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EXPERIMENTAL EVALUATION OF A VOLTS-PER-HERTZ REFERENCE CIRCUIT FOR THE ISOTOPE BRAYTON SYSTEM

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16. Abstract

In Brayton-cycle power systems, the speed decreases rapidly with overload. If the voltage decreases linearly with speed (frequency), the power decreases as the square of the voltage. This makes the system more tolerant of overloads. A volts-per-hertz reference circuit, consisting of a volts-per-hertz sensor and a voltage limiter, was designed and fabricated. This reference circuit was incorporated in an existing voltage regulator to control a turbine-driven alternator. Test results show that the control does function to reduce voltage at speeds below the rated speed and that it performed successfully during transients.

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SUMMARY

In Brayton-cycle power systems, the speed decreases rapidly with overload. If the voltage decreases linearly with speed (frequency), the power decreases as the square of the voltage. This makes the system more tolerant of overloads. A volts-per-hertz reference circuit, consisting of a volts-per-hertz sensor and a voltage limiter, was designed and fabricated. The volts-per-hertz reference circuit was incorporated in an existing voltage regulator to control a turbine-driven alternator. Test results show that the control does function to reduce voltage at speeds below the rated speed and that it performed successfully during transients.

INTRODUCTION

The electrical power source for the dynamic space power systems under investigation at the Lewis Research Center is a turbine-driven alternator. The rotational speed and alternator output frequency of this turboalternator are maintained by parasitic speed controllers. These controllers complement the useful (vehicle) load in order to maintain a constant alternator speed. The voltage regulators in this system function to maintain rated alternator output voltage above 75 percent of design speed.

When the total alternator power is being used by the useful load, the parasitic load is zero. If the useful demand is greater than the power developed by the system, the alternator decelerates. The voltage regulator supplies rated voltage to sustain the overload and thereby maintains the decelerating torque. At about 75 percent of design speed, the voltage starts to decrease. However, at this speed the efficiency of the power system has decreased sufficiently to allow further loss of speed. The result is that the system shuts down. Only a few watts of additional useful-load demand could cause this sequence of events.

In the 1200-hertz Brayton system (ref. 1) presently under investigation, protection against this type of shutdown is included. When the speed is 10 percent below rated value, all useful load is disconnected from the system. The operator can then reapply useful load up to the rated value. In order to permit small overloads without removal of all useful load, a volts-per-hertz reference circuit has been designed, constructed, and tested. This circuit replaces the fixed-voltage reference in the voltage regulator. The output voltage of the volts-per-hertz reference circuit increases with increasing frequency up to the rated frequency. Above the rated frequency, the output voltage remains relatively constant. Upon an overload, the alternator voltage and frequency decrease until a new power balance is achieved.

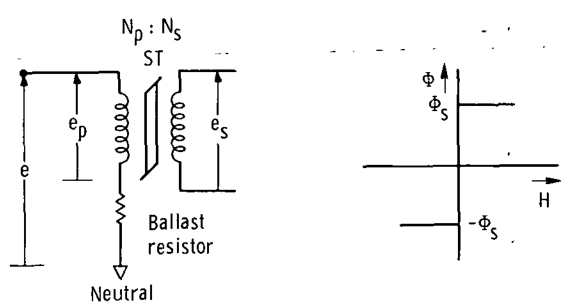
This report presents a description of a volts-per-hertz reference circuit and an experimental evaluation of its performance. In addition, the system performance of an alternator, using the volts-per-hertz reference circuit in the voltage regulator, was experimentally determined. These results are also presented.

PRINCIPLE OF OPERATION

A schematic diagram of the volts-per-hertz (V/Hz) sensor is shown in figure 1(a). The frequency-sensitive component is the saturating transformer (ST). The ideal magnetic-core characteristic is shown in figure 1(b). The transformer has a very high impedance until the core saturates. With this high impedance, the instantaneous primary voltage e_p is equal to the instantaneous supply voltage e. Then,

$$e = e_p = N_p \frac{d\varphi}{dt}$$

where N_p is the number of primary turns, φ is the instantaneous core flux level, and



(a) Circuit schematic.

(b) Flux - coercive force (Φ - H) characteristic.

Figure 1. - Volts-per-hertz sensor.

t is time. Rearranging and integrating yields

$$\int_0^t e_p \, dt = N_p \, \Delta\Phi$$

where $\Delta\Phi$ is the total change in flux level. If the supply voltage is of sufficient magnitude to drive the core into saturation during each half-cycle of the supply voltage, then $|\Delta\Phi| = 2\Phi_s$ and

$$\int_0^{t_s} e_p \, dt = 2N_p\Phi_s$$

where t_s is the time to saturation and Φ_s is the saturation flux level. The average primary voltage E_p is

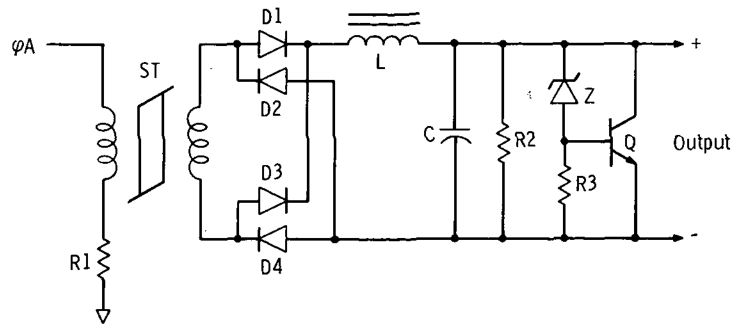
$$E_p = \frac{2}{T}\int_0^{t_s} e_p \, dt = \frac{4N_p\Phi_s}{T} = 4N_p f\Phi_s$$

where T is the period of the voltage and f is the reciprocal of T. The ballast resistor supports the supply voltage when the transformer saturates. The average secondary voltage is

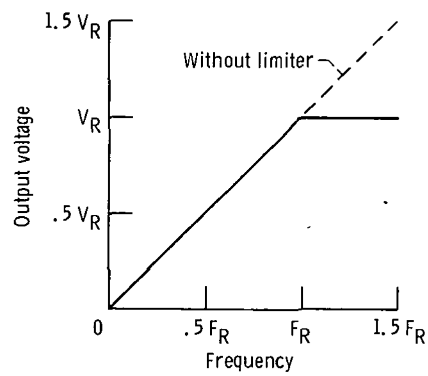
$$E_s = \frac{N_s}{N_p} E_p = 4N_s f\Phi_s$$

From this relation it can be seen that, as long as the core is driven into saturation once during each half-cycle of the supply voltage, the average secondary voltage is directly proportional to the supply frequency. Detailed discussions of practical circuits, including design information, can be found in references 2, 3, and 4.

Figure 2(a) is a schematic diagram of the volts-per-hertz reference circuit which was tested. The secondary voltage is full-wave rectified and filtered to obtain a nearly ripple-free dc voltage. The function of the zener diode Z, the resistor R_3, and the transistor Q is to limit the output voltage at rated frequency, as shown in figure 2(b).



(a) Schematic diagram.



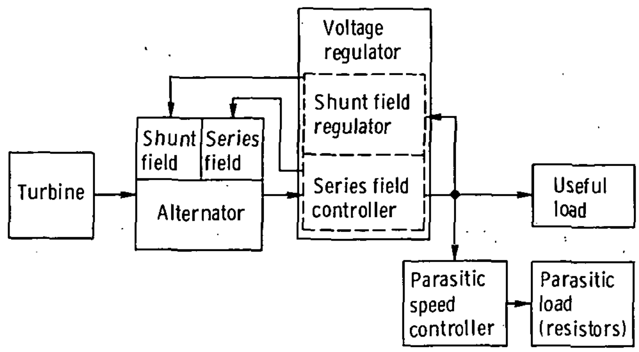
(b) Ideal volts-per-hertz characteristic. Subscript R denotes rated value.

Figure 2. - Volts-per-hertz reference circuit.

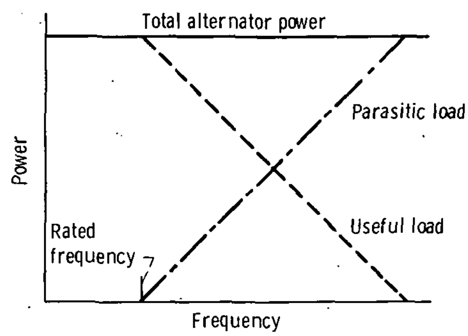
APPARATUS

Test-Facility Equipment

A block-diagram representation of the system in which the V/Hz reference circuit was tested is shown in figure 3(a). The major components of the system are the turbine, the alternator, the voltage regulator, and the parasitic speed controller. The turbine is designed to produce 11.9 kilowatts at 36 000 rpm at an air pressure drop of 8.3×10^4 newtons per square meter. The alternator is a solid-rotor modified-Lundell machine. It is rated at 14.3 kilovolt-amperes, 0.75 lagging power factor, 120/208 volts, three phase, and 1200 hertz at 36 000 rpm. The voltage regulator consists of a series field controller and a shunt field regulator. The series field controller provides excitation to one field of the alternator; this excitation is directly proportional to armature current. The shunt field regulator provides excitation to the other field; this excitation is required



(a) Block diagram of the electrical system.



(b) Ideal load division of the alternator power.

Figure 3. - Test system.

to maintain constant voltage output of the alternator. This regulator will be described in more detail in the next section. The parasitic speed controller applies an increasing parasitic load to the alternator with increasing frequency, as shown in figure 3(b). The parasitic load complements the useful load so as to maintain a total alternator load over the indicated frequency range.

Detailed electrical performance characteristics of this system (with a vacuum-rated package of the voltage regulator and the parasitic speed controller) are given in references 5 and 6. All system testing was performed at room ambient temperature. Prior to system testing, the volts-per-hertz reference circuit was tested over a range of temperatures.

Voltage Regulator

As mentioned previously, the additional excitation required to maintain constant voltage is provided by the shunt field regulator. A block diagram of this regulator is shown in figure 4. The comparator compares the output of the voltage sensor with the reference voltage. If this output is greater than the reference, a signal is provided to

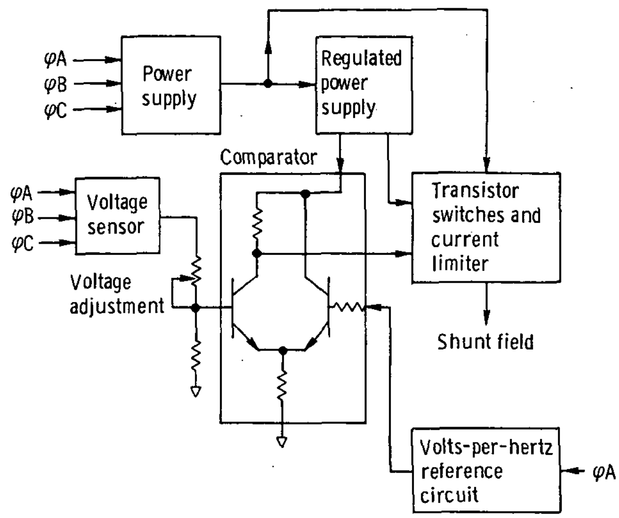


Figure 4. - Diagram of shunt field regulator.

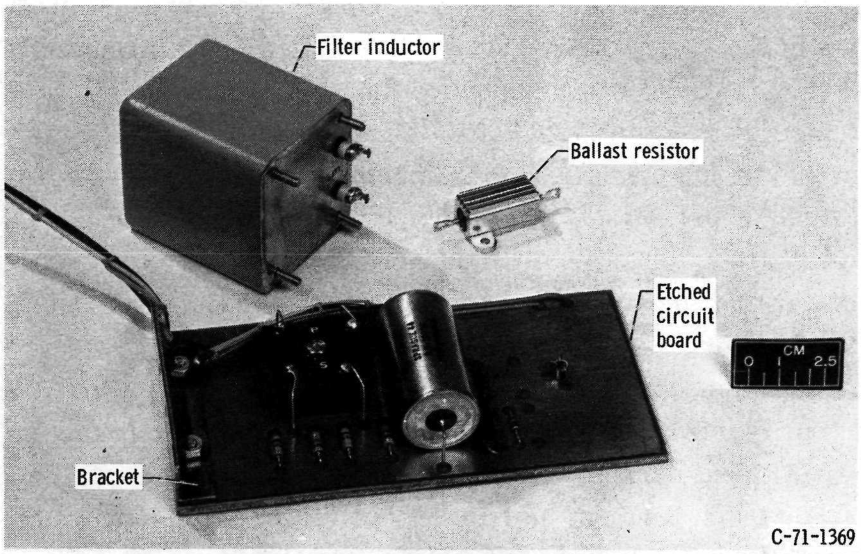
the transistor switches, resulting in a decrease in the shunt field current. The current limiter holds the field current to a maximum preset value. The regulator was converted to a V/Hz regulator by replacing the constant-voltage reference with the V/Hz reference circuit.

Volts-Per-Hertz Reference Circuit

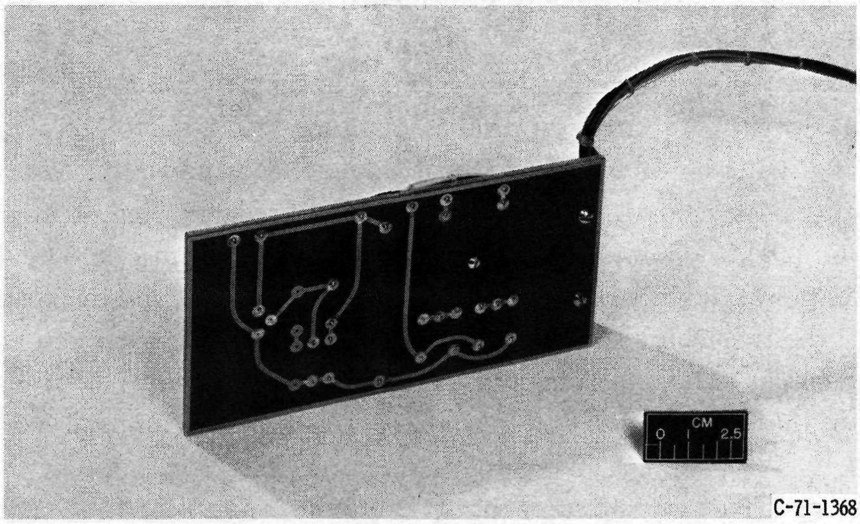
Figure 5 presents photographs of the reference circuit. This circuit was constructed to be suitable for use in a vacuum. The etched circuit board, the filter inductor, and the ballast resistor would be mounted to a cold plate in the vacuum configuration.

Instrumentation

Prior to system testing, the V/Hz reference circuit was tested by itself at various ambient temperatures. The power source was a variable-frequency, variable-voltage supply with a voltage distortion of less than 0.25 percent. The input voltage and input current were measured with true-rms meters and a 0.1-ohm shunt. The accuracy of these meters was ±1 percent. The true-rms wattmeter had an accuracy of ±3 percent. The output voltage of the reference circuit was measured with an integrating digital voltmeter of 0.01-percent (±1 digit) accuracy. The frequency of the input voltage was measured with a counter that was accurate to ±1 hertz. The temperatures were measured with iron-constantan thermocouples and panel meters with accuracies of ±3 percent.



(a) Components.



(b) Bottom view of etched circuit board.

Figure 5. - Photographs of volts-per-hertz reference circuit.

For the systems test, the input parameters were not measured. The output voltage of the circuit and the temperatures were measured with the meters previously described. The alternator output voltage was measured with a true-rms responding digital meter which had an accuracy of ±(0.5 percent of input plus 0.015 percent of range). For the transient tests, a light-beam oscillograph was used. The galvanometers had undamped, natural resonant frequencies of 400 hertz or 1000 hertz. The linearity was 2 percent. The response time of all traces to step inputs to the transducers was not greater than 10 milliseconds.

PROCEDURE

For the tests of the V/Hz reference circuit by itself, the inductor, the ballast resistor, and the circuit board were mounted on an aluminum plate which was installed in an oven. The temperature of the bracket which attached the circuit board to the plate was varied from 20° to 80° C in 10° C increments. The temperature of the air in the oven was typically 3° C below the bracket temperature. Data were taken after at least 2 hours had elapsed after a change in temperature. Two sets of data were taken. For the first set, the ratio of input voltage to frequency was maintained at 0.1 for frequencies from 600 to 1200 hertz. From 1200 to 1800 hertz, the input voltage was kept at 120 volts. The load impedances applied to the reference circuit were 20 kilohms, 100 kilohms, and an open circuit. The following parameters were measured: (1) frequency, (2) input voltage, (3) input current, (4) input power, (5) output voltage, and (6) output ripple voltage. For the second set of data, at each frequency point between 600 and 1800 hertz, input voltages of 60, 80, 100, 110, 120, 130, and 140 volts were applied. The loads applied were an open circuit and 100 kilohms. The same six parameters were measured.

For the system tests, the reference circuit was installed in the shunt field regulator. The voltage-adjustment potentiometer in the regulator was adjusted to obtain an alternator output of 120 volts at 1200 hertz without the useful or parasitic load applied. Then, with the parasitic speed controller connected to the alternator, the turbine inlet conditions were established to obtain about 10.7 kilowatts total alternator output power. The frequency at this power level was 1225 hertz. Data were taken for increasing values of useful load until the frequency had dropped to 1000 hertz. The parameters measured were alternator output voltage, frequency, and reference-circuit output voltage. Oscillograph traces of these parameters were then obtained for the stepped removal of all useful load.

The final system test was a transient startup from zero speed. With the alternator producing about 6 kilowatts and with no useful load applied, the turbine air-inlet valve was closed. After the turboalternator had reached zero speed, the inlet valve was opened. Oscillograph traces were obtained for frequency, alternator voltage, reference-circuit output voltage, and the two field currents. This startup relied on the residual magnetism of the alternator rotor.

RESULTS AND DISCUSSION

Reference Circuit Tests

The V/Hz reference circuit was designed to be usable in a vacuum. For vacuum operation of the Brayton system, the components of the voltage regulator and of the parasitic speed controller are mounted on a cold plate. The temperature of this cold plate is normally in the range of 30° to 40° C. Therefore, figure 6 was selected as the representative characteristic of the reference circuit at the thermal design point. The temperature of the bracket which attached the circuit board to the aluminum plate in the oven was 40° C, while the air temperature in the oven was about 37° C.

The curve in figure 6 was obtained with the input volts-to-hertz ratio maintained at 0.1 (i.e., 120 V/1200 Hz) for frequencies up to 1200 hertz. Above 1200 hertz, the input voltage was maintained at 120 volts. The load impedance for this curve is 100 kilohms. This curve is shown, since it is not expected that the load impedance would ever be lower than this value. The curves obtained for a load impedance of 20 kilohms and for the open-circuit case will be shown later.

The ripple on the output voltage of the reference circuit was monitored on an oscilloscope during these tests. It was found that the maximum peak-to-peak ripple voltage

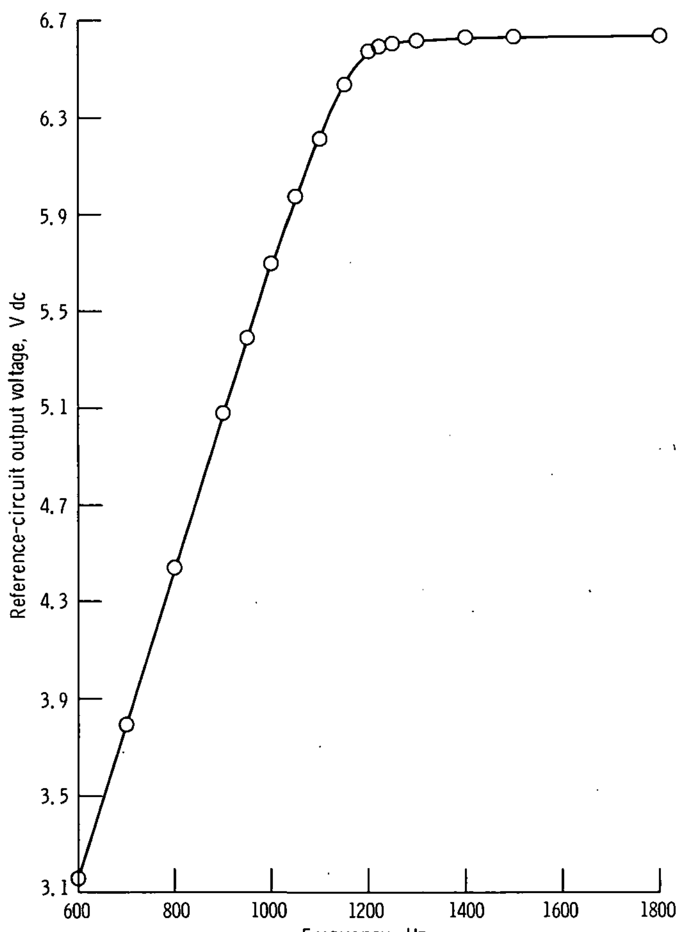


Figure 6. - Volts-per-hertz reference characteristic. Bracket temperature, 40° C; air temperature, 37° C; load impedance, 100 kilohms; ratio of input voltage to frequency, 0.1 for frequencies up to 1200 hertz.

was about 3 millivolts over the expected operating range. This small value can be neglected.

The input power and volt-amperes to the reference circuit are shown in figure 7. The maximum values of 8.4 watts and 11.3 volt-amperes occur at rated frequency. As the frequency decreases below the rated frequency, the power decreases, since the decrease in input voltage is more rapid than the increase in the saturation time of the core. As the frequency increases above the rated frequency, the power again decreases, since the input voltage remains constant and the time during which the core is in saturation decreases.

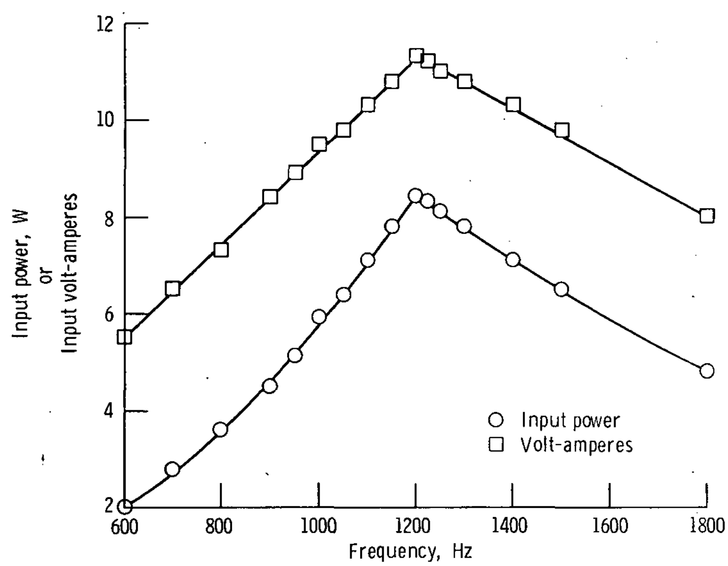


Figure 7. - Input power and volt-amperes to the reference circuit.

Voltage sensitivity. - As was discussed previously, the average secondary voltage of the saturating transformer is insensitive to supply-voltage variations as long as there are sufficient volt-seconds to drive the core into saturation once during each half-cycle. Figure 8 presents the sensitivity of the output voltage to variations in the supply voltage. The sensitivity is determined by measuring the percent change in the output voltage per volt change in the supply voltage. A low sensitivity is especially important in the normal system operating range of 1200 to 1225 hertz. In this range, the rms value of the alternator voltage may change by as much as 5 percent of rated voltage (see ref. 5). It was verified in tests to be discussed later that the sensitivity of the reference circuit was low enough to be negligible.

The effect of voltage variations on input power and on volt-amperes is shown in figure 9. When the input voltage is 10 volts higher than the normal operating voltage, the maximum power increases to 10.6 watts and the volt-amperes increase to 13.6. Such

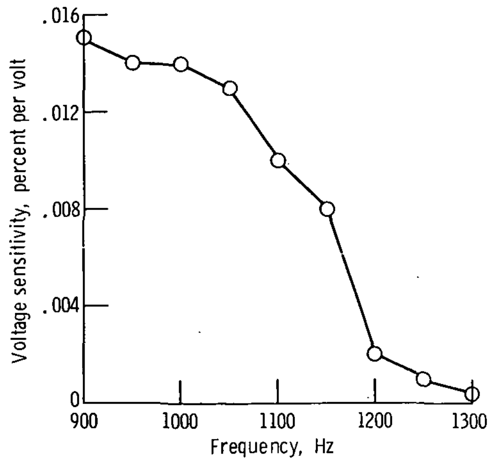


Figure 8. - Voltage sensitivity of the reference circuit.

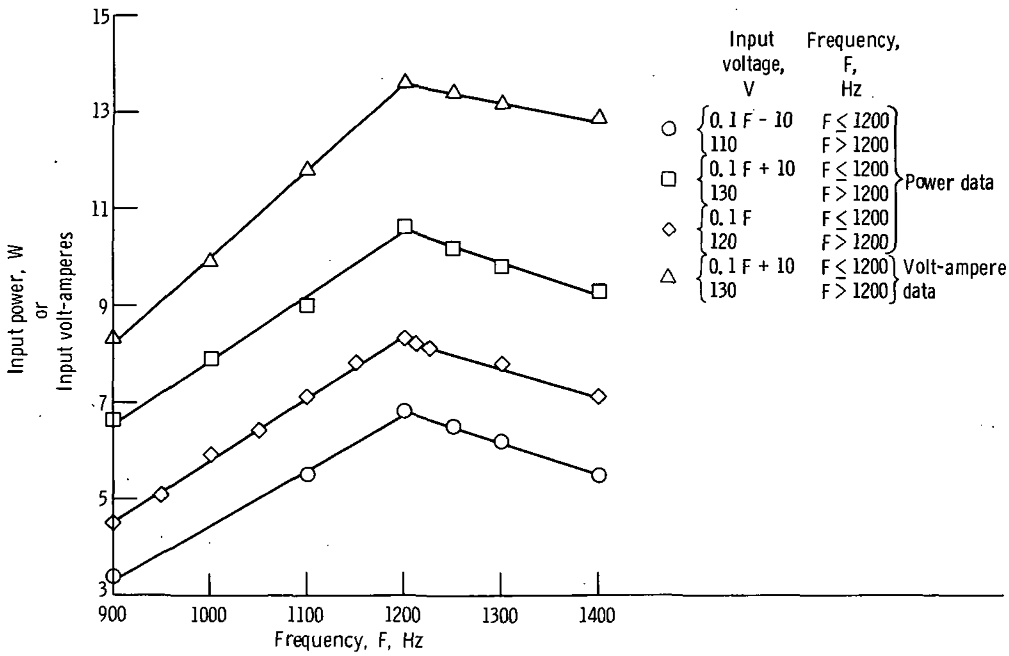


Figure 9. - Effect of input-voltage variations on power and volt-amperes.

large voltages will occur during transients. The effect the additional losses have on the total losses of the shunt regulator is to increase them from 41 watts to 49.4 watts (ref. 5).

Temperature sensitivity. - Figure 10 illustrates the effect of temperature on the V/Hz characteristic. The voltage deviation is the difference between a datum-point value and the base value, and this difference is expressed as a percentage of the base value. The base value is the output voltage obtained at a frequency of 1200 hertz and a

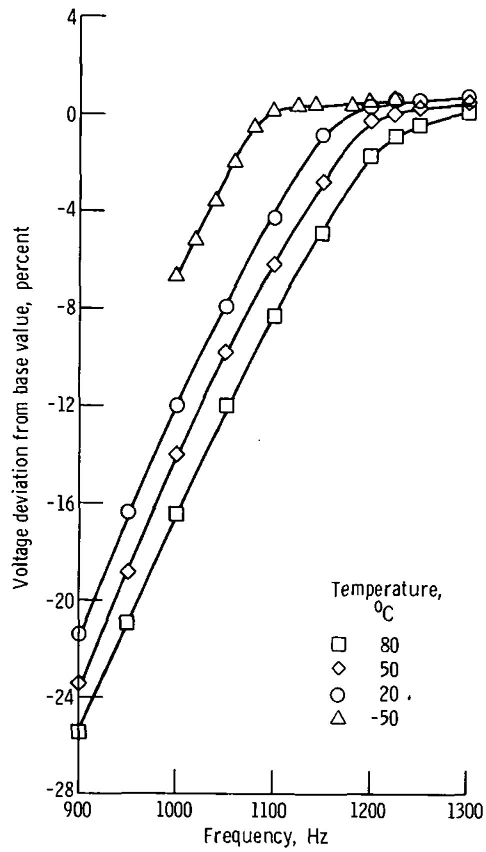


Figure 10. - Effect of temperature on volts-per-hertz characteristic. Base voltage, 6.572 V; load impedance, 100 kilohms.

bracket temperature of 40° C. The base value is 6.572 volts.

The expected operating temperature range is 20° to 40° C. The 80° C curve was obtained to ensure proper operation of the reference circuit in case the higher temperature were encountered in a system test. The -50° C curve represents the condition for a cold start in a space environment. The exact value of the percentage decrease below rated frequency is not crucial. But the deviation over the frequency range of 1200 to 1225 hertz is important. Over the expected temperature range, the voltage deviation is ±0.3 percent at 1200 hertz. At 80° C, the voltage deviation is 1.7 percent. For the -50° C case, zero deviation occurred at 1100 hertz. For all cases, the voltage returned to the nominal value when design temperature was reestablished.

Load sensitivity. - Figure 11 shows the effects of loads of 20 kilohms, 100 kilohms, and an open circuit on voltage at frequencies of 1200 and 1225 hertz. There is no significant difference between the 100-kilohm and the open-circuit curves. The comparator in the shunt field regulator presented no measurable load to the reference circuit. Therefore, the open-circuit curve would apply to system testing. However, if another

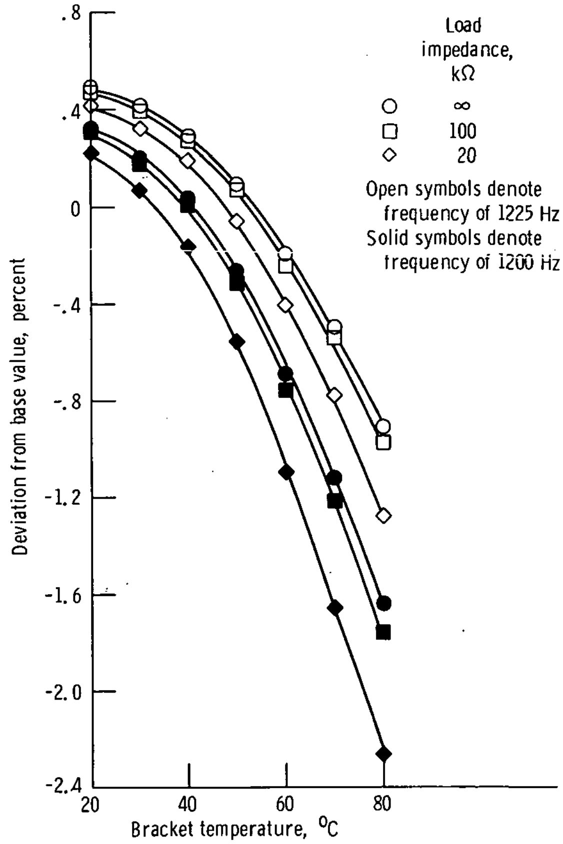


Figure 11. - Effect of load impedance and temperature on the reference voltages at frequencies of 1200 and 1225 hertz.

load is to be connected to the reference circuit, it is recommended that the impedance be greater than 100 kilohms.

At a temperature of 40° C, the reference voltage increased by 0.27 percent for an increase in frequency from 1200 to 1225 hertz. At a frequency of 1200 hertz, the reference voltage decreased by 0.27 percent for an increase in temperature from 40° to 50° C. At a temperature of 50° C, the reference voltage increased by 0.34 percent for an increase in frequency from 1200 to 1225 hertz. This performance is considered acceptable.

System Tests

The result of the initial test with the V/Hz reference circuit installed in the shunt field regulator is shown in figure 12. With no load applied to the alternator, the voltage-adjusting potentiometer was adjusted to obtain 120 volts at 1200 hertz. The alternator frequency was varied by adjusting the turbine inlet pressure. This curve is representative of the V/Hz characteristic for all the systems tests since there was no measurable

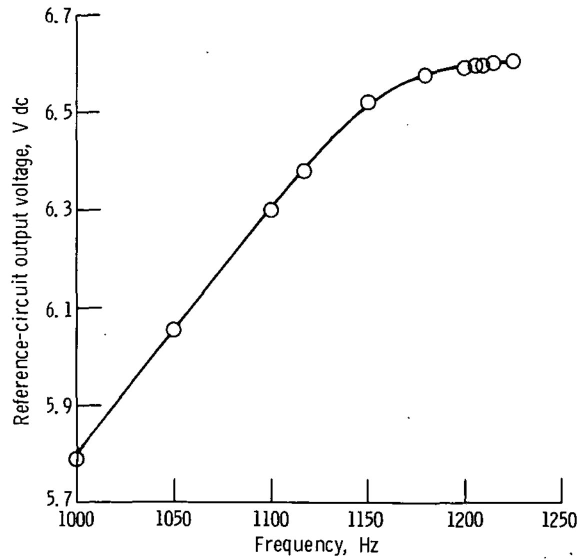


Figure 12. - Volts-per-hertz characteristic with the circuit installed in the shunt field regulator. Bracket temperature, 23° C; ambient temperature, 22° C.

change in the bracket and ambient temperatures. The bracket temperature remained at 23° C, and the ambient temperature remained at 22° C.

Normal system operation. - For rated system operating conditions, the total alternator power is 10.7 kilowatts. With no useful load applied, this power is dissipated by the parasitic speed controller. The frequency is typically between 1224 and 1225 hertz. As useful load is applied, the frequency decreases. At about 1200 hertz, the useful load absorbs the total alternator power. Figure 13 shows the alternator voltage, the total harmonic distortion of this voltage, and the output voltage of the volts-per-hertz reference circuit over the frequency range of 1200 to 1225 hertz. The large variation in the distortion is caused by the phase-controlled loading of the parasitic speed controller (ref. 5). This distortion also causes a variation in the alternator output voltage. The voltage regulator senses the average voltage and not the true-rms value. As can be seen in figure 13, the alternator voltage has no discernible effect on the reference-circuit output voltage. From 1200 to 1225 hertz, the reference voltage increases by 0.17 percent. This is the same increase as is obtained when the input voltage is maintained at a constant 120 volts.

Overload test. - At about 1200 hertz, the useful load (plus various losses) is equal to the alternator output power. As additional useful load elements (in this case, resistors) are applied to the alternator, the alternator speed and voltage decrease until a new power balance is achieved. The steady-state values of alternator voltage and reference-circuit output voltage for this test are shown in figure 14. The alternator voltage is not 120 volts at 1200 hertz because of the regulation characteristics of the combination of the altenator and the voltage regulator. Also, at frequencies above

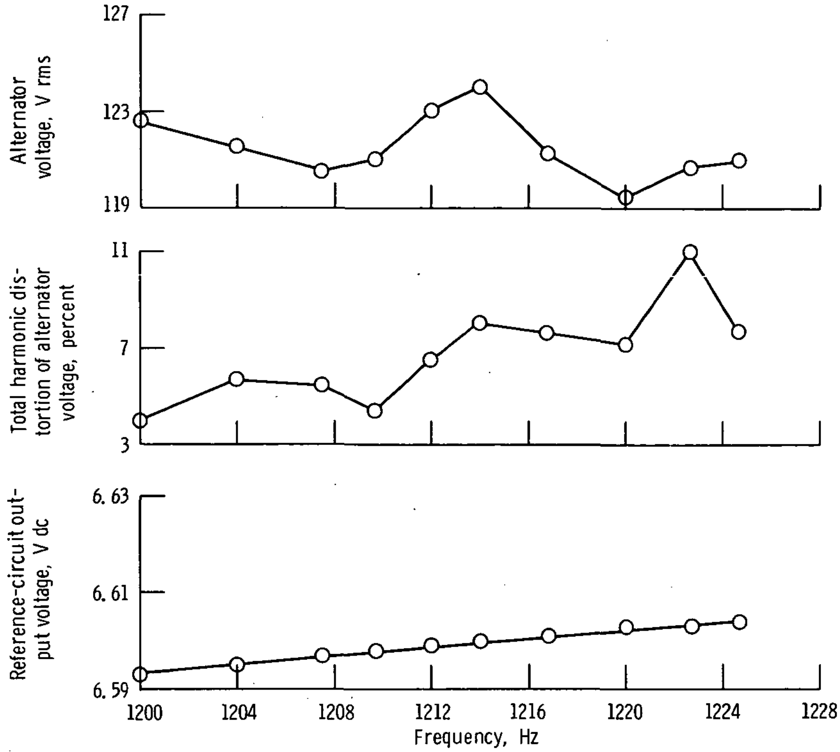


Figure 13. - Performance for the normal system operating range.

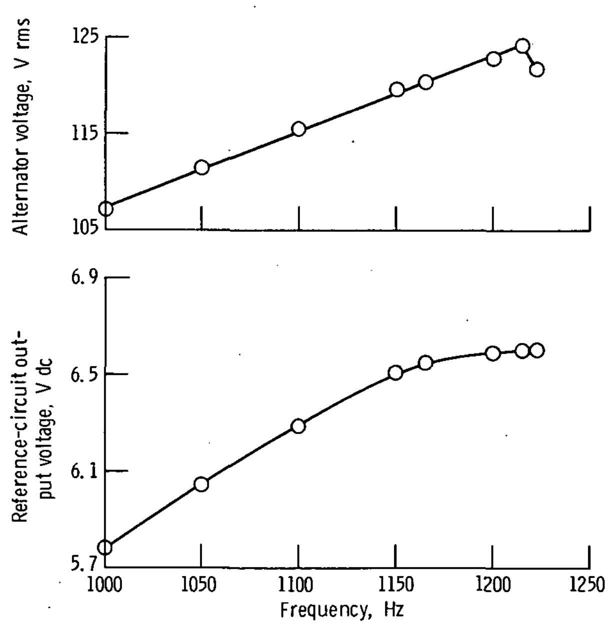


Figure 14. - Performance under overload.

1200 hertz, the speed controller is active and it affects the voltage, as mentioned previously. However, the voltage does decrease linearly with frequency. At 1000 hertz, the voltage on phase A is about 107 volts. In an operating Brayton system, the frequency at which all useful load would be removed was selected to be 10 percent below rated frequency, or 1080 hertz. At this frequency, the alternator voltage is about 114 volts.

When an overload was applied sufficient to bring the frequency down to 1000 hertz, all useful load was removed in one step. Traces of frequency, reference-circuit output voltage, and alternator voltage were obtained. These traces are shown in figure 15. The traces for an actual Brayton system would be somewhat different because of the difference between the dynamics of the rotating units. The reference voltage follows the change in the frequency with no apparent delay, and at frequencies above 1200 hertz, the output voltage of the reference circuit is virtually constant. The alternator voltage peaks at 127 volts as the useful load is removed. It recovers to the regulation range in 0.1 second, and it follows the change in the reference voltage until about 0.75 second has elapsed. At this time, the speed controller starts to apply parasitic load. The resulting load transient causes the large swings in alternator voltage. The alternator output power returns to its original value and all the transients have essentially settled in 1.1 seconds.

Transient startup. - To ensure that the alternator voltage would build up from zero speed while relying on the residual magnetism of the rotor, a transient startup was performed. Turbine-inlet conditions were established to obtain an alternator output of about 6 kilowatts. No useful load was applied. The turbine air-inlet valve was closed and the turboalternator coasted to zero speed. At zero speed, the inlet valve was opened. Traces of frequency, alternator voltage, reference-circuit output voltage, and the two field currents were originally obtained as functions of time. The startup time from zero speed to 1225 hertz was 4.2 seconds. In order to make the data applicable to other systems where the startup times are much different, the data shown in figure 16 were plotted against frequency.

The voltage is so low at frequencies below 300 hertz that the transducer used cannot respond. At this frequency the regulator begins to function. The voltage does not build up linearly with frequency (i.e., constant volts-per-hertz) for two reasons: (1) the voltage input to the reference circuit is so low that it cannot provide the proper reference voltage and, more important, (2) the voltage is too low to permit proper regulation of the voltage regulator. At an alternator voltage of about 40 volts (which occurs at 800 hertz), the reference circuit begins to supply a voltage which increases linearly with frequency. But the shunt field regulator is unable to regulate until the input voltage is greater than 60 volts. This voltage is achieved at a frequency of 850 hertz. The shunt field current increases to the current-limiter set point of 6 amperes. The regulator remains in the current limiting mode until, at a frequency of 1000 hertz, the alternator

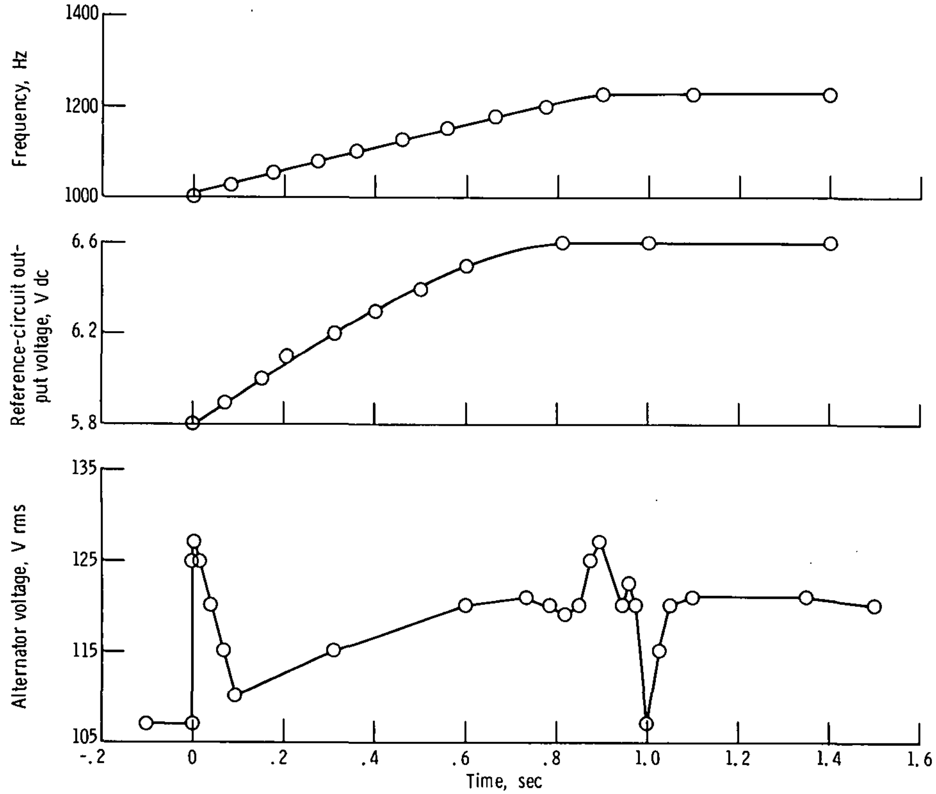


Figure 15. - Transient upon stepped removal of overload at time = 0.

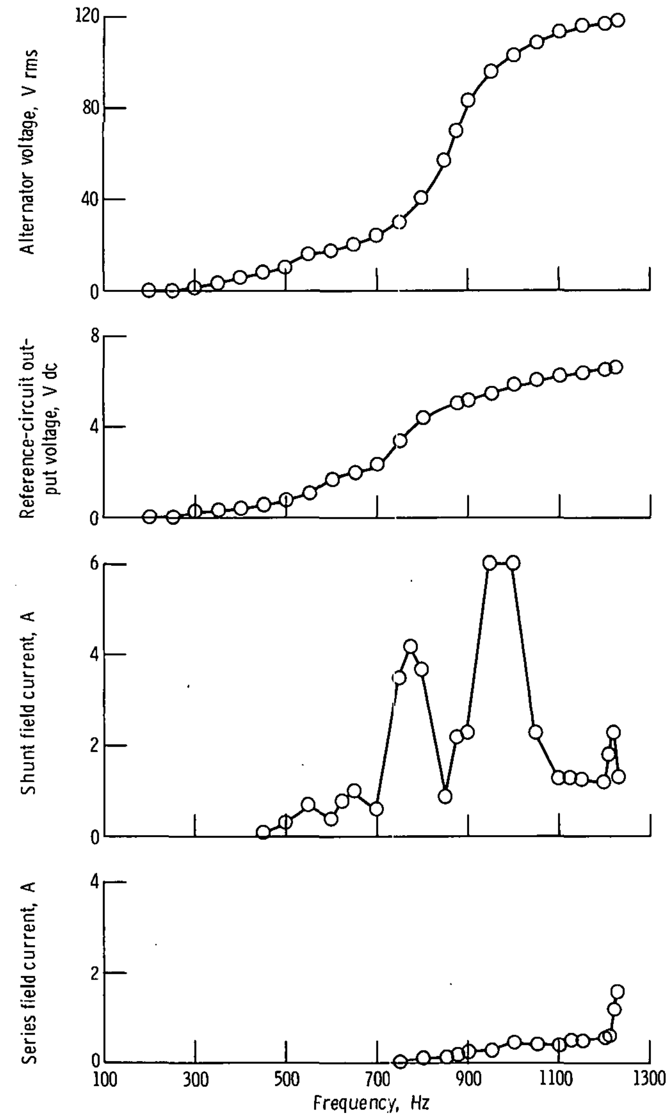


Figure 16. - Transient startup. Startup time (0 to 1225 Hz), 4.2 seconds.

voltage is about 103 volts. Now the regulator is functioning in the regulation mode. At 1200 hertz, the speed controller applies parasitic load. This load application causes the series field current to increase sharply; and it also causes the small change in the shunt field current. Finally, at 1225 hertz, steady-state operating conditions are achieved.

SUMMARY OF RESULTS

A volts-per-hertz reference circuit for use in the 1200-hertz, Brayton-cycle voltage regulator has been designed, constructed, and tested. Test results for the circuit by itself over the expected normal operative temperature range (20° to 40° C) indicate satisfactory performance. The voltage decreases linearly with decreasing frequency below the rated frequency, but it remains relatively constant over the normal frequency range of 1200 hertz to 1224 hertz. System testing indicates satisfactory performance at room ambient temperature (23° C). The following is a listing of specific test results:

1. The reference circuit provides an output voltage of 6.57 volts dc at a temperature of 40° C, at an input voltage of 120 volts rms, and at a frequency of 1200 hertz. It dissipates a maximum power of 8.4 watts at 11.3 volt-amperes.

2. With a constant volts-per-hertz input and at a temperature of 40° C, the output voltage decreases by about 14 percent for a decrease in frequency from 1200 to 1000 hertz.

3. At a temperature of 40° C, the reference voltage increases by 0.27 percent for an increase in frequency from 1200 to 1225 hertz.

4. System testing with the reference circuit installed in the shunt field regulator verified that this circuit is insensitive to normal alternator-voltage variations and to total harmonic distortion up to 11 percent.

5. Upon application of overloads, the alternator voltage decreased linearly from 123 volts at 1200 hertz to 107 volts at 1000 hertz.

6. Stepped removal of the overload showed no significant time lag between the frequency and the reference-circuit output voltage.

7. During a transient startup, the alternator voltage built up to rated value, relying only on the residual magnetism of the rotor.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 15, 1971,
112-27.

REFERENCES

1. Klann, John L.: 2 to 10 Kilowatt Solar or Radioisotope Brayton Power System. Intersociety Energy Conversion Engineering Conference. Vol. 1. IEEE, 1968, pp. 407-415.
2. Billings, William W.: Frequency Sensors for Aircraft Electric Power Systems. IEEE Trans. on Aerospace and Electronic Systems, Supplement, vol. AES-2, no. 4, July 1966, pp. 170-182.
3. Evans, W. G.: Saturating Transformer Reference Circuit. AIEE Trans., vol. 73, pt. 1, 1954, pp. 610-616.
4. Storm, Herbert F.: Applications of Nonlinear Magnetics. AIEE Trans., vol. 77, pt. I, July 1958, pp. 380-388.
5. Ingle, Bill D.; Wimmer, Heinz L.; and Bainbridge, Richard C.: Steady-State Characteristics of a Voltage Regulator and a Parasitic Speed Controller on a 14.3-Kilovolt-Ampere, 1200-Hertz Modified Lundell Alternator. NASA TN D-5924, 1970.
6. Wimmer, Heinz L.; and Ingle, Bill D.: Transient Characteristics of a Voltage Regulator and a Parasitic Speed Controller on a 14.3 Kilovolt-Ampere, 1200-Hertz Modified Lundell Alternator. NASA TN D-5925, 1970.

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