G. R. Gunther-Mohr
S. Triebwasser

Simple Constant-Temperature Oven and Control System

Abstract: A number of laboratory measurements require a constant and uniform ambient temperature. A thermocouple-monitored system consisting of an oven, a stable reference source and a chopper-amplifier controller unit has been developed. This system provides a stable and uniform temperature, ±0.1°C from 200° to 1050°C in a cylindrical region 5 cm in diameter and 12 cm long. Each of the parts of the system is discussed and their operation as an integrated whole considered.

Introduction

An ideal oven from the point of view of temperature control is one in which the controlling thermostat can immediately act to correct any deviation of heat input or loss from the values required to maintain a predetermined temperature. In practice this ideal is most closely approached with a thermostat which has a small dead space and a small heat capacity and which is in very close thermal contact with the heated region. An oven constructed in principle like an oven for a frequency-standard crystal[1] meets these requirements by completely surrounding the experimental space with a stable region of small thermal inertia whose temperature can easily be controlled. This region is thermally lagged from the rest of the oven to enable it to make small temperature excursions independently of the rest of the system. Since the thermostat is usually localized, this region must respond over its whole extent equally and in phase with changes of power.

Description of the oven

The oven shown diagrammatically in Fig. 3 incorporates the above design principles. The heater region is powered by three independent filamentary heaters of equal resistance so wound as to produce no magnetic field in the experimental space. Fig. 1 depicts the heater assembly partially wired. The end heaters are four times as concentrated as the middle ones to allow compensation of losses without unduly increasing the length of the oven. By proper adjustment of the power to the three independent heating elements, the temperature on the axis of the experimental space can be made uniform

[1] K. J. Clapp, General Radio Experimenter, Vol. XIX, No. 3.

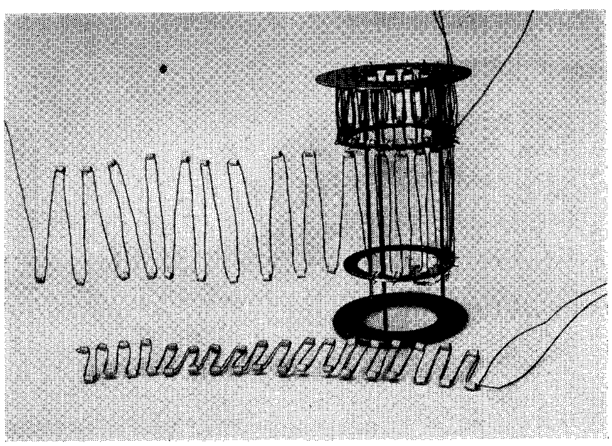


Figure 1
Heater assembly. Construction materials are Kanthal and alundum tubing exclusively.

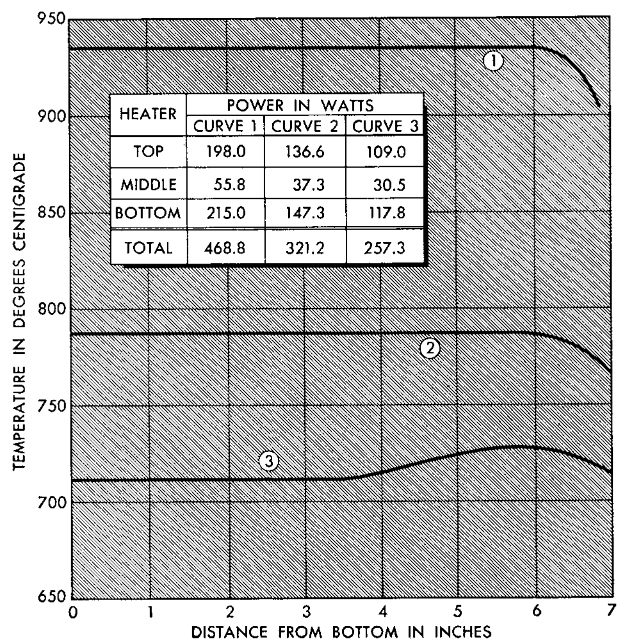


Figure 2
Typical temperature distribution curves and appropriate power data.

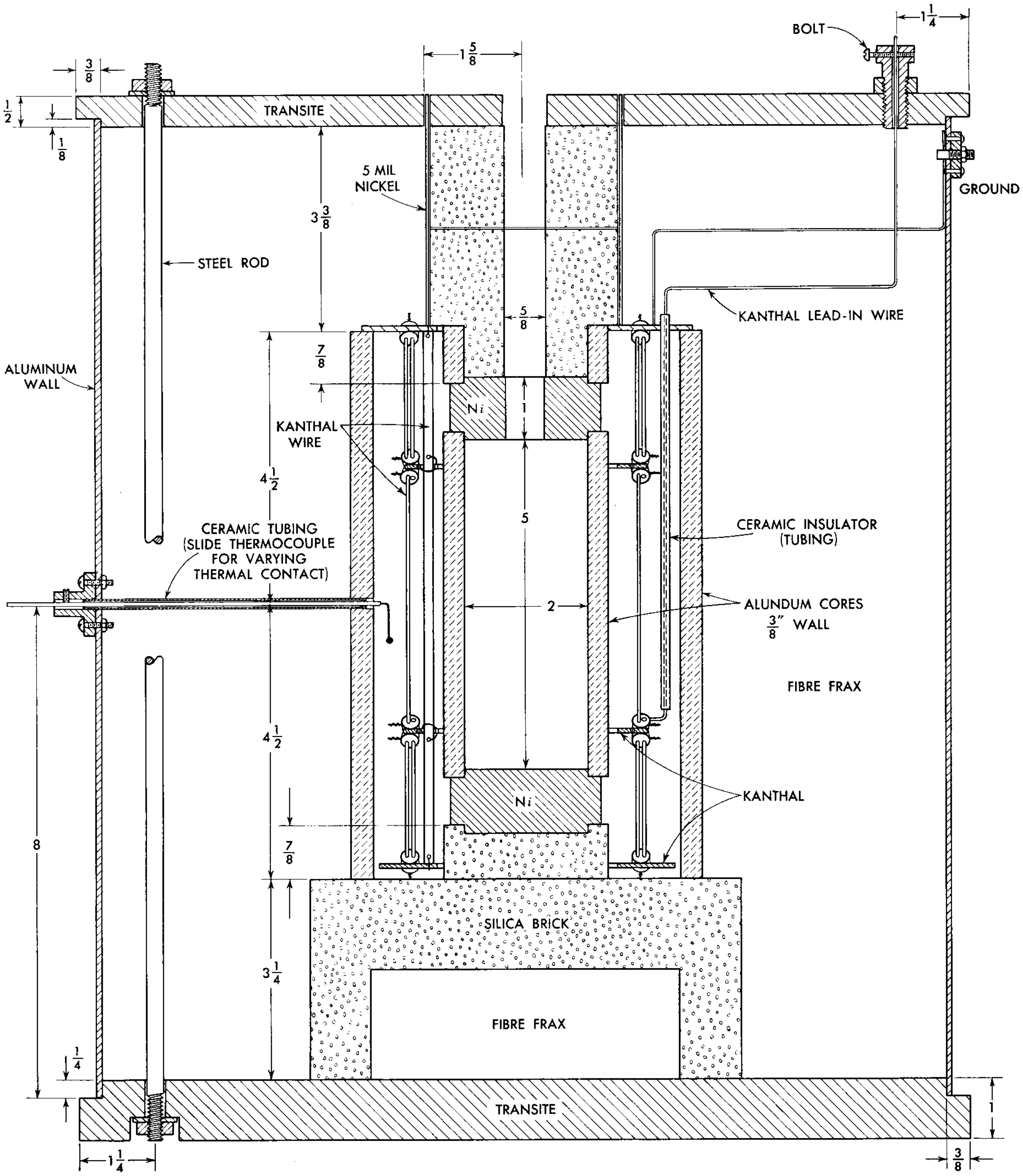


Figure 3
Oven assembly showing principal construction details.

to ±0.1°C or can be adjusted for a uniform variable gradient. Typical temperature distribution curves and power data are shown in Fig. 2. Distribution (3) was chosen to allow rapid heating of a sample to its equilibrium temperature in the oven. The temperature limit of 1050°C is set by the nickel plugs at both ends of the experimental space, though the heater elements are made of "Kanthal A-1" alloy which will stand continuous operation at 1350°C. Replacement of the nickel with Kanthal A-1 would raise the operating limit to 1350°C. The simple construction used allows the lagging core between the heater space and the experimental space to be removed together with the plugs without disassembling the oven.

The thermocouples are spaced equally around the circumference of the heater region in a close and adjustable thermal contact with it. Variations of temperature (±0.2°C) in the heater region with a period of a few seconds in on-off control are filtered out of the experimental space by the lagging provided. Until now the

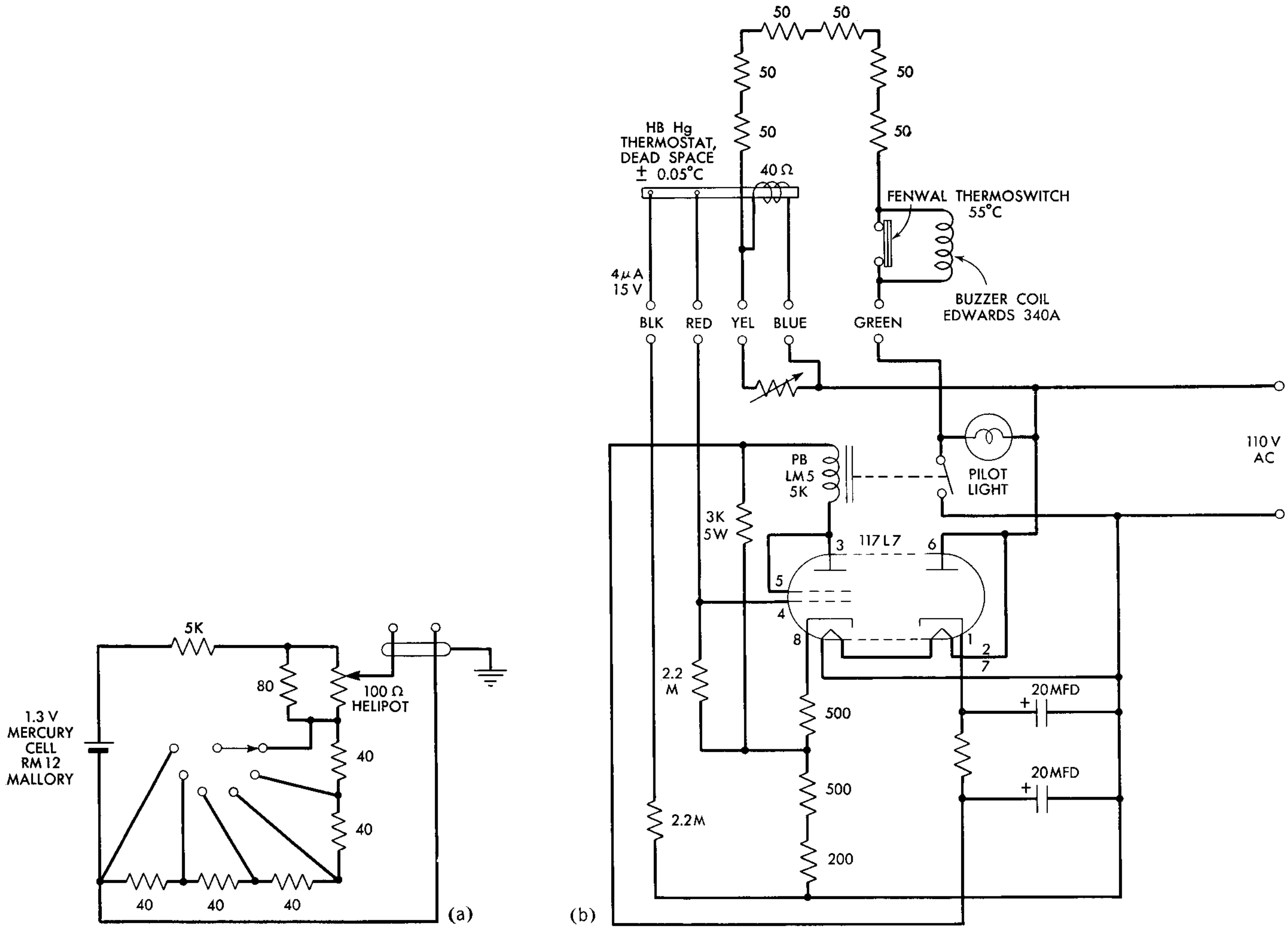


Figure 4
Reference voltage source (a) and reference oven control circuit (b).

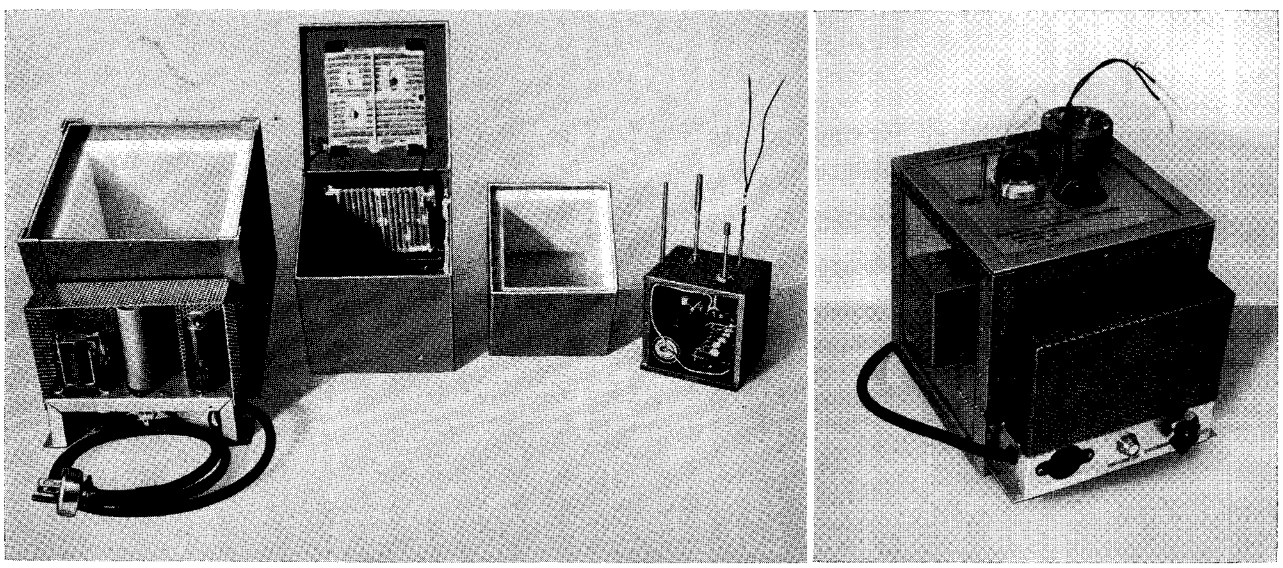


Figure 5 (a) (b)
Reference oven constructional details.

adjustable thermal contact has not been used since it did not prove necessary for the control limits desired. Adjustments of this type as well as easily visualized simple improvements would help cut down the overshoot now present.

In order to achieve long-term stability of temperature control with a thermocouple as temperature measuring element, it is necessary to provide a stable reference temperature for the cold junction and also a stable reference voltage against which to compare the thermocouple emf. To supply those needs, we have enclosed a heavy walled (¼″) copper box containing the circuit of Fig. 4(a) in a crystal oven of standard design[1] while Fig. 4(b) shows the oven-heater control circuit. Figs. 5(a) and 5(b) show the oven disassembled and fully assembled. The copper box, whose long-term temperature stability is ±0.05°C (short-term stability is much better), contains several thermocouple wells into which reference junctions can easily be waxed. The voltage source has an output in the range from 0 to 60 mv in steps of a few microvolts. Its output is not measurably affected by small variations of the oven control temperature but does show a steady linear decrease with time at the rate of less than 5 parts in 10^5 per day. If necessary this decrease can be compensated for. The temperature control system is wired together on a one-inch thick copper block mounted above the reference source as shown in Figs. 5(b) and 6.

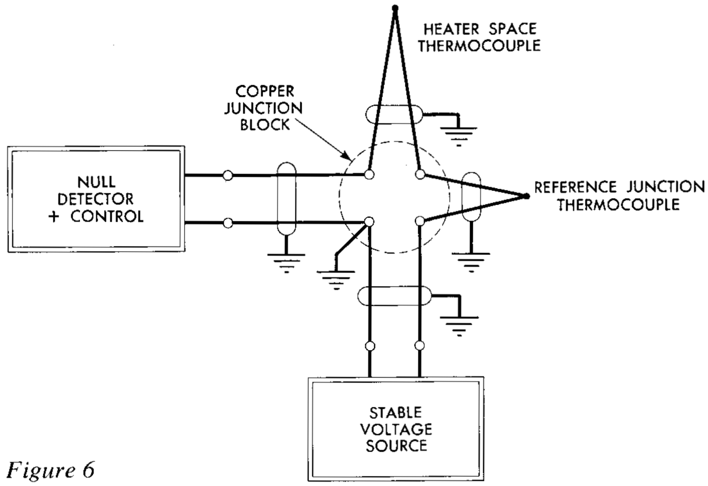


Figure 6
Control system schematic wiring diagram.

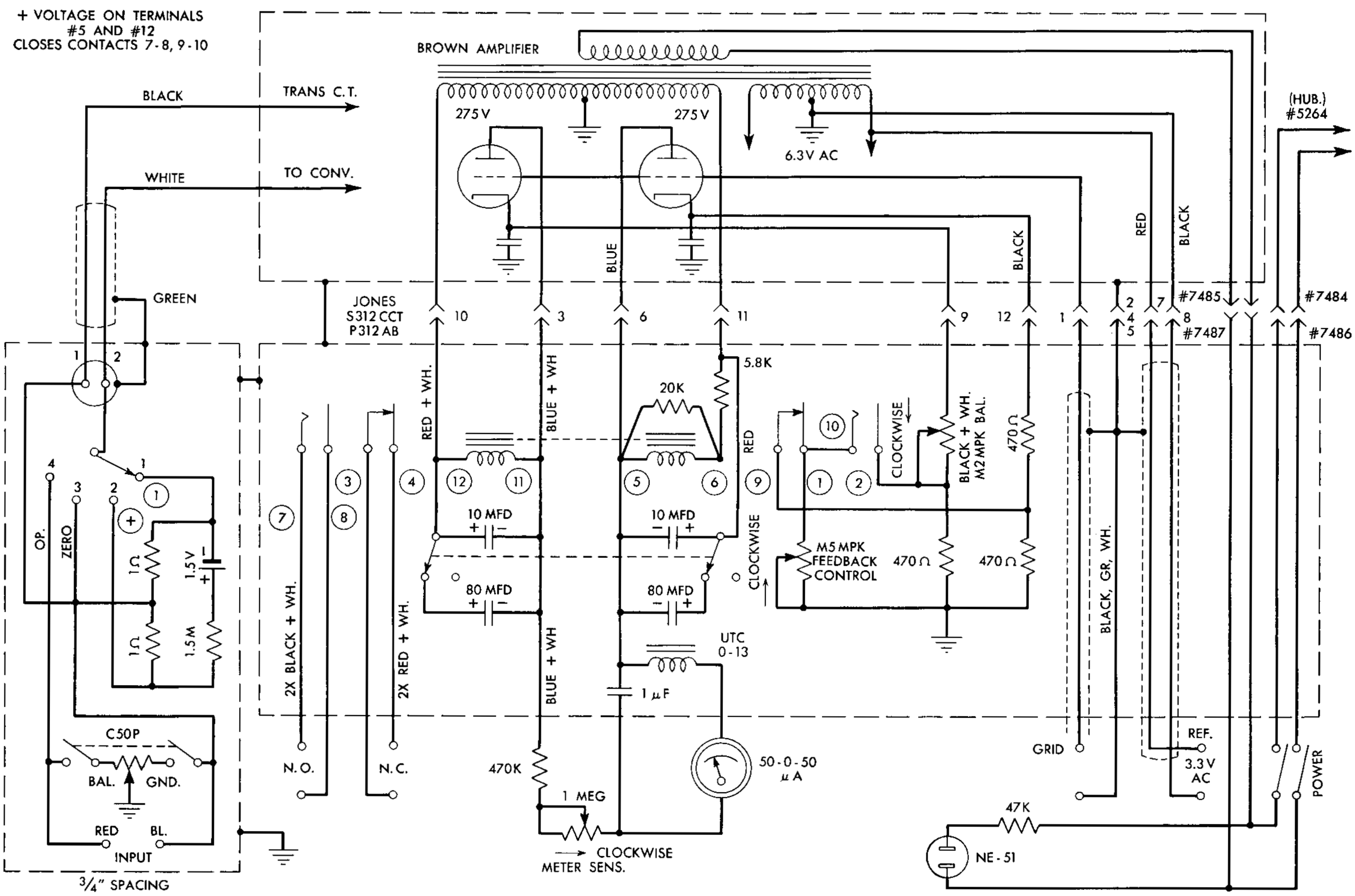


Figure 7
Chopper amplifier null indicator and control unit.

The null indicator and control unit of Fig. 7 is a fairly versatile instrument for the type of work described in this report. We have incorporated a calibrating system on the input to the converter so that we can quickly check the sensitivity of the instrument. This is useful if the metering feature is to be used. As a null indicator the instrument is similar in characteristics to the Brown Elec-tronik Null Indicator, but with a sensitivity ~0.05 μv/div, as compared with the commercial device's 1.0 μv/div.

The basic element of the controller is a Brown Instrument Co. #3566410 chopper amplifier whose circuit diagram appears in Fig. 7. The two triodes shown actually each consist of ½ tubes V_3 and V_4 in parallel (12AU7's). A Sigma 6HY2A2B-91067 differential relay effectively senses the sign of the unbalance voltage at the input to the converter. Contacts (7, 8) and/or (3, 4) are used for the control function. For low power requirements the Sigma relay may control the load current directly. We found the circuit of Fig. 8 convenient for control from many points of view. In this operation the controller throws relay (1) of this figure. The network in the cathode circuit including contacts (1, 9) and (2, 10) provides feedback which enables us to reduce the "dead space" (the region between "just release" and "just operate") to zero. This function is very important for slow furnaces to decrease the overshoot. In this case, the degree of long-term control depends only on the stability of the zero of the amplifier and the stability of the thermocouples, reference junction and reference emf. The controller with the feedback circuit activated is stable to 0.1 μv at the input.

For proportional control application the coils of the differential relay can be replaced by 25K resistors. Then the voltage that drives the meter can be fed to the grids of pass tubes. Used in conjunction with two Chatham 6336 tubes the system described has an overall transconductance of 5 x 10^4 mho, or 1 μv change in input produces 0.05 amp change in load current. In this case, only one-half the available gain was used since the grid voltage was taken as the output of one of the plates rather than as the difference between them. Full gain can be utilized if care is taken with the placement of ground points.

Operation

With the furnace set at 1000°C, more or less typical behavior of the system is as follows:

1. The average power to the furnace is about 600 watts.

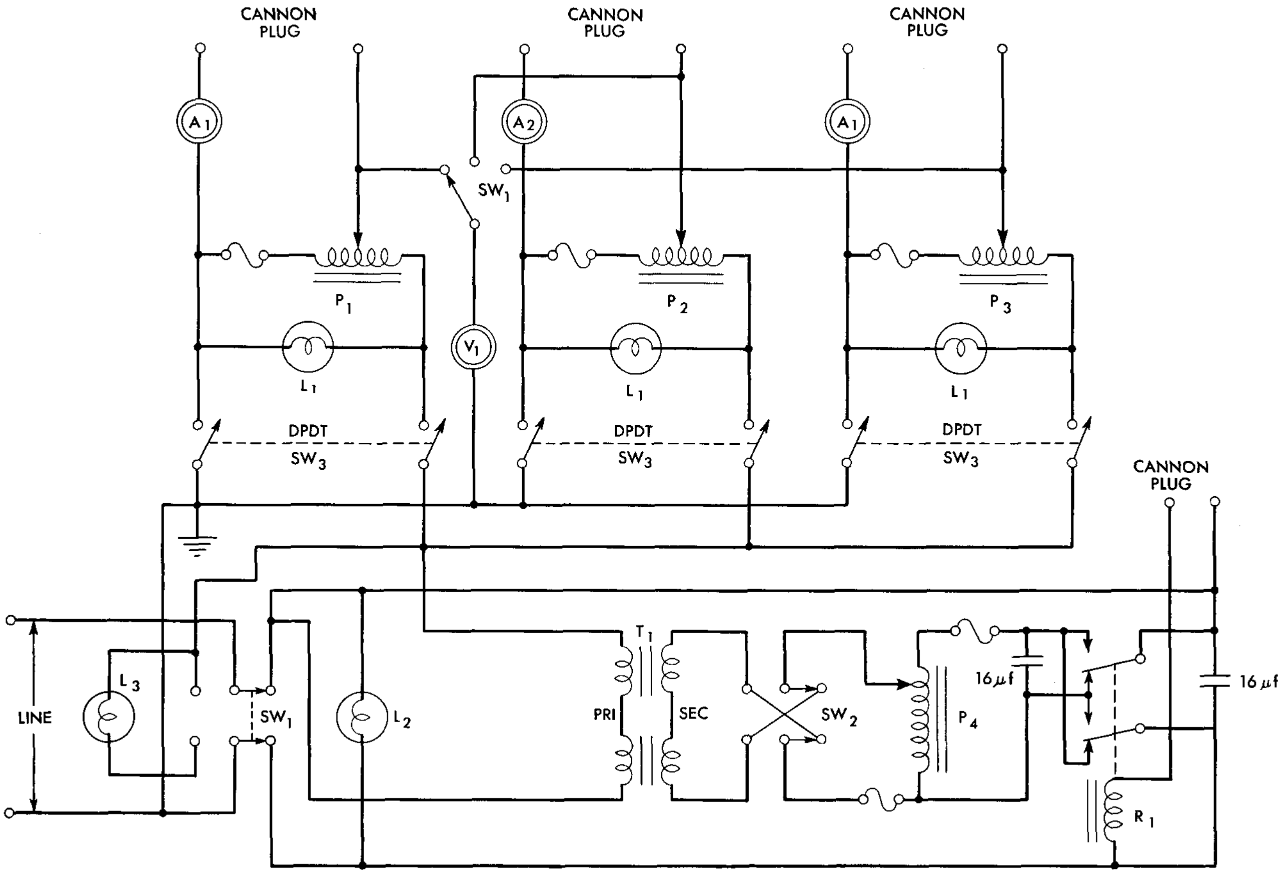


Figure 8

Oven power supply and control unit. SW_1 selects line voltage or controlled line voltage. SW_2 selects phase. T_1 is a suitable 110-volt filament transformer.

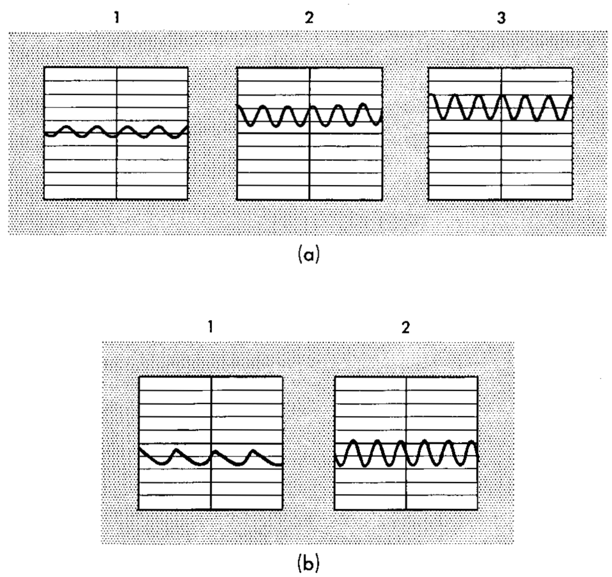
2. With the controller operating at 10% over and under power the control cycle takes 6 seconds. The control thermocouples swing above and below the control point about 6μv ($\sim$0.15°C for a chromel-alumel thermocouple).

3. The temperature of the experimental space shows no measurable short-term fluctuation.

4. The long-term stability is as good as the long-term absolute accuracy of a type K_2 potentiometer. With the system running over a three week period, the emf of a Pt, Pt 10% Rh thermocouple never differed by so much as 2μv between any two readings, when taken against a well-stirred ice bath as reference.

For the mode of operation described above, heating and cooling rates are equal at about 0.2°C/sec. Since over and under powers are $\sim$60 watts, this means the effective heat capacity of the furnace is 300 joules/°C of which 55 joules/°C are in the heater wires themselves.

Fig. 9 shows a series of curves of temperature versus time for various values of the under and over voltages. It is obvious that increasing the voltage throw decreases the period but increases the temperature excursions. For very fast cycles the response time is being limited by factors other than the furnace speed. These are the various RC time constants in the control circuit and the rather massive relay that we have used. In none of the cases shown in Fig. 8 was the feedback feature of the controller utilized. For a fast furnace, this features does not add appreciably to the degree of control. However, we have found it to be an extremely desirable addition for a furnace in which there is so much thermal lagging that the response time is long compared with controller speed.



		(a)			(b)	
		1	*2*	*3*	*1*	*2*
Over Voltage		5	15	25	5	20
Under Voltage		5	15	25	15	30
Time	On	0.059	0.044	0.038	0.102	0.046
(min.)	Off	0.049	0.043	0.043	0.026	0.036

Figure 9

Temperature cycling of heater space with various power conditions (ordinate ¼°C per division).

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