Sept. 25, 1951 W. H. VOGELSBERG 2,569,121

ELECTRICAL HEATING UNIT

Filed Aug. 8, 1949

FIG. 2.

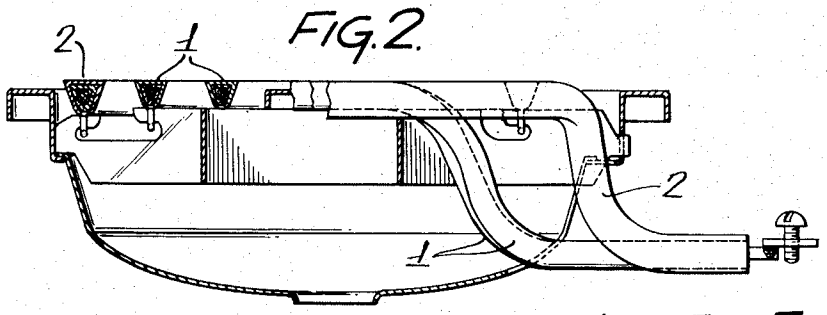


FIG. 3.

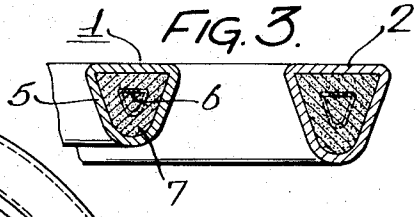


FIG. 1.

FIG. 4

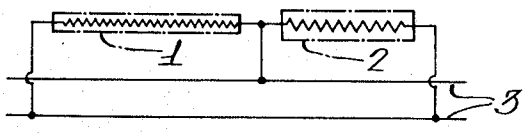
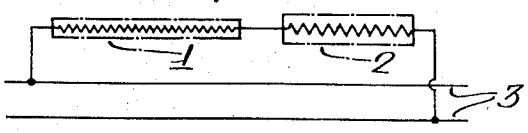


FIG. 5



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ELECTRICAL HEATING UNIT

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4 Claims. (Cl. 219—37)

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This invention relates to electric range heating units of the sheathed or tubular type, and more particularly to the utilization of a multi-section unit of this type in a system for flashing the unit, i. e. overenergizing it during a short time interval so that it heats quickly. In such a system, the flashing operation is followed by run or normal operation at some normal rate of energization.

In my copending application, Serial No. 87,462, filed April 14, 1949, a system for flashing and subsequent normal operation of a two-section heating unit is shown. In that system, the two sections are arranged in parallel across the supply line for a predetermined period until the heating unit attains the selected temperature, and then the sections are arranged in series across the line for normal operation under a corresponding preselected average rate of energization.

An important feature of that system is its utilization of a two-wire supply and the fact that the preselected wattage input can be obtained by cyclically opening and closing a single set of contacts in circuit with the serially connected sections of the heating unit. The desire to maintain the inherent simplicity offered by that system by trying to adapt it for use with the majority of the sheathed or tubular type heating units manufactured for range use has led to a serious problem of thermal unbalance in the operational characteristics of said units.

Of course, if a sheathed or tubular heating unit were composed of sections of equal lengths, of identical cross sections, and of equal resistances, it is apparent that the sections would heat at the same rate when arranged in parallel across an applied potential and would operate at the same temperature when connected in series across the same potential. However, the greater number of electric range units of this type manufactured at present are composed of sections of unequal lengths and of substantially equal cross sections. These units are usually adapted to discrete inputs and, depending on whether they make use of a two or three wire supply system, are capable of being arranged in various series and parallel combinations to obtain from three to seven heats. The use of these units with the discrete input type of heat control does not place any restrictions on the relative lengths of the sections that comprise a two-section heating unit. The absence of any such restriction permits arrangements for obtaining optimum wattage distribution over the area of the heating unit and permits simplified geometric arrangements of the sections.

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In adapting heating units of this type to series-parallel flashing, it is desirable to maintain the optimum geometries secured by using sections of an unequal length. Moreover, in making an adaptation of this type, it is advisable to utilize as many as possible of the manufacturing tools used for making such heating units. However, the use of sections of unequal lengths in a series-parallel flashing arrangement gives rise to a thermal balance problem.

If the sections were made of equal resistance, the sections would not come up to the same temperature at the same time, nor would they run at the same temperature under normal energization. During flash the longer section would receive less watts per lineal inch and would operate at a lower temperature. During normal operation the voltage would divide evenly across each section, each section receiving exactly one-quarter of the flash energization, and so the longer section would still run at the lower temperature. On the other hand, if the resistances were adjusted so that the resistances per lineal inch in the two sections were made equal, the sections would operate at the same temperature under normal energization. However, during flash the shorter section, having less total resistance, would draw more current than the larger section and would therefore attain the operating temperature much sooner than the larger section. Furthermore, if the sections were arranged to flash correctly, the conditions for normal operation would be upset. In this case the shorter section would have the greater resistance and would receive the greater part of the applied voltage, and therefore it would operate during normal energization at a higher temperature than the longer section.

The principal object of the present invention is to surmount the above-mentioned problem, and to provide a two-section heating unit of the sheathed or tubular type having sections of unequal lengths which when arranged in parallel for flash will attain substantially the same temperature in the same period of time, and when arranged in series will operate at substantially the same temperature under normal energization.

This invention contemplates, as a solution to this problem, the provision of a sheathed or tubular heating unit having sections of unequal length wherein the cross-sectional areas, the surface areas and the resistances are selected so that (a) during flash, the ratio of the wattage to the thermal mass associated with each unit length of the active portion of each section is substantially

the same, (b) during run, the ratio of the wattage to the effective dissipative area for each unit length of the active portion of each section is substantially the same.

The invention may be fully understood from the following detailed description with reference to the accompanying drawing, wherein:

Fig. 1 is a plan view of the novel electric range heating unit in circuit with a control switch and supply line;

Fig. 2 is a sectional view taken along line 2—2 of Fig. 1;

Fig. 3 is an enlarged fragmentary sectional view similarly taken;

Fig. 4 is a diagrammatic illustration of the arrangement of the sections of the heating unit during flash conditioning; and

Fig. 5 is a diagrammatic illustration of the arrangement of the sections during run condition.

Referring to Fig. 1, there is shown a sheathed or tubular heating unit comprising an inner section 1 and an outer section 2. The geometry of the sections as shown is that used by one of the range unit manufacturers and in itself is not a novel feature of the present invention. To secure this geometry, it is necessary that the length of the inner section 1 be greater than that of the outer section 2. The heating unit is connected to a supply line 3 through a control device 4. This control device may be of the type disclosed in the aforementioned copending application. It suffices merely to note here that the device 4 serves to establish the connections shown in Figs. 4 and 5. The specific structure and detailed operation of the device 4 are of no concern here.

The individual sections 1 and 2 of the heating unit consist of a tubular sheath 5 within which is disposed a helical resistance element 6 embedded in a compacted mass of heat conducting but electrically insulating refractory material 7.

To operate this system, the user merely rotates a control knob 8 associated with the control device 4 to the desired heat. This device effects automatic flash of the heating unit until said unit attains a temperature corresponding to the selected heat. The circuit connections set up during this flash cycle are shown in Fig. 4; as indicated, the sections 1 and 2 are arranged in parallel during this interval. After the sections attain the desired temperature, the control device automatically terminates this flash condition and connects the sections 1 and 2 of the heating unit in series across the supply line (Fig. 5). This is the condition for normal energization. To obtain heats at some wattage less than full normal energization, the control device may be adapted to open and close a single set of contacts in circuit with the serially connected sections 1 and 2, giving an average rate of energization corresponding to the heat selected.

In accordance with the present invention, the unequal length sections 1 and 2 are constructed with the shorter section of larger cross-section area than the longer section. As has been pointed out previously, if the resistances of the two sections of identical cross sections are assumed to be equal, the longer section will lag behind the heating of the shorter section during the transient period referred to as the flash interval. By increasing the cross-sectional area of the shorter section, a larger amount of thermal mass is then associated with each unit length of this section, thereby slowing down the transient temperature rise of said section during flash. The larger cross-sectional area of the shorter section also means increased dissipation area per lineal inch of said section, so that during normal operation the shorter section which was originally running too hot will have its operating temperature reduced.

Further, to obtain the balanced conditions in the particular embodiment shown, it is also necessary to alter the resistances of the sections. The magnitude of the change will become apparent from the discussion to follow, for it is possible to derive certain approximate expressions for the various dimensions and resistances of the heating unit sections which form one embodiment of this invention.

For the sake of this discussion we will use the following nomenclature, the subscripts referring to sections 1 and 2 respectively:

A_1, A_2—cross-sectional area, square inches.
c_1, c_2—weighted specific heat of materials comprising section, watt-seconds per pound per degree Fahrenheit.
E—line potential, volts.
H_1, H_2—combined coefficient of heat transfer due to radiation and convection, watts per square inch per degree Fahrenheit.
i—current flowing through both sections during normal operation, amperes.
l_1, l_2—effective length of section, inches.
P_1, P_2—perimeter of cross-sectional area, inches.
R_1, R_2—electrical resistance of section, ohms.
s_1, s_2—length of a side of section having equilateral triangular cross section, inches.
t—time of flash interval, seconds.
ΔT_1, ΔT_2—temperature rise of section above ambient, degrees Fahrenheit.
W_1, W_2—power input to section, watts.
p_1, p_2—weighted density of materials comprising section, pounds per cubic inch.

Then, assume for simplicity in this derivation that there is no heat loss during the flash interval due to dissipation from the section surfaces or by conduction through the section ends. The temperature rise during this flash interval of t seconds can therefore be expressed by equating the watt-seconds going into each section to the energy absorbed in increasing the temperature of the unit to the desired value above ambient. Thus for section 1

$$W_1 t = c_1 \rho_1 A_1 l_1 \Delta T_1 \tag{1}$$

Expressing the wattage in terms of the applied voltage E and solving for the temperature rise of the particular section above ambient,

$$\Delta T_1 = \frac{E^2 t}{c_1 \rho_1 A_1 l_1 R_1} \tag{2}$$

Similarly, the temperature rise ambient for section 2 is,

$$\Delta T_2 = \frac{E^2 t}{c_2 \rho_2 A_2 l_2 R_2} \tag{3}$$

Now by equating the temperature rise in each section to satisfy the balanced flash conditioning we obtain,

$$\Delta T_1 = \Delta T_2 = \frac{E^2 t}{c_1 \rho_1 A_1 l_1 R_1} = \frac{E^2 t}{c_2 \rho_2 A_2 l_2 R_2} \tag{4}$$

Simplifying and solving for the ratio of the resistances,

$$\frac{R_1}{R_2} = \frac{c_2 \rho_2 A_2 l_2}{c_1 \rho_1 A_1 l_1} \tag{5}$$

During run condition the two sections are arranged in series across the applied potential (Fig. 5). The steady state temperature rise of these sections above ambient can be expressed by equating the wattage input to each section to

the heat transferred to the atmosphere and surroundings by the dissipative effects of radiation and convection from the surface areas of the sections. This assumes that no heat is being transferred by conduction to the heating unit supporting frame, to the heating unit ends, or to any vessel that might be placed upon said unit. Thus for section 1,

$$W_1=H_1P_1l_1\Delta T_1 \tag{6}$$

The wattage can be expressed in terms of the current flowing through both sections and the resistance of the particular section, and the expression solved in terms of the temperature rise of the particular section above ambient.

$$\Delta T_1=\frac{i^2R_1}{H_1P_1l_1} \tag{7}$$

Similarly, the steady state temperature rise for section 2 is,

$$\Delta T_2=\frac{i^2R_2}{H_2P_2l_2} \tag{8}$$

For equal steady state run temperatures,

$$\Delta T_1=\Delta T_2=\frac{i^2R_1}{H_1P_1l_1}=\frac{i^2R_2}{H_2P_2l_2} \tag{9}$$

Simplifying and solving again for the ratio of the resistances,

$$\frac{R_1}{R_2}=\frac{H_1P_1l_1}{H_2P_2l_2} \tag{10}$$

combining expressions (5) and (10) we establish

$$\frac{c_2\rho_2H_2A_2P_2}{c_1\rho_1H_1A_1P_1}=\left(\frac{l_1}{l_2}\right)^2 \tag{11}$$

This expression can be further simplified by assuming that the product of the weighted specific heats and densities in coil 2 and coil 3 are approximately equal and by assuming that the heat transfer coefficients due to the combined dissipation effects of radiation and convection are equivalent for both coils. Thus:

$$\frac{A_2P_2}{A_1P_1}=\left(\frac{l_1}{l_2}\right)^2 \tag{12}$$

If we assume that the particular sections shown are each of substantially equilateral triangular cross section, it is possible to express (12) in terms of the lengths of the sides of the cross section, s_2, s_3. Thus,

$$\frac{\frac{\sqrt{3}}{4}s_2^2\cdot 3s_2}{\frac{\sqrt{3}}{4}s_1^2\cdot 3s_1}=\left(\frac{l_1}{l_2}\right)^2$$

$$\left(\frac{s_2}{s_1}\right)^3=\left(\frac{l_1}{l_2}\right)^2 \tag{13}$$

Thus we have established from this derivation for the embodiment shown that the ratio of the lengths of the sides s_1, s_2 of the sections is inversely proportional to the two-thirds power of the ratio of the effective section lengths. It is possible, if l_1, l_2 and the length of the side of the one of the sections, e. g., s_1, are preselected, to approximate s_2 by utilizing expression (12). Moreover, by going back to either expression (5) or (10) (and assuming that $H_1=H_2$ and $c_1\rho_1=c_2\rho_2$) and substituting for A_1, P_1 and A_2, P_2 the equivalent in terms of s_1 and s_2 respectively, it is possible to determine the ratio of the resistances R_1/R_2. It will be noted that once the length of the sides and effective lengths of the sections are determined, the ratio of the resistances is definitely fixed. The absolute values of the resistances are of course determined by the wattage rating for the heating unit during run condition.

To illustrate how these relations may be used, assume that it is desirable to maintain a pattern geometry similar to that of Fig. 1 with the length of side $s_1=.375''$ and with the effective lengths $l_1=16.2''$ and $l_2=12.3''$. Substituting in Equation 12 we obtain $s_2=.450''$. By using Equation 5 or 10 a value of 21.3 ohms is found for R_1 and 23.3 ohms for R_2. This assumes that it is desired to maintain 1250 as the full normal wattage across a 236 volt line.

Actually a set of sections built according to these specifications would show that section 2, of larger cross section, lagged behind the heating of section 1. During run the sections would appear to be operating at almost the same temperatures although section 2 would actually be operating at a slightly lower temperature than section 1. A set of sections which would give substantially balanced sections on flash and run would have $s_2=.43''$, $R_1=21.1$ ohms and $R_2=23.5$ ohms. Thus compared with a fully balanced set of sections, the calculated length of section side in this particular example is in error about 3%, while the resistances are about 1% in error.

It is possible to derive more exact expressions for the ratios of the lengths of the section sides, the effective lengths of sections and resistances, by including the effect of dissipation from the surface of the sections during the transient or flash interval. Further, it is possible to include the effect of change of specific heat, density, resistance and heat transfer coefficients with temperature. In addition, the effect of time lag and temperature differential between the temperature of the section heating wire and the section sheath temperature could be included. These and other variations might be accounted for but it is considered unnecessary to go into a more detailed analysis for the understanding of this invention.

It should be pointed out that the choice of a section of equilateral triangular cross section is arbitrary, for balanced conditions can be obtained with sections of circular and other cross sectional shapes. The factor of major importance is that the cross sectional area, the surface area per unit length of section and the section length are chosen to substantially satisfy expressions equivalent to (4) and (9) for the particular shapes considered.

The conditions explained thus far treat for the most part with the operation of the heating unit at its rated capacity, or rather the "high" heat setting on the control knob 8. This includes the flashing of the heating unit to the selected temperature and the subsequent operation thereof under normal operation at a continuous energization. The aforementioned application shows a flash system wherein a two-section heating unit is energized from a two-wire supply line and is operable during run at heats less than the full heat by the opening and closing of a set of contacts in circuit with the two sections serially connected across the two-wire supply. It has been found especially desirable to operate a system in this manner and the heating unit of the present invention is particularly adapted to systems of this nature.

It should be mentioned that in the design of the system which flashes to a temperature corresponding to a selected input, it is unnecessary that the temperature of the heating unit at the

instant of flash termination correspond exactly with the steady state operation temperature under no load, i. e., no vessels on top of the heating unit. Thus it may be desirable to terminate flash at some temperature less than the operating temperature to compensate for the inherent overshoot in a heating unit comprising materials of considerable mass and finite heat conductivity. Moreover, at certain inputs it may even be desirable to overshoot the normal operating temperature corresponding to the selected input. Variations of this nature are considered well within the scope of the present invention.

I claim:

1. A heating unit adapted to flashing, comprising at least two sheathed or tubular sections of unequal lengths adapted to be connected in parallel or in series across a two-wire supply line, said sections having different cross-sectional areas determined approximately from the equation

$$\frac{c_2\rho_2H_2A_2P_2}{c_1\rho_1H_1A_1P_1}=\left(\frac{l_1}{l_2}\right)^2$$

wherein the subscripts refer to the respective sections, c represents weighted specific heat, ρ represents weighted density, H represents combined coefficient of heat transfer due to radiation and convection, A represents cross-sectional area, P represents perimeter of such area, and l represents effective section length.

2. A heating unit adapted to flashing, comprising at least two sheathed or tubular sections of unequal lengths adapted to be connected in parallel or in series across a two-wire supply line, said sections having different cross-sectional areas determined approximately from the equation

$$\frac{A_2P_2}{A_1P_1}=\left(\frac{l_1}{l_2}\right)^2$$

wherein the subscripts refer to the respective sections, A represents cross-sectional area, P represents perimeter of such area, and l represents effective section length.

3. A heating unit adapted to flashing, comprising at least two sheathed or tubular sections of unequal lengths adapted to be connected in parallel or in series across a two-wire supply line, said sections having different cross-sectional areas substantially of equilateral triangular shape and determined approximately from the equation

$$\left(\frac{S_2}{S_1}\right)^3=\left(\frac{l_1}{l_2}\right)^2$$

wherein the subscripts refer to the respective sections, S represents the length of the side of the triangular cross section, and l represents effective section length.

4. A heating unit adapted to flashing, comprising at least two sheathed or tubular sections of unequal lengths adapted to be connected in parallel or in series across a two-wire supply line, the parameters of said sections being related according to the following equations:

$$\frac{R_1}{R_2}=\frac{c_2\rho_2A_2l_2}{c_1\rho_1A_1l_1}$$

$$\frac{R_1}{R_2}=\frac{H_1P_1l_1}{H_2P_2l_2}$$

wherein the subscripts refer to the respective sections, R represents resistance, c represents weighted specific heat, ρ represents weighted density, A represents cross-sectional area, P represents perimeter of said area, l represents effective section length, and H represents combined coefficient of heat transfer due to radiation and convection.

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