COILED FILAMENT RESISTANCE THERMOMETERS

By C. H. Meyers

ABSTRACT

Platinum resistance thermometers with strain free windings which are smaller than those previously used are described, and the method of construction is given. By double helical winding the coil of a 25 ohm thermometer is reduced to about 5 mm diameter and 2 cm length, and the outside diameter of the thermometer is about the same as that of the ordinary mercury-in-glass thermometer. These thermometers are hermetically sealed, and thermometric lag is reduced by filling them with helium.

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I. INTRODUCTION

In a previous paper, T. S. Sligh [1] has discussed the properties of platinum resistance thermometers in general, explained the method used for calculating temperatures, and described the construction of resistance thermometers ordinarily used at this bureau.

Strain-free thermometers with smaller dimensions have sometimes been found desirable for use in special apparatus, and to fill this need several such thermometers have been constructed. When these thermometers are mounted in a glass tube the over-all diameter is about 7 mm, or about the size of an ordinary mercury-in-glass thermometer. Since the length of the coil is only about 2 cm this design of resistance thermometer is suitable for any location where a mercury thermometer may be used.

A detailed description of this special design of thermometer coil and its construction will be given as well as a description of modifications in the design of leads and thermometer head.

II. THERMOMETER COIL

The design of the thermometer coil is illustrated in Figure 1, which is a photograph of a model built for illustrative purposes. In Figure 1, (*A*) shows this model mounted on the quartered mandrel upon which it was wound, and (*B*) shows the coil removed from the mandrel. The size of the actual thermometer coil is illustrated by the scale drawn in (*A*).

In the construction of the thermometer coil, the platinum winding was mounted upon a mica cross of the type mentioned in Sligh's

[1] B. S. Sci. Papers, vol. 17 (S407), p. 49, 1922.

paper. The various steps in the construction of this cross and the coil are given in Figure 2. The dimensions given are those actually used and are given in millimeters unless otherwise stated in the figure.

Mica was cut into strips by clamping the part to be used under a bar of the proper width and trimming away the portions extending on each side by a repeated back and forth motion of a sharp-edged steel tool. As mentioned in the paper already referred to, a thin safety-razor blade forms a convenient source of material for such a

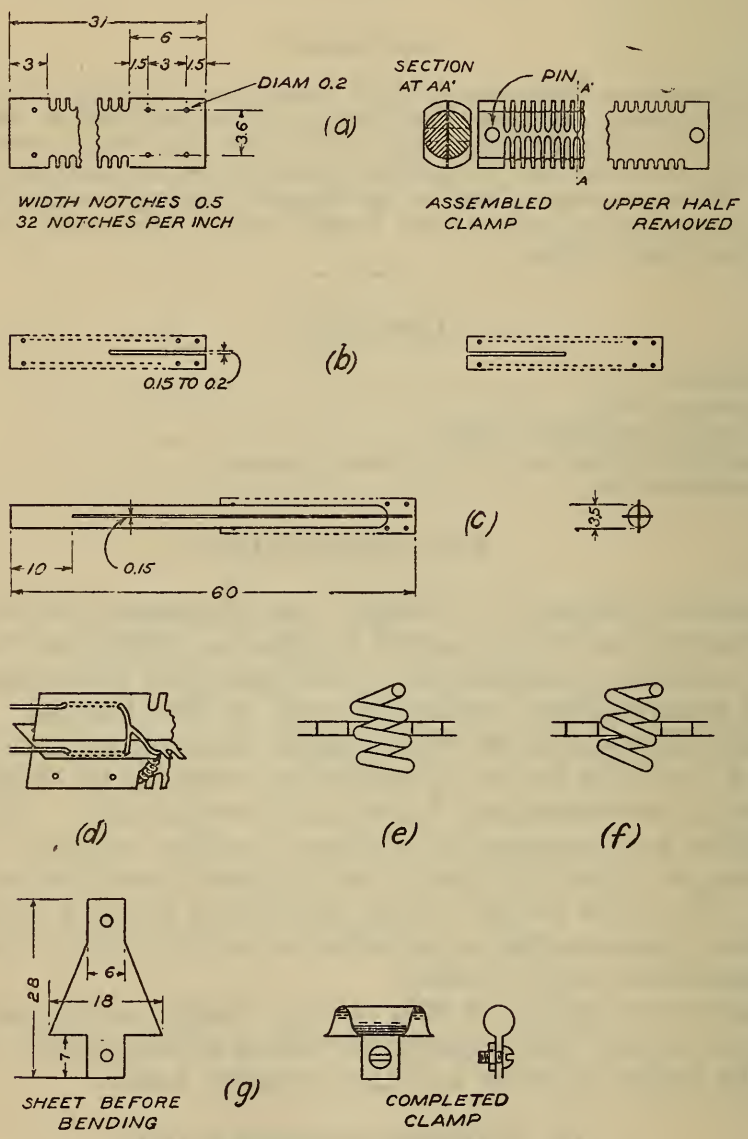

FIGURE 2.—*Construction of thermometer coil*

tool. The mica strip may be split to the desired thickness (about 0.1 mm), or teeth may cut in the strip before splitting. For cutting the teeth the mica was placed in a toothed clamp, such as shown to the right in Figure 2 (*a*), the halves of which were kept in alignment by pins. This clamp was gripped between vise jaws. Teeth were cut in the mica with a special saw consisting of 0.5 mm steel wire mounted upon a light jeweler's hack-saw frame. The saw cut equally well when the wire was charged with carborundum by rolling between two plates of glass or when the wire was merely roughened by rub-

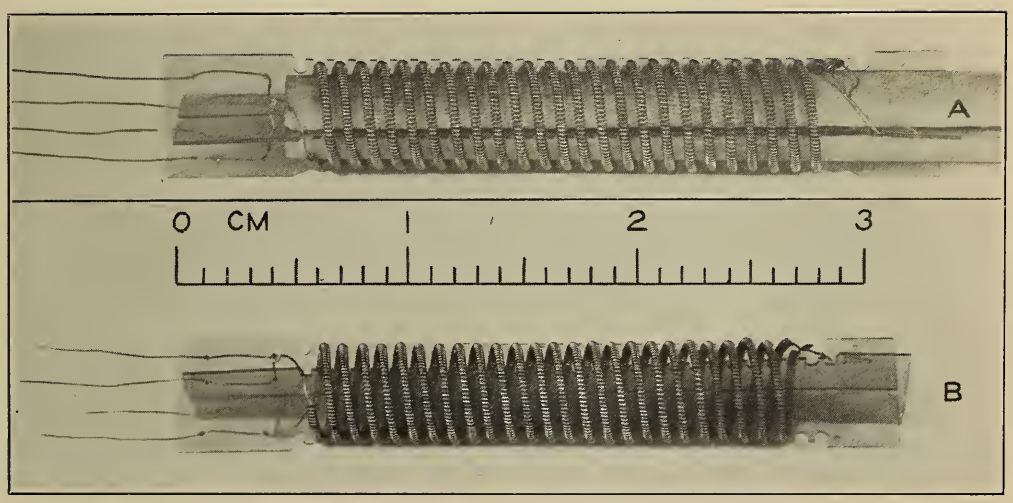

FIGURE 1.—*Large model of thermometer coil*

A, Mounted upon mandrel; B, removed from mandrel.

bing transversely with a carborundum stone. This saw produced a smooth-edged notch with parallel sides and a rounded bottom. Both steel piano wire and nickel wire have been used successfully in cutting notches from 0.1 to 0.5 mm wide. Copper wire was not found as satisfactory on account of excessive stretching of the wire. After the mica had been notched it was removed from the clamp, and the six holes shown in Figure 2 (*b*) were drilled. Piano wire was ground to form a flat drill for this purpose. The slots shown were cut and the slotted pieces of mica were pushed together to form a cross in which the teeth were arranged to accommodate a bifilar winding of uniform pitch. This cross was inserted in the quartered steel mandrel illustrated in Figure 2 (*c*).

Platinum wire nominally 0.1 mm in diameter was used in these thermometers, and the length of wire required was 1.8 to 2.4 m, depending upon the actual diameter of the lot of wire used. The requisite amount of wire was cut into two pieces, each of which was wound into a helix with an outer diameter of about 0.45 mm. For this purpose a steel wire (0.23 mm diameter) was used as a mandrel, one end being mounted in a lathe and the other end attached to a ball bearing, an arrangement which permitted fairly uniform rotation of the taut steel wire. When hard-drawn platinum wire was available the following procedure was successful: One end of the wire was attached to the mandrel and the other end to a thread which led over a pulley to a weight of about 30 g. The pulley was placed in such position relative to the lathe that the consecutive turns of the helix were wound in contact; it was far enough from the lathe (about 3 m) so that the angle of winding remained substantially constant. When the winding was completed both ends of the helix were released and one end was kept from rotating while the lathe was rotated in such direction as would tend to unwind the helix until the other end began to slip on the mandrel. The mandrel was then removed from the lathe, its end freed from any roughness which might scratch the platinum wire and the helix pushed off. The helix was then stretched until its length under no tension was approximately doubled, the result being an almost uniform spacing of the wire.

The method just described was not successful for annealed platinum wire. When the use of such wire was necessary, it was either wound along with a spacing wire so that the turns were in contact and the spacing wire later unwound, or the platinum wire was fed from the moving tool carriage of a thread-cutting lathe. For the latter method a lathe with two heads geared together is desirable since the irregularities in the motion of the ball bearing cause irreugular spacing of the wire. After winding, the mandrel was dissolved in hot hydrochloric acid.

Short leads of platinum were welded to form a T on one end of each of the two helices. A small oxy-gas flame was used in the present work, although the arc method described by Sligh might have been used with due precaution to arrange the work so that the electric current would not anneal the helix. It was found that the helices stretched less during winding and that the coil suffered less from accidental distortions if the wire was not annealed until the winding upon the mica cross was completed. Both pairs of leads were then threaded into the mica cross as shown for one pair in Figure 2 (*d*).

The choice of the direction of winding upon the cross was determined by the direction of winding of the helices which had been wound with a left-hand pitch. Figure 2 (*e*) and (*f*) show a magnified view of the edge of the mica with such a helix crossing it. The direction of winding upon the cross corresponding to that at (*e*); that is, a winding with a right-hand pitch was chosen as the one in which two consecutive turns of the helix would be less likely to straddle the mica. The helices were wound upon the cross under the tension caused by a weight of 2 or 3 g attached to each of their free ends. The clamp of thin sheet copper designed as shown in Figure 2 (*g*) for both right and left hand windings, was slipped over the coil to hold the winding in place while the ends of the helices were joined to the platinum tie wire visible in Figure 1, and tied to the mica. After removing the clamp and the quartered mandrel from the coil, the latter was annealed in an electric furnace for two or three hours at 600° to 650° C.

During this annealing the resistance of the 25 ohm thermometers decreased about 0.5 ohm, an amount which had to be allowed for in choosing the initial length of wire.

After the preliminary annealing the resistance of the coil was adjusted by cutting out the proper amount of wire and rewelding, the mandrel and clamp being replaced during the operation. The coil was then again annealed at the same temperature for about five hours.

III. LEADS AND THERMOMETER HEAD

As in the thermometers described by Sligh, mica disks served the double purpose of separating the internal leads and breaking up convection currents in the stem of the thermometer. The mica disks were cut with a punch and die of the type ordinarily used for blanking and perforating sheet metal. An attempt to use Sligh's method of keeping the mica disks normal to the axis of the thermometer by staggering the holes through which the leads were threaded was unsuccessful for the small size of washers used.

Better results were obtained by tapering the wire so that disks with holes which fitted the wire snugly could be used. Although tapering the full length of the leads gave the best appearing result, it was found that with care the mica disks could be slid along the uniform wires without serious enlargement of the holes, and that part or all of the tapered portion could be discarded. Gold wire 0.2 mm diameter was tapered in hot acqua regia by moving the wire up and down thus varying the time of immersion along the length of the wire. The holes in the disks used with these leads were made with drills formed from 0.16-mm steel wire. A pile of the disks was placed in the jig illustrated in Figure 3 (*a*) and four equally spaced holes were drilled. The insertion of a piece of the wire used for drills in one hole before removal of the disks from the jig made it possible to thread the whole pile of disks onto the ends of the leads as a unit. After the requisite number of disks had been threaded on, the leads were put under tension and each disk slid singly into the desired position, the spacing used being about 5 to 10 mm. A short copper wire was silver soldered or welded to one end of each of the gold leads for convenience in later sealing the thermometer head with soft solder, and one of the short platinum leads on the thermometer coils was welded to the other end.

Since some of these thermometers were to be used in an inverted position and would probably come in contact with oil, it was desirable to avoid the use of cement or wax for sealing. The method of bringing the internal leads out through the Pyrex tube is shown in Figure 3 (*b*). Four platinum disks 0.02 or 0.03 mm thick were beveled at the edge

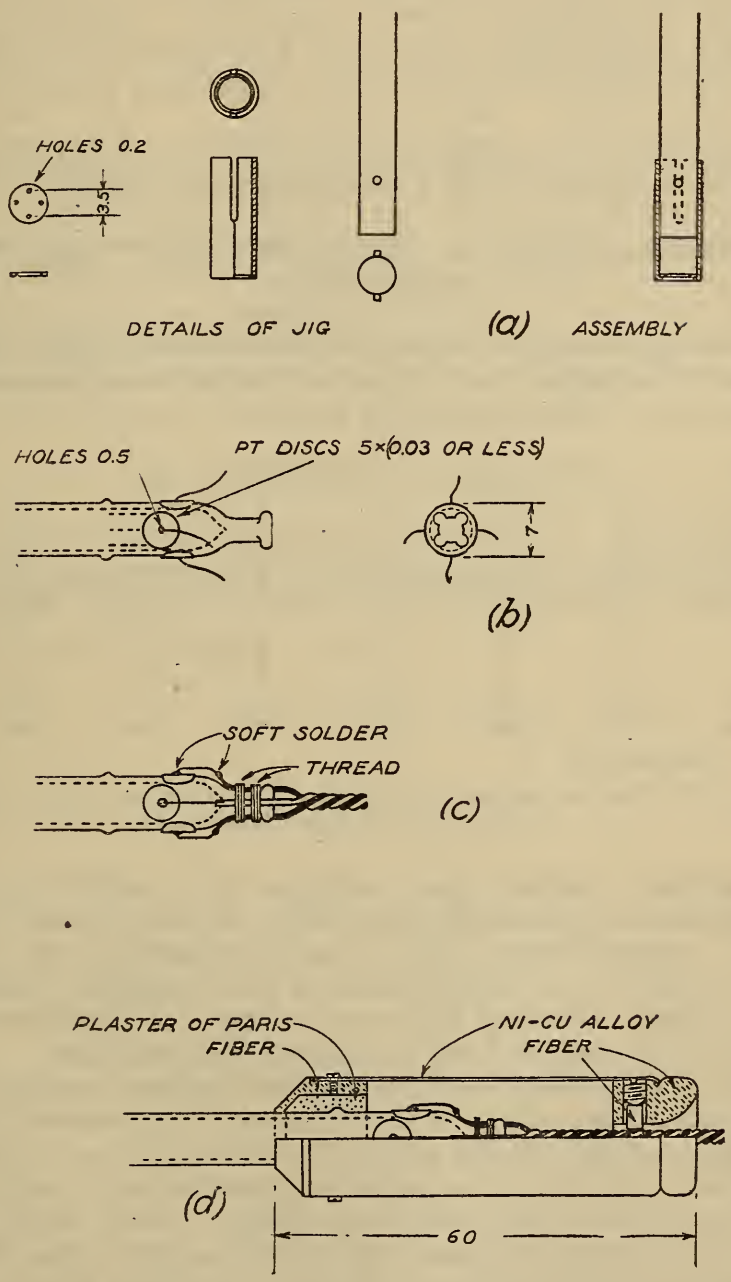

FIGURE 3.—*Construction of leads and head*

by running through rolls and curled to fit the glass tube. These were temporarily held in place by a clamp of nichrome wire and fused to the glass as described by Housekeeper.[2] It was found that the formation of bubbles under the platinum could be minimized by keeping the work far out in the flame. The addition of some oxygen to the air supplied to the torch was also found advantageous for Pyrex. Holes

[2] J. Am. Inst. Elect. Eng., vol. 42, p. 954, 1923.

through the platinum and glass were made at the centers of the disks with a hot tungsten wire. Benton [3] used a hot platinum wire for perforating glass, but tungsten has the advantage of being stiffer and forming an oxide which does not readily stick to the glass.

The short copper wires at the end of the gold leads were threaded through the holes, which were then closed with soft solder. Caution must be used in soldering; a hot iron must not be applied to the cold glass lest the platinum be loosened. The external leads were then attached as in Figure 3 (*c*). The assembled head is shown in Figure 3 (*d*).

The thermometers were filled through the bulb end with dry helium at various pressures less than 1 atmosphere and sealed.

IV. CHARACTERISTIC PROPERTIES OF THE THERMOMETERS

As is to be expected, the values for the resistance in ice, steam, and sulphur have the same proportions as for previous thermometers in which platinum of the same purity was used.

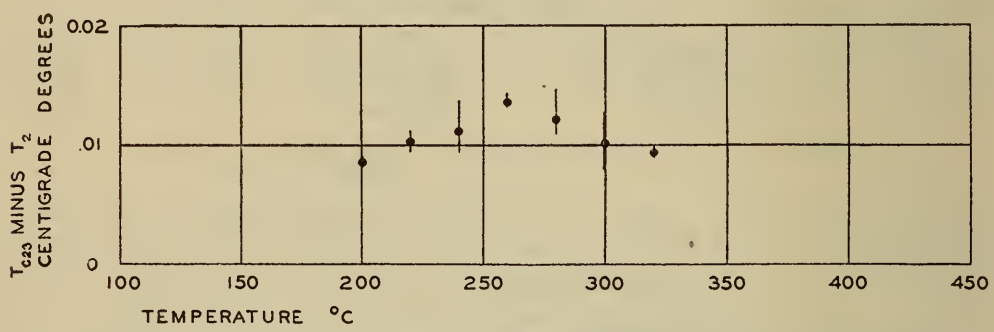

FIGURE 4.—*Comparison of coiled-filament thermometer with ordinary platinum resistance thermometer*

To determine whether the readings of a coiled-filament thermometer deviated appreciably from those of thermometers previously used, such a thermometer (No. 2) was compared in the range 200° to 320° C. with C_{23}, a thermometer of the customary design as described by Sligh. During this comparison the thermometers were immersed in a stirred oil bath of uniform temperature.

In Figure 4 the difference in centigrade degrees obtained by subtracting the readings of the coiled-filament thermometer from those of C_{23} are plotted as ordinate with the temperature as abscissa. The differences are no greater than might be expected in this region between two thermometers of the customary design. Each circle represents the mean of the observations at a given temperature while the vertical line through the circle represents the spread of the observations. A curve of differences should by definition pass through zero at 100° and at 444° C., but experimental errors in calibration, especially at the latter point, probably introduce considerable differences on the scale chosen in Figure 4, hence no attempt has been made to draw such a curve. It may be concluded that the coiled-filament winding introduces no appreciable peculiarity in the readings of the thermometer.

Since winding the wire in a helix reduces the effective area for heat

[3] J. Ind. Eng. Chem., vol. 11, p. 623, 1919

transfer between the thermometer and its surroundings, it is to be expected that the thermometric lag will be thereby increased, as well as the temperature difference between the thermometer coil and its surroundings necessary to dissipate the heat generated by the measuring electric current.

Measurements of the apparent resistance in an ice bath for several values of measuring current show that this temperature difference is proportional to the square of the current, and for 1.5 ma through a 25 ohm coil 5 mm in diameter and 2 cm long is about 0.004°C. when air filled and 0.001° C. when helium filled. In the paper by Sligh already mentioned the temperature difference for the larger type of thermometer filled with air is given as 0.001° C. for a current of 1.5 ma.

With the use of currents up to 5 ma the ratio between this temperature difference and the power input in the thermometer may be determined with sufficient accuracy so that variations with time in this ratio may be used as a measure of air leakage into the thermometer tube. One thermometer of the type described filled with helium at about 40 mm absolute pressure has shown no appreciable leakage over a period of two years.

V. ACKNOWLEDGMENTS

The author wishes to thank H. F. Stimson, F. R. Caldwell, and others for valuable suggestions and assistance in the construction of these thermometers, and E. F. Fiock for the data given in Figure 4.

WASHINGTON, September 1, 1932.