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ELONGATE ELECTRICAL ASSEMBLIES

This invention relates to circuits containing elongate self-regulating heaters.

Many elongate electrical heaters, eg. for heating
5 pipes, tanks and other apparatus in the chemical
process industry, comprise two (or more) relatively low
resistance conductors which are connected at one end to
the power source and run the length of the heater, with
a plurality of heating elements connected in parallel
10 with each other between the conductors. An advantage
of such heaters is that they can, if necessary, be cut
to length. In one class of such heaters, the heating
elements are in the form of a continuous or segmented
strip of conductive polymer which lies between the
15 conductors. In a second class, the heating elements
are in the form of one or more resistive heating wires
which progress down the length of the heater and are
connected at intervals to alternate conductors; such
heaters are usually referred to as zone heaters. Zone
20 heaters, when cut to length, have a cold spot at the
cut end, the length of the cold spot depending on where
the cut is made. For many uses, elongate heaters are
preferably self-regulating. This can be achieved, for
example, in the first class given above, by using a
25 continuous strip of conductive polymer at least a part
of which exhibits PTC behavior, and in the second
class, by connecting the heating wire(s) to one or both
of the conductors through a connecting element composed
of a PTC material.

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Although the conductors in such elongate heaters
are of relatively low resistance, there is still

a finite loss of potential between them as the distance from the power source increases, and this limits the length of heater which can be employed, since the power generated by the heating elements depends in part upon the potential difference between the conductors. The maximum length of such a heater can be increased by increasing the size of the conductors, but this is expensive and results in a heater which is heavier and has reduced flexibility. Another limitation of self-regulating heaters is that their resistance, when cold, is often much less than their resistance at steady state operation; consequently they draw a much larger current when they are first switched on, and therefore suffer from the problem of current inrush. Another limitation of many heaters is that they can only be powered by supply voltages within a particular range.

Elongate heaters of various kinds, and conductive polymers for use in such heaters, are disclosed in U.S. Patents Nos. 2,952,761, 2,978,665, 3,243,753, 3,351,882, 3,571,777, 3,757,086, 3,793,716, 3,823,217, 3,858,144, 3,861,029, 4,017,715, 4,072,848, 4,085,286, 4,117,312, 4,177,376, 4,177,446, 4,188,276, 4,237,441, 4,242,573, 4,246,468, 4,250,400, 4,255,698, 4,272,471, 4,314,230, 4,315,237, 4,318,881, 4,330,704, 4,334,351, and 4,361,799, J. Applied Polymer Science 19, 813-815 (1975), Klason and Kubat; Polymer Engineering and Science 18, 649-653 (1978), Narkis et al; and German OLS No. 1,634,999; 2,755,077; 2,746,602; 2,755,076; and 2,821,799;; and published European Application Nos. 38,713, 38,714, 38,715, 38,718, 63,440 and 67,679. The disclosure of each of the patents, publications and

applications referred to above is incorporated herein by reference.

We have now discovered that substantial improvements can be made in the performance of elongate self-regulating heaters comprising two elongate electrical connection means and a plurality of electrical elements which are connected in parallel between them, by connecting the power supply to one of the electrical connection means at one end of the device and to the other electrical connection means at the other end of the device, via a third connection means. In this way, the problem of current inrush is reduced and improved power distribution is obtained.

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A first aspect of the invention provides an electrical circuit which comprises

- (1) an elongate self-regulating heater which comprises
 - (a) a first elongate electrical connection means;
 - (b) a second elongate electrical connection means; and
 - (c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means;
- (2) a third elongate electrical connection

means; and

- (3) a source of electrical power which (a) is connected to the one end of the first connection means and (b) is connected to the opposite end of the second connection means by the third connection means.

A second aspect of this invention provides an electrical circuit which comprises

- (1) a first elongate self-regulating heater which comprises

(a) a first elongate electrical connection means;

(b) a second elongate electrical connection means; and

(c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means;

- (2) a second elongate self-regulating heater which comprises

(a) a first elongate electrical connection means;

(b) a second elongate electrical connection means; and

- (c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means; and

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- (3) a two-phase AC power source;

one end of one of the connection means of the first heater being connected to the first phase of the power source, the opposite end of the other connection means of the first heater being connected to one end of one of the connection means of the second heater; and the opposite end of the other connection means of the second heater being connected to the second phase of the power source.

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A third aspect of the present invention provides an electrical circuit which comprises

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- (1) a first self-regulating heater which comprises

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- (a) a first elongate electrical connection means;

- (b) a second elongate electrical connection means; and

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- (c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means;

(2) a second elongate self-regulating heater
which comprises

5 (a) a first elongate electrical connection means;

(b) a second elongate electrical connection means; and

10 (c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means;

15 (3) a third elongate self-regulating heater which comprises

(a) a first elongate electrical connection means;

20 (b) a second elongate electrical connection means; and

25 (c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means; and

30 (4) a three-phase AC power source;

one end of one of the connection means of each of the first, second and third heaters being connected to the

first, second or third phase of the power source, and the other ends of the other connection means of each of the heaters being connected to a different phase or to each other.

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In circuits according to all aspects of the invention, the plurality of electrical elements (c) may be provided, for example, by a continuous strip of a conductive polymeric material which exhibits PTC behaviour. Such a strip is electrically equivalent to a plurality of closely spaced discrete electrical elements connected in parallel with each other between the first and second electrical connection means.

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When the heaters are connected in the circuits in the manner according to the invention, and the two connection means have the same impedance (as is usually the case), the potential drop between the two connection means is similar (and, in theory at least, can be the same) at the near end of the heater as at the far end. This balancing of the potential drop over the length of the heater leads to substantially improved performance. In addition, the voltage dropped over each of the elements (c) is less than the voltage dropped over the elements (c) nearest the power source when the heater is connected in the conventional way. The reduction in the voltage dropped over the elements (c) is particularly marked when the third connection means has substantial impedance. Furthermore, by connecting a self-regulating heater in this way, the problem of current inrush is substantially reduced. In addition, since the power supply is connected to the second connection means (at the other end of the heater

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through the third connection means, which can be of any kind, very valuable results can be obtained by correlation of the properties of the third connection means with the remainder of the circuit in particular their relative impedances and their variation with temperature. Examples of suitable third electrical connection means include

- (1) a simple conductor, e.g. a wire or metal strip, which
 - (a) has an impedance which does not vary substantially in the temperature range of operation and which is substantially the same as, or substantially less than, or substantially greater than, the impedance of each of the first and second electrical connection means; or
 - (b) has an impedance which decreases substantially as the temperature increases; or
 - (c) has an impedance which increases substantially as the temperature increases;
- (2) another electrical device, eg. a self-regulating heater, comprising two elongate electrical connection means and a plurality of electrical elements which are connected in parallel between them; and
- (3) when a DC power supply is used, a ground connection.

The heaters used in the present invention are usually physically located so that one end of the heater is nearer to the power supply than the other. Accordingly, for ease and clarity in describing and claiming the invention, the terms "near end" and "far end" are used in this specification to identify the ends of the elongate connection means and the heaters containing them. It is to be understood, however, that the invention includes heaters which have been arranged, eg. in a loop, so that the "far end" is closer to the power supply than the "near end" or so that the near and far ends are equidistant from the power supply.

The invention is illustrated by the accompanying drawings, in which

Figure 1 is a diagrammatic view of a conventional PTC conductive polymer strip heater which comprises conductors 1 and 2 embedded in a conductive polymer strip 11 and which is conventionally connected to a power supply 8;

Figure 2 is a diagrammatic view of a conventional zone heater which comprises heating wires 15 connected to conductors 1 and 2 and which is conventionally connected to a power supply 8;

Figure 3 is a diagrammatic view of a conductive polymer strip heater as in Figure 1 which is connected to a power

supply through a third connection means 3
to provide a circuit of the invention;

Figure 4 is the equivalent circuit of Figure 3;

Figure 5 is a cross-section through a composite
device which comprises a heater and a
third connection means as shown
diagrammatically in Figure 3, the heater
and the connecting means being provided
with insulating polymeric jackets 12 and
34 respectively, and also comprising
polymeric insulating body 41 which
connects the heater and the connection
means;

Figure 6 is a diagrammatic view of a zone
heater in which heating wires 32 are
connected to conductors 1 and 2 through
PTC components 31 and which is connected
to a power source to provide a circuit of
the invention;

Figure 7 shows the current in the circuit of
Figures 1 and in the circuit of Figure 4
as a function of time immediately after
the circuit has been completed;

Figure 8 shows how power is generated, during
steady state operation of the circuits of
Figures 1, 2 and 4, between the two ends
of the heater;

Figure 9 is the same as Figure 3, except that the near ends of the first and second conductors are connected to each other through a resistor 35;

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Figure 10 is the same as Figure 3 except that the near ends of the conductors 1 and 2 are connected to each other through a voltage-limiting device 36, eg. a Zener diode.

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Figures 11 to 15 are circuits in which two conductive polymer PTC heaters are connected to a two phase power source to form circuits of the invention;

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Figures 16 to 19, 28 and 29 are circuits in which three conductive polymer PTC heaters are connected to a three phase power source to form circuits of the invention;

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Figures 20 to 26 are cross-sections through composite devices suitable for use in Figures 13 to 19, 28 and 29; and

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Figure 27 is a diagrammatic view of a test circuit used in the Examples.

30 For brevity and clarity in describing the present invention, the term "elongate parallel heater" is used in this specification to denote an elongate self-regulating heater which preferably has a length of at least 330 ft and which comprises

- (a) a first elongate electrical connection means;
- (b) a second elongate electrical connection means;
and
- (c) a plurality of electrical elements which are
connected in parallel with each other between
the first and second connection means.

10 The electrical circuits of the present invention
comprise

- (1) an elongate parallel heater; and
- 15 (2) a power source which is connected by a third
elongate electrical connection means to the
near end of the first connection means of the
heater (1) and to the far end of the second
connection means of the heater (1).

20 As indicated above, a wide variety of third electrical
connection means can be used to connect the power
source to the far end of the second connection means.
The third connection means can be physically separate
25 from, or physically secured to (but electrically
insulated from) the elongate parallel device.

The various electrical connection means will often
be simple conductors, which can be composed of the same
30 or different materials, e.g. round metal wires (which
may be solid or stranded) or flat metal strips, and are
sometimes simply referred to herein as conductors. It
is to be understood, however, that any form of

electrical connection means can be used. Generally it is desirable that in the (or each) elongate parallel heater, (a) the first and second conductors are substantially the same as each other; (b) each of the
5 conductors has substantially the same cross-section throughout the length of the device; (c) the resistance of the conductors is as low as is consistent with other factors such as weight, flexibility and cost; and (d)
10 the conductors are at a constant distance from each other (they may be for example, straight or spiralled).

As previously noted, a characteristic feature of the present invention is that when the first and second connection means are the same, the potential drop
15 between them is similar at the near end of the heater as it is at the far end of the device. Theoretically the potential drop can be the same at the near end and the far end, but in practice, variations in electrical and/or thermal characteristics along the length of the
20 device can result in substantial deviations from theory. Nevertheless the balancing of the potential drop along the length of the heater is much better than when the near ends of the first and second connection means are connected to the power source. This improved
25 balancing enables longer circuit lengths to be used.

The electrical elements (c), preferably comprise a PTC element, which can be composed of a conductive polymer or a ceramic. The PTC element can itself be
30 the sole heating element; alternatively it can have a ZTC resistive heating element in series with it. The elements (c) can be in the form of at least one element composed of a conductive polymer. The composition of

the conductive polymer element may be the same throughout, or can vary; thus the conductive polymer element can comprise two or more longitudinally extending components which have different electrical characteristics, or it can be an element which consists essentially of a PTC conductive polymer or an element which comprises a ZTC component element and at least one PTC component element, for example at least one PTC component element which surrounds one of the elongate conductors.

In another embodiment of the invention, the elements (c) are in the form of one or more heating wires which are connected at intervals to the two conductors through PTC elements.

A wide variety of different effects can be obtained by correlating the electrical characteristics of the elongate parallel heater and of the electrical connection means which connects the power source and the far end of the second electrical connection means of the elongate parallel device. For example, in the simplest circuits of the invention, as illustrated for example in Figures 3, 4 and 6, the third connection means is a simple conductor, and the electrical character of the circuit depends very much on the relative resistances of third connection means and the components (a), (b) and (c) of the elongate parallel heater and any change thereof with temperature. The impedance of the third connection means can be purely resistive or part or all of the impedance can be inductive or capacitative; for example the third connection means can be a SECT (skin effect current tracing) heater.

In one class of circuits, the impedance of the third connection means is substantially less than, preferably less than 0.5 times, particularly less than 0.2 times, the impedance of each of the first and second conductors, at least at room temperature and generally also at higher temperatures, eg. throughout the range 25 to 200°C, and preferably at all temperatures likely to be encountered in use of the device.

In a second class of circuits, the impedance of the third connection means is substantially the same as eg. 0.9 to 1.1 times, the impedance of each of the first and second conductors, at least at room temperature and generally also at higher temperatures, eg. throughout the range 25 to 200°C, and preferably also at all temperatures likely to be encountered in use of the device.

In a third class of circuits, the impedance of the third connection means is substantially greater than, preferably more than 1.2 times, especially more than 3 times, eg. 3 to 15 times, the impedance of each of the first and second conductors, at least at room temperature and generally also at higher temperatures, eg. throughout the range 25 to 200°C, and preferably also at all temperatures likely to be encountered in use of the device. In such circuits, the third connection means functions as a series heater, thus contributing to the power output of the heater. Under normal (i.e. steady state) operating conditions, the ratio of the impedance of (and usually but not necessarily the heat generated by) the third connection

means to the impedance (and usually but not necessarily the heat generated by) the parallel heater may be, for example, from 0.05 to 20, preferably 0.1 to 2.0, particularly 0.1 to 0.5. There may be some loss of the local self-regulating characteristic of the PTC heater, because the third connection means continues to generate heat until the whole of the PTC heater has been converted to the high impedance state. Under the expected operating conditions of the heater, therefore, the heat output of the PTC heater is preferably 2 to 15 times the heat output of the third connection means. The use of a relatively high impedance third connection means also results in a substantially lower proportion of the applied voltage being dropped over the elements (c) of the elongate parallel heater.

In a fourth class of circuits, the third connection means has an impedance which increases with temperature. The increase can be small, as in a conventional resistance wire heater, eg. the impedance at 300°C can be 1.2 to 2 times the impedance at 25°C. Alternatively, the increase can be relatively large, as in an elongate parallel heater as defined in which the components (c) are provided by a PTC conductive polymer strip, for example the impedance at a temperature below 300°C can be at least 10 times its impedance at 25°C.

In a fifth class of circuits, the third connection means has an impedance which decreases with temperature, eg. which at 150°C is less than 0.8 times, preferably less than 0.2 times, its impedance at 25°C. Such a third connection means can control current inrush without having substantial impedance under normal operating conditions.

In a sixth class of circuits, a fixed resistance is connected between the near ends of the first and second connection means of the elongate parallel heater. Such a circuit is illustrated in Figure 11. The resistance is preferably selected so that it is substantially higher than the impedance of the heater at 25°C and comparable with it (e.g. 0.5 to 5 times preferably 0.5 to 2 times) at normal operating temperatures; in this way, the voltage dropped over the parallel-connected elements at normal operating conditions is reduced.

In a seventh class of circuits, a voltage-limiting device, e.g. a Zener diode, is connected between the near ends of the first and second connection means of the heater. A circuit of this kind is illustrated in Figure 12. The voltage-limiting device ensures that the voltage dropped over the parallel-connected elements cannot exceed a predetermined value.

As indicated above, the third elongate connection means can itself be an elongate parallel heater as defined, and the invention includes a number of particularly useful circuits which comprise a two or three phase power supply and two or three elongate parallel heaters as defined; these heaters are preferably the same, but can be different. Many, but not all, of these circuits comprise a neutral, and when they do, the neutral is preferably provided by an elongate electrical connection means. However, it is also possible to use a floating neutral.

Thus an eighth class of circuits of the invention comprises

- (1) a first elongate parallel heater as defined;
- (2) a second elongate parallel heater as defined;
and
- (3) a two phase AC power source;

one end of one of the connection means of the first
heater being connected to the first phase of the power
source; the opposite end of the other connection means
of the first heater being connected to one end of one
of the connection means of the second heater; and the
opposite end of the other connection means of the
second heater being connected to the second phase of
the power source. Preferably the circuit also includes
a further electrical connection means which connects the
neutral of the power source to the connection between
the two heaters. Various circuits of this kind are
shown in Figures 11 to 15, in which the neutral connec-
tion which is preferably present is shown as a broken
line. Preferred circuits (because they are balanced)
are those in which the near ends of the first connection
means of the two elongate parallel heaters are connected
to the first and second phases respectively of the
power supply and the far ends of the second connection
means of the two heaters are connected to each other
and to the neutral of the power supply, as shown in
Figure 11 for heaters which are physically located
side-by-side and in Figure 14 for heaters which are
physically located end-to-end.

A ninth class of circuits of the invention
comprises

- (1) a first elongate parallel heater as defined;
 - (2) a second elongate parallel heater as defined;
 - 5 (3) a third elongate parallel heater as defined;
and
 - (4) a three phase AC power source;
- 10 one end of one of the connection means of each of the
first, second and third heaters being connected to the
first, second or third phase of the power source, and
the other ends of the other connection means of each of
the heaters being connected to a different phase (delta
15 connection) or to each other (star connection). When
the other ends are connected to each other, there is a
neutral point in the circuit and the circuit preferably
includes a further electrical connection means which
connects the neutral point and the neutral of the power
20 source. However, a floating neutral can also be used.
Various circuits of this kind are shown in Figures 16
to 19, 28 and 29 in which the preferred neutral connec-
tion is shown as a broken line. Figure 28 is a par-
ticularly preferred, balanced circuit.
- 25 When the circuits of the eighth and ninth classes
comprise an elongate connection means which carries the
circuit current, as in Figures 12 to 15, 18, 19, 28 and
29, then the impedances of the connection means and of
30 the elongate devices (and their variation, if any, with
temperature) can be correlated in order to obtain
desired results, as generally discussed above.

In Figures 11 to 19, 28 and 29 the various heaters are shown as conductive polymer heaters, but the same circuits are very suitable for use with other elongate parallel self-regulating heaters.

When the elongate parallel heaters in the circuits of the eighth and ninth classes, are physically located side-by-side, they can be separate from each other or physically secured to each other. The various elongate connection means needed to complete the different circuits can likewise be separate from the other circuit components or physically secured to one or more of them.

Composite devices which can be used in the circuits of the eighth and ninth classes include those defined in paragraphs (1) and (2) below and are claimed in Divisional Application No 8525177 [MP0812 GB2 (Div)]. Our Divisional Application describes and claims composite devices which are suitable for use in the circuits of the present invention which comprise a two-phase or three-phase power source. Cross-sections of particular examples of such devices are shown in Figures 20 to 26, in each of which a tube 41 of insulating polymeric material physically connects at least one PTC conductive polymer heater (101, 102 and 103) having an insulating polymeric jacket and at least one wire conductor (111, 112, 113 and 114) having an insulating polymeric jacket.

- (1) Composite devices which comprise at least two elongate parallel heaters as defined, and which can also include one or more elongate connection means. Figures 20, 21 and 22 show devices of this type. The device of Figure 20 is suitable for use in the circuit of Figure 11; it is to be noted that the neutral connec-

tion means 111 in Figure 20 (and likewise in Figures 22, 23, 24 and 25) can be smaller than the conductors in the heaters themselves. The device of Figure 21 is suitable for use in the circuit of Figures 12 and 13. The device of Figure 22 is suitable for use in the circuit of Figures 17.

- (2) Composite devices which comprise at least one elongate parallel heater as defined and at least two elongate connection means. Figures 23, 24, 25 and 26 show devices of this type. The device of Figure 23 is suitable for use in Figure 14, and also in Figure 15 with the smaller conductor not being used in the part of the circuit furthest from the power source. The devices of Figures 24 and 25 are suitable for use in Figure 28 and also in Figure 18, with one of the large conductors not being used in the part furthest from the power source, and also in Figure 29 with the small conductor not being used in the mid-section and with the small conductor and one of the large conductors not being used in the section furthest from the power source. The device of Figure 26 is suitable for use as the middle portion of the circuit of Figure 19.

EXAMPLES

The invention is illustrated in the following Examples, in which Example 1 is a Comparative Example. In these Examples the power source was 120 volts AC and

the heater was a self-regulating conductive polymer strip heater available from Raychem Corporation under the trade designation 10PTV1. The heater comprised a pair of 18 AWG tin-coated copper stranded wire electrodes embedded in a strip of PTC conductive polymer comprising carbon black dispersed in radiation cross-linked poly(vinylidene fluoride). The heater had a passive power of about 9 watts/foot. The heater was cut into sections which were, successively, 10, 150, 10, 150 and 10 feet long. Resistors of small but precisely known resistance were used to connect the wire electrodes of the different sections. In the Examples, the potential drop over each of these resistors was measured and hence the currents flowing in the different parts of the connection means were calculated. In Examples 1 and 2, only the first 170 feet of the heater were used (the remainder being disconnected) and in Example 3 the whole 330 feet of the heater were used. In Example 1, which is a comparative Example not in accordance with the invention, the first 170 feet of the heater was connected to the power supply in the conventional way (as shown in Figure 1). In Examples 2 and 3, the heater was connected to the power supply in accordance with the invention (as shown in Figure 3), using a third connection means which was an insulated 18 AWG tin-coated copper stranded wire and which was secured to the heater as shown in Figure 6. In each of the Examples, the heater and the third connection means were secured by adhesive tape to a 2 inch diameter steel pipe having water at about 9°C circulating through it, and were then covered with 1 inch thick thermal insulation. The assembly used in Example 3 is

shown diagrammatically in Figure 29, from which it will be noted that the 10 foot heater section nearest the power source is designated Section 1, that the 10 foot heater section 160 feet from Section 1 is designated Section 2, and that the 10 foot heater section furthest from the power source is designated Section 3. The assembly used in Example 2 was as shown in Figure 29 except that the third wire was connected to the end of Section 2.

The results obtained in the Examples are summarized in the Table below, which shows the Inrush Factor (ie. the ratio of the current to the steady state current) initially and after 10, 60 and 120 seconds; the current (in amps) in each bus wire (electrode) in each of Sections 1, 2 and 3; the voltage drop (in volts) between the bus wires in each of Sections 1, 2 and 3 and the power generated in watts/foot) in (a) the bus wires of the heater, (b) the conductive polymer element in the heater, (c) the third wire in the assembly, and (d) in total, each of Sections 1, 2 and 3.

The various figures given in the Table below reflect the fact that the Examples were made with a view to obtaining a qualitative rather than quantitative assessment of the benefits of the present invention. No undue reliance should, therefore, be placed on the precise relationships between the different figures. However, the figures clearly demonstrate that by connecting the power source to the far end of the heater through a third connection means, there is obtained a reduction in current inrush, a more even power distribution along the length of the heater

T A B L E

Ex. No.	Length (ft)	3rd Wire (gauge)	Inrush Factor after (secs)			Current in Section			Voltage in Section			Power in Bus Wires in Section			Power in Cond. Pol. in Section			Power in Third Wire in Section			Total Power in Section			
			Initial	10	60	120	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
1	170	None	1.6	1.4	1.1	1.1	16	1	-	120	100	-	3.8	0	-	10.5	11	-	-	-	-	14.3	11	-
2	170	18	1.4	1.3	1.1	1.0	15	15		93	93		1.7	2.0		8.7	9.1	-	1.6	1.6	-	12	12.7	-
3	330	18	1.2	1.1	1.1	1.0	19	10	19	52	42	53	2.7	1.5	3.1	3.3	2.2	3.3	2.6	2.6	2.6	8.6	6.3	9.0



Claims

1. An electrical circuit which comprises
 - (1) an elongate self regulating heater which comprises
 - (a) a first elongate electrical connection means;
 - (b) a second elongate electrical connection means;
and
 - (c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means;
 - (2) a third elongate electrical connection means;
and
 - (3) a source of electrical power which (a) is connected to the one end of the first connection means and (b) is connected to the opposite end of the second connection means by the third connection means.
2. A circuit according to claim 1 wherein the electrical elements (c) comprise a continuous strip of a PTC conductive polymer.
3. A circuit according to claim 2 wherein the first and second elongate electrical connection means comprise two substantially identical parallel metal wires which are in direct physical contact with the continuous strip of conductive polymer.



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4. A circuit according to any one of the preceding claims, wherein the heater is a zone heater.

5. A circuit according to any one of the preceding claims wherein the third connection means is a metal wire.

6. A circuit according to any one of the preceding claims, wherein at 25°C the impedance of the third connection means is less than 0.5 times the impedance of the first connection means and less than 0.5 times the impedance of the second connection means.

7. A circuit according to any one claims 1 to 5 wherein at all temperatures in the range 25° to 200°C, the impedance of the third connection means is 0.9 to 1.1 times the impedance of the first connection means and 0.9 to 1.1 times the impedance of the second connection means.

8. A circuit according to any one of claims 1 to 5 wherein at 25°C the impedance of the third connection means is more than 2 times the impedance of the first connection means and more than 2 times the impedance of the second connection means.

9. A circuit according to Claim 8 wherein under the normal steady state operating conditions of the circuit, the impedance of the third connection means is more than 3 times the impedance of the first connection means and more than 3 times the impedance of the second connection means.



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10. A circuit according to Claim 8 or 9 wherein under the normal steady state operating conditions of the circuit, the ratio of the heat generated by the heater to the heat generated by the third connection means is from 2 to 15.
11. A circuit according to any one of claims 1 to 5 wherein the impedance of the third connection means at 150°C is less than 0.2 times its impedance at 25°C.
12. A circuit according to any one of claims 1 to 10 wherein the impedance of the third connection means at 300°C is 1.2 to 2 times its impedance at 25°C.
13. A circuit according to any one of claims 1 to 10 wherein the impedance of the third connection means at a temperature between 25°C and 300°C is at least 10 times its impedance at 25°C.
14. A circuit according to any one of the preceding claims wherein the power source is a single phase AC power source.
15. A circuit according to any one of claims 1 to 13 wherein the power source is a two phase AC power source.
16. A circuit according to any one of the preceding claims wherein the heater is at least 330 feet long.
17. A circuit according to any one of the preceding claims which comprises a voltage-limiting device connected between the ends of the first and second connection means which are closer to the power source.



18. A circuit according to any one of the preceding claims which comprises a fixed impedance which (i) is connected between the ends of the first and second connection means which are nearer to the power source and (ii) has an impedance which is substantially higher than the impedance of the heater at 25°C and 0.5 to 5 times the impedance of the heater under the normal steady state operating conditions of the circuit.

19. An electrical circuit which comprises

(1) a first elongate self-regulating heater which comprises

(a) a first elongate electrical connection means;

(b) a second elongate electrical connection means; and

(c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means;

(2) a second elongate self-regulating heater which comprises

(a) a first elongate electrical connection means;

(b) a second elongate electrical connection means; and



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(c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means; and

(3) a two-phase AC power source;

one end of one of the connection means of the first heater being connected to the first phase of the power source, the opposite end of the other connection means of the first heater being connected to one end of one of the connection means of the second heater; and the opposite end of the other connection means of the second heater being connected to the second phase of the power source.

20. A circuit according to Claim 19 wherein the first and second heaters are arranged end to end so as to form a circuit whose physical length is at least as great as the sum of the lengths of the heaters; the end of the first connection means of the first heater which is closer to the power source is connected to the first phase of the power source; the end of the first connection means of the second heater which is closer to the power source is connected to the second phase of the power source; and the ends of the second connection means of the first and second heaters which are further from the power source are connected to each other and to the neutral of the power source.

21. A circuit according to Claim 20 wherein in each of the heaters the electrical elements (c) comprise a continuous strip of a PTC conductive polymer.



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22. A circuit according to Claim 21 wherein in each of the heaters the first and second elongate electrical connecting means comprise two substantially identical parallel metal wires which are in direct physical contact with the continuous strip of PTC conductive polymer.

23. A circuit according to claim 22 wherein each of the first and second heaters is a zone heater.

24. A circuit according to any one of claims 19 to 23 wherein each of the first and second heaters is at least 330 feet long.

25. An electrical circuit which comprises

(1) a first elongate self-regulating heater which comprises

(a) a first elongate electrical connection means;

(b) a second elongate electrical connection means; and

(c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means;

(2) a second elongate self-regulating heater which comprises

(a) a first elongate electrical connection means;



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(b) a second elongate electrical connection means; and

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(c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means;

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(3) a third elongate self-regulating heater which comprises

(a) a first elongate electrical connection means;

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(b) a second elongate electrical connection means; and

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(c) a plurality of electrical elements which are connected in parallel with each other between the first and second electrical connection means; and

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(4) a three-phase AC power source;

one end of one of the connection means of each of the first, second and third heaters being connected to the first, second or third phase of the power source, and the other ends of the other connection means of each of the heaters being connected to a different phase or to each other.

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26. A circuit according to Claim 25 wherein the first, second and third heaters are arranged end-to-end



5 so as to form a circuit whose physical length is at
least as great as the sum of the lengths of the
heaters; the end of the first connection means of the
first heater which is closer to the power source is
connected to the first phase of the power source; the
end of the first connection means of the second heater
10 which is closer to the power source is connected to the
second phase of the power source; the end of the first
connection means of the third heater which is closer
to the power source is connected to the third phase of
the power source; and the ends of the second connection
15 means of the first, second and third heaters which are
further from the power source are connected to each
other and to the neutral of the power source.

27. A circuit according to Claim 25 wherein the end
of the first connection means of the first heater which
is nearer to the power source is connected to the first
phase of the power source; the end of the first connec-
5 tion means of the second heater which is nearer to the
power source is connected to the second phase of the
power source; the end of the first connection means of
the third heater which is nearer to the power source is
connected to the third phase of the power source; the
10 end of the second connection means of the first heater
which is further from the power source is connected to
the second phase of the power source; the end of the
second connection means of the second heater which is
further from the power source is connected to the third
15 phase of the power source; and the end of the second
connection means of the third heater which is further
from the power source is connected to the first phase
of the power source.

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28. A circuit according to any one of Claims 25 to 27 wherein in each of the heaters the electrical elements (c) comprise a continuous strip of a PTC conductive polymer.

29. A circuit according to Claim 28 wherein in each of the heaters the first and second elongate electrical connection means comprise two substantially identical parallel metal wires which are in direct physical contact with the continuous strip of PTC conductive polymer.

30. A circuit according to any one of Claims 25 to 27 wherein each of the first, second and third heaters is a zone heater.

31. A circuit according to any one of Claims 25 to 30 wherein each of the first, second and third heaters is at least 330 feet long.

32. A circuit according to claim 1, 19 or 25 substantially as hereinbefore described.

33. A circuit according to claim 1 substantially as hereinbefore described with reference to and as illustrated in Figures 3 and 4 of the accompanying drawings.

34. A circuit according to claim 1 substantially as hereinbefore described with reference to and as illustrated in Figures 9 and 10 of the accompanying drawings.

35. A circuit according to claim 19 substantially as hereinbefore described with reference to and as

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illustrated in any one of Figures 11 to 15 of the accompanying drawings.

36. A circuit according to claim 25 substantially as hereinbefore described with reference to and as illustrated in Figure 28 of the accompanying drawings.

37. A circuit according to claim 25 substantially as hereinbefore described with reference to and as illustrated in any one of Figures 16 to 19, and 29 of the accompanying drawings.
