A FURNACE TEMPERATURE REGULATOR.

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SYNOPSIS.—By making the heating coil of an electric furnace one arm of a wheatstone bridge, and combining this with a galvanometer regulator, thus keeping constant the resistance of the coil, we can, regardless of variations in the current supply, and with no attention, maintain constant the temperature of furnaces not too directly influenced by the temperature of the room, or where the surrounding air is kept constant. The power available in this regulator is relatively very great indeed; nothing has to be inserted within the furnace cavity, and the lag is practically nothing; the regulator is often almost at its best under conditions most unfavorable to other regulators. It has held a small furnace constant to 0.1° for hours at temperatures from 500° to 1400°.

THIS paper describes a temperature regulator for electric furnaces, which has extraordinary sensitiveness and is effective under extreme conditions.

We had already succeeded in automatically regulating to about 5° at 1400° by letting a thermocouple recorder make electric contacts which actuated a polarized relay controlling a larger magnet which controlled the current. But we wished to regulate to about 0.1°, or 50 times as close, and at the same time to change the heating current by 10 per cent., in order to minimize the amount of attention required from the observer. This change in the heating current was found to change the furnace temperature so rapidly that to prevent fluctuations of 0.1° an adjustment nearly once a second was needed. Since the sensitiveness of a galvanometer falls off rapidly as the period is shortened, this combination of sensitiveness and speed required hundreds of times the energy that could be obtained from a platinum thermocouple.

This energy was obtained by drawing on the heating current of the furnace. The platinum furnace coil was made one arm of a wheatstone bridge, Fig. 1, so that the regulation was really by a resistance thermometer with a current of from 12 to 18 amperes. This method of regulating by controlling the coil temperature has, besides the great supply of energy, two other advantages. It avoids all necessity of introducing appliances into the furnace cavity, and it eliminates entirely the lag between heater and regulator, since the two are now identical.[1]

[1] Any device employing a wheatstone bridge has also the advantage of being more easily made to use the galvanometer as a null instrument—a thing necessary in work of high precision.

It has one important disadvantage; the temperature of the furnace is nearly always somewhat influenced by that of the room, so it may vary slightly, even when the coil temperature is maintained constant.

These peculiarities determine the most favorable conditions for this type of regulator. For furnaces whose small cavities render undesirable the introduction into them of any apparatus; for those whose small mass causes a quick response to current changes, and so calls for absence of lag, and for quickness, that is, sensitiveness, in the regulator, this type may have superior advantages. These conditions are more apt to occur in work at relatively high temperatures, and such temperatures also impair the efficiency of this regulator less than that of some others. Where the furnace is more capacious, or more massive, and hence adapted to more sluggish regulation, there is less need for the present regulator, and if the ends of the furnace contribute a considerable portion of its surface other regulators may even be more satisfactory.

Adjustments or tests of these regulators are very tedious if the furnace is large, and doubly so, of course, if the room temperature requires exact manipulation for the test. The approximate value of the effect of room temperature on one furnace was rather rapidly determined, as follows: First the constant rate, V, at which the furnace cooled with heating shut off, was observed, as well as φ, the thermal head, or temperature difference causing heat flow; that is, the difference between furnace and room. Then by Newton's Law of Cooling, we have $K_1 = V/\varphi$, where K_1 is the thermal leakage modulus of the furnace to the room. Second, the way was observed in which the furnace temperature changed when, after this had become constant, the coil was suddenly brought to a different temperature and held there. Then K_2, the modulus of the coil to the furnace, is obtained by applying the formula

$$\theta = \theta_z + (\theta_0 - \theta_z)e^{-K_2 t},$$

where θ is furnace temperature; and θ_0 and θ_z are its initial and final values, with θ_z also the second value of the coil temperature. If we then put θ_1, θ_2, θ_3, for the temperatures of coil, furnace, and room respectively, it is clear that the furnace in equilibrium will reach a temperature such that the heat coming to it from the coil equals that which it loses to the air, or that

$$K_2(\theta_1 - \theta_2) = K_1(\theta_2 - \theta_3);$$

that is

$$\theta_2 = \frac{K_1\theta_3 + K_2\theta_1}{K_1 + K_2},$$

so, as may be seen by simple differentiation, a given change in the room (θ_3) produces $K_1/(K_1 + K_2)$ times as much change in the furnace (θ_2).

This calculation gives too high results, since when the furnace is heated no heat escapes from it by way of the heating wire, while it does so escape during the determination of K_1. It is evident that if the heating coil is, instead of a wire, a flat strip of metal practically covering all the surface of the furnace, there would be almost no effect from the room. By combining with the heater wire a wire of copper or nickel exposed to the air a large amount of compensation can be obtained for the room effect. If the room is cooler the exposed wire is cooler; in order to make the combined resistance the same the heater wire must run warmer than usual; and thus it overcomes the cooling effect of the room. The difficulty with such an arrangement is, first, the time required to adjust for correct compensation, and second, the effect of lag, which tends to throw the balance out, except for slow changes.

In the furnace which we tested for K_1 and K_2 the indications were satisfactory, but the end effects, which were complicated by separately controlled coils, proved to be a disturbing factor. In our high temperature platinum-wound furnace, where the ends were small, and the coil adhered closely to the chamber wall, no effect from the room temperature was ever noticed, and the furnace, after once reaching equilibrium, usually held to 0.1° for several hours, even at 1400°. The room, however, seldom varied over 5°.

Since an account of this regulator was first presented in public, by Mr. Adams (at the Washington meeting of the Physical Society, April, 1913) several experimenters have used the principle of a heater-thermometer-regulator in oil baths. This is an appropriate use for it, for if the wire is in contact with the oil K_2 is very large, and the room temperature disturbance is therefore small, especially if K_1 can be kept small by covering the top.

As Fig. 1 indicates, some mechanical arrangement is necessary to cause the current-regulating switches to move according to the changes in the position of the galvanometer boom. This can very readily be accomplished in one of several fairly familiar ways. The easiest, perhaps, is the one suggested in the first paragraph of this paper, namely, having the boom pressed up or down at intervals so as to either strike or miss a contact maker (or either one of a pair) which controls a suitable relay. A light motor-driven mechanism pressing the boom every second or so is then the only special machinery required. The Leeds and Northrup Co. furnish a stock instrument which operates in this way. They also offer a form in which the switches are moved by the motor, without magnets. This is a little tardy in its action, since the switch setting for a given pressing of the boom is not made till the next pressing occurs.

But if one of the ratcheting rheostats now available is used, the single step can be made smaller and the period does not need to be so short. If we had planned to use such a rheostat our own time requirement would not have been so exacting as it was. Our own mechanical arrangement[1] utilizes the power and certainty of the motor to operate the switch, but gives nearly the promptness of a magnet, so that a single switch is enough

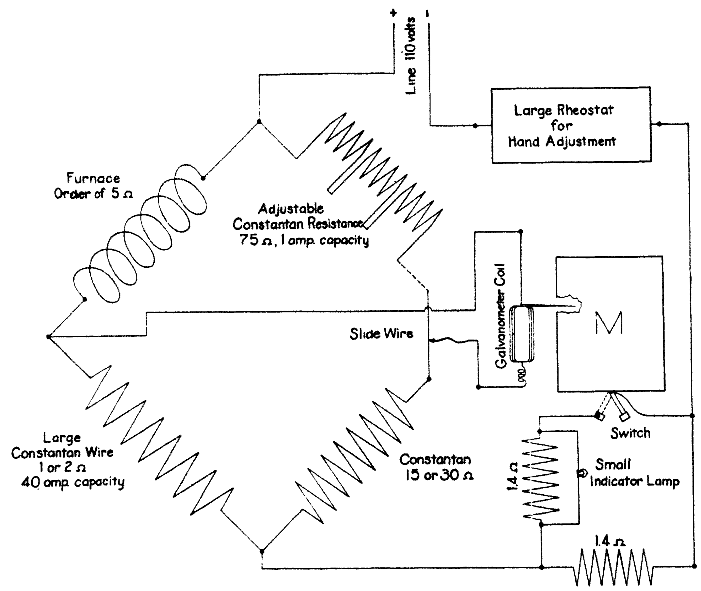

Fig. 1.

for the regulation. The change in switch setting due to one pressing of the boom produces a large effect on the galvanometer before the next pressing occurs. This instrument is not represented because Mr. Shaw now thinks he could get as great efficiency with a simpler design, and no such design has been completely worked out.

Our galvanometer coil was an old wooden-spooled affair, of the type much used in the nineties, provided with a more modern magnet. With a 1-second period, auxiliary oil damping was needed. The boom was 5 cm. long, and a shift of 0.1 mm. at its end was enough to cause a change of the switch setting. This shift was produced by 24 microvolts across terminals. For 14 amperes (about the average current) 24 microvolts corresponded to a change of 0.004°, so the possibilities of the arrangement in the way of sensitiveness are, as was to be expected, in excess of any conceivable requirement. Indeed, it is clear that since the

[1] Designed by Mr. C. M. Shaw, Master Mechanic of the Laboratory.

sensitiveness of an underdamped galvanometer varies as the square of the period, for a period of 3 seconds or more this galvanometer would adjust to 0.1° with a silver-constantan couple (5 microvolts per 0.1°), or with a smaller resistance thermometer. This is, however, an arrangement for lower temperatures and larger furnaces, and is one which abandons the special feature which this paper is written to describe.

Since this special feature, namely, operation by means of the furnace coil itself, calls for resistance variation with temperature, it is not so well adapted to nichrome coils, whose temperature coefficient is very small. Nevertheless, our own arrangement is apparently sensitive enough to work with them, especially where the period can be lengthened a little. We actually used, at 500°, a nickel manganese alloy of high coefficient, but do not feel justified in recommending it as satisfactorily free from liability to injury by oxidation, even at that temperature. Satisfactory alloys may be known, however, whose temperature coefficient is higher than that of ordinary nichrome, and there seems to be no doubt that such can be made. The loss of power in the other three arms of the wheatstone bridge can generally be made negligible if the galvanometer sensitiveness is comparable to ours. The device, in its present form, evidently is not applicable to alternating currents.

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