output and can be expected from most dc to dc convertors. The current lag also produces loops in the I-V curves displayed on the oscilloscope. At higher frequencies of load oscillation the current lag time is a larger fraction of the cycle, and the fraction of time at optimum load is decreased.

CONCLUSIONS

The present method of oscillating the output load to facilitate oscilloscope display of I-V characteristics of RTG's has certain advantages over the static measurement method. The complete I-V curve in the power quadrant may be obtained dynamically in the time required for a single static measurement. Also, the dynamic curve gives a more accurate indication of the characteristics under constant temperature operation.

Future work planned on measuring the dynamic characteristics of thermoelectric power generators will include the following:

1. More accurate simulation of a chopped output similar to that used in dc to dc conversion.

2. Extension of testing to other thermoelectric generators (e.g. Si-Ge thermoelectric systems).

3. Extension of power transient study by use of X-Y plotter with Mosely Autograph Waveform Translator for more accurate readout.

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1. Huffman, Fred N., and Louis W. Gross, Performance Data and Environmental Test Results of SNAP III Under Contract No. AT(30-3)-217.

2. Krawczak, W.G., Letter in reference to Contract No. NAS5-486, Invoice No. 1438-5-60 to NASA Goddard Space Flight Center, dated August 31, 1960.