Heater Control for Nonisothermal Temperature Studies

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A simply constructed device for the control of water baths used for nonisothermal studies may be constructed of materials common to most laboratories. The temperature programs are prepared from graph paper and sheet metal; they can be made in 10–30 min. to produce any desired temperature program within the span available to a water bath. The device was tested on three simple temperature functions.

THE EARLY stages of a scientific project are often blocked by quite mundane problems. Although a particular exotic device may be commercially available, the experimentor must weigh carefully the possibilities for using the device in other work and the cost against the likelihood that the proposed project may never develop. In such a situation, a makeshift article, although not perhaps so refined or accurate as one might desire, may often suit the initial studies and permit the necessary background to be obtained, so that the decision for or against purchase can be made intelligently.

The present authors were faced recently with such a problem entailing the generation of several rather exotic temperature-time functions and found that the cost of the commercial device to perform such an operation all but precluded its purchase for the intended project. The result of deliberation was the device described here. It is capable of producing any desired temperature function using calculated templates prepared from polar graph paper and thin metal; and it is able to reproduce the desired function to ±0.3-1° using only routine care in template cutting; and it is sufficiently sturdy and reliable (despite its simplicity) to permit routine daily use.

A semidiagrammatic drawing of the finished device is shown in Fig. 1. It consists of five parts: the variable-speed drive motor, controller, and gears; the function cam; the cam follower; the thermoregulator; and the bath and regulator relay.

Motor and Controller.—The motor used was a shunt wound, direct current motor[1] with a built-in two-stage gear step-down giving a speed range of 0:111 r.p.m. The slow speed shaft was directly coupled to an 800:1 speed reducer, producing a final speed range of 0–8 1/3 r.p.h. While the speed controller supplied with the instrument could have been used, it was more desirable to replace the infinitely variable control with several finite calculated steps. For this reason, the manufacturer's original control design was modified to that shown in Fig. 2. With the resistor values shown, four speeds are available—one fast for moving the cam to any position to begin a run (0.3 r.p.m.) and three other slower ones, two fixed (0.2 and 0.25 r.p.h.) and one slightly variable.

Mercury Thermoregulator.—It seemed that a mercury thermoregulator was the most practical. It is inexpensive; its volume change with temperature is very nearly linear; and it could be made to respond quickly to temperature changes. The regulator was designed to have an adjustable mercury content (zero point) and a high surface-to-volume ratio to speed its response. The longest convenient capillary length was 5 in., and all calculations were based on this length and an anticipated total temperature change of 50°, although it can be seen that these are not limitations of the system described. The thermoregulator capillary was made from a length of uniform bore 1-mm. glass tubing sealed to a 7-mm. o.d. coil. The total volume of the coil and capillary was made to be close to 12 ml. and closed with a 2-mm. stopcock at the other end.[2] The stopcock connects the regulator bulb with a reservoir above it; the reservoir has a small hole at the side and a rubber bulb at the top. The exact dimensions and the

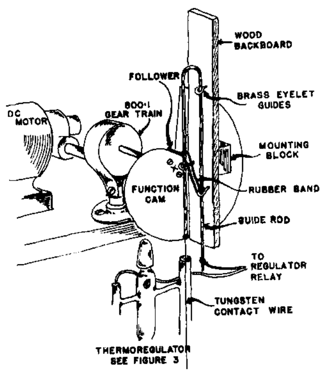

Fig. 1.—Diagram of the complete control assembly showing the arrangement of the parts.

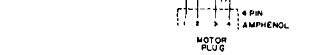

Fig. 2.—Circuit for the motor controller, modified from the 2T60 controller (G. K. Heller Co.). All resistances are in ohms and capacitances in microfarads.

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[1] Model 2T60-36, the G. Heller Co., Las Vegas, Nev.

[2] The sensitivity of the thermoregulator is a function of its volume and its capillary radius, according to the formula

$$\frac{dH}{dT} = \frac{1}{\pi r^2}(\alpha V_0 + 2\beta V_0 T + \ldots)$$

or

$$\frac{dH}{dT} = \frac{\alpha V_0}{\pi r^2}$$

if one may assume the value of β to be small enough to ignore all second-order terms, *i. e.*, the volume of mercury changes linearly with temperature. If a maximum capillary length of L cm. is to be used with a bore of r cm. over a temperature span of $\Delta T°$, the volume of mercury in the reservoir at $T_0(V_0)$ must be $V_0 = (\pi r^2 \Delta H)/(\alpha \Delta T)$.

design of the regulator are shown in Fig. 3. The total quantity of mercury in the regulator is adjusted, after allowing it to come to equilibrium in the water bath at the starting temperature, by opening the stopcock with a finger over the side hole and either forcing mercury in or removing it with the rubber bulb. When the desired level of mercury has been obtained, the stopcock then is closed. An exact adjustment to the starting temperature is made then by running the cam drive until the regulator operates.

Function Cam.—The cam is made of thin sheet metal, such as galvanized iron or aluminum, cut slightly oversized, then filed to the exact shape. The shape is calculated as height as a function of time over the time for one revolution produced by the motor and gears used (about 4 hr. here) and plotted on polar graph paper (similar to K and E No. 46-4410). Then this sheet is glued over the exact center of the cam mounting holes. The cam may be cut just outside of this line with shears and filed to the exact shape desired. The cam may be calculated and cut either to lift or to lower the cam follower, but the lifting method was chosen here so that if the drive motor was inadvertently left on when the peak temperature was reached, the follower simply drops, stopping the heating without damage. A cam set to lower will jam it against the bottom in the same situation. The exact shape of the lifting cam is calculated easily for any function desired.[3]

Cam Contact Arm.—The contact arm and guide was made of 1/16 in. stiff iron wire, brass eyelet hangers, a 3/8 × 1 in. clear pine board, and a rubber band and was assembled as shown in Fig. 1. The wire that contacted the mercury was made of 6 in. of fine tungsten wire, brazed to the end of the iron guide wire. The rubber band was used to insure that the follower maintained contact with the cam at all times. To avoid sticking and slipping, the follower arm, cam, and guide rod were lubricated with stopcock grease.

[3] The equations used for cutting the cams, for a few simple heating functions are

for the function $T = T_0 + bt$ (linear heating):

$$H = \left(\frac{\alpha V_0 b}{\pi r^2}\right) t$$

for the function $T = T_b - T_0 e^{-zt}$ (log heating):

$$H = \left(\frac{\alpha V_0}{\pi r^2}\right) (\Delta T_0 e^{-zt})$$

or

$$\log H = \log \left(\frac{\alpha V_0 \Delta T_0}{\pi r^2}\right) - \frac{z}{2.3} t$$

for the function $\frac{1}{T} = \frac{1}{T_0} - ht$ (reciprocal heating):

$$H = \frac{\alpha V_0 h T_0^2 t}{\pi r^2 (1 - hT_0 t)}$$

or

$$\frac{1}{H} = \frac{\pi r^2}{\alpha V_0 h T_0^2} \left(\frac{1}{t}\right) - \frac{\pi r^2}{\alpha V_0 T_0}$$

where H is the height of the mercury and thus the cam follower as a function of time t; α is the coefficient of cubical expansion for mercury; V_0, the initial mercury volume; b, z, and h, the heating rate constants for linear, logarithmic, and reciprocal heating, respectively; r the radius of the regulator capillary; and T_0 and T_b the initial and reservoir temperature, respectively.

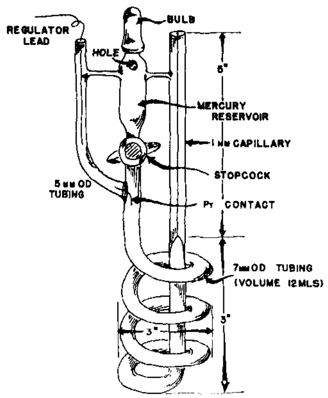

Fig. 3.—The mercury-in-glass adjustable zero thermoregulator for use with the heater controller.

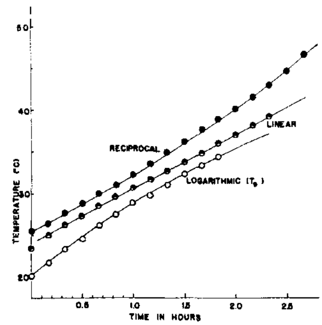

Fig. 4.—Graphs of the temperature-time relationships obtained with the three function cams described in the text. Key: ◒, linear; ○, logarithmic; ●, reciprocal.

Results with the Completed Device.—The complete unit, as described and used with cams cut for the three functions mentioned (See *Footnote 3*), was used to control a relay operated water bath.[4] Sample results of three such tests are shown in Fig. 4.

The points on the graphs were taken from a potentiometric recorder tracing made using a copper-constantan thermocouple having crushed ice as its reference temperature. The solid curves in the figure were drawn from the theoretical relationship. (See *Footnote 3.*)

Over those narrow temperature ranges (<50°) the accuracy of the drive and thus the regulation is about ±1/2°.

The authors have no doubt that with more sophistication and care, particularly in the preparation of the cam, this device should be capable of more accurate results—all this at the expense of the simplicity of the device as shown in this report. As built and described, the controller operates easily and reproducibly, and the cams are quickly (about 20 min.) and easily made to fit any temperature function desired. The speed range selected for the motor permits one complete temperature cycle experiment to be completed in 1 day with time for any ancillary experimental work that might be required.

[4] The water bath and controller used in the test study was an Aminco model 4-1544 complete system, but with the mercury thermoregulator replaced by the device described in this paper.