United States Patent [19]

Ando

[11] 3,755,650

[45] Aug. 28, 1973

[54] **ELONGATED HEAT-GENERATING APPARATUS PROVIDING FOR A REDUCTION IN THE HIGHEST VOLTAGE TO BE APPLIED**

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[30] Foreign Application Priority Data

Nov. 20, 1970 Japan..........................45/102479

[52] **U.S. Cl.**.............. **219/301,** 219/10.49, 219/300, 219/477, 307/83, 323/44 R, 338/295

[51] **Int. Cl.**.. **H05b 3/00**

[58] **Field of Search**................. 219/300, 301, 10.49, 219/10.51, 535, 477; 307/54, 69, 83; 323/44 R; 338/295

[56] **References Cited**

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Primary Examiner—A. Bartis

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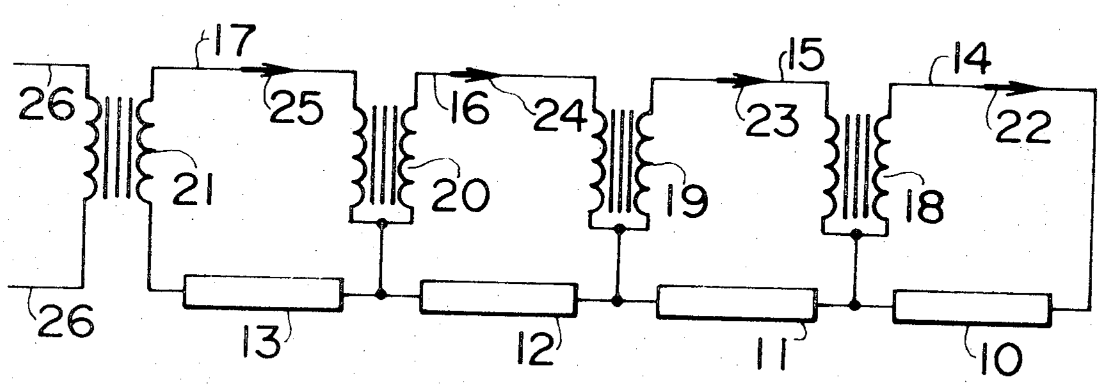
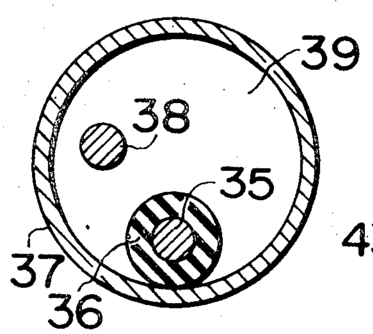
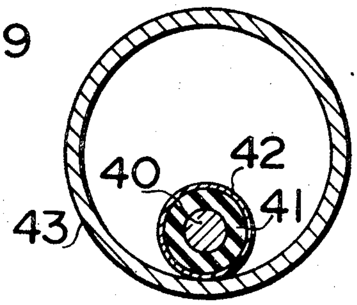
[57] **ABSTRACT**

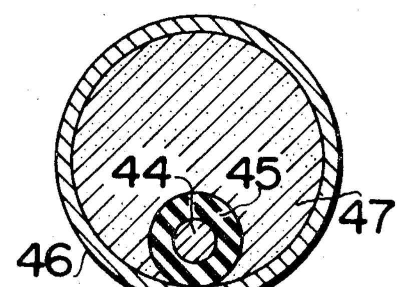
An elongated heat-generating apparatus is divided into at least two sections and a transformer is provided at each division between adjacent sections of said at least two sections and linked with the electrical circuits of the adjacent sections. The output voltage of the transformer is as near as possible to the highest voltage allowed for the section, the resistance of which is adjusted in relation to the definite voltage to meet the required quantity of heat in that section.

5 Claims, 7 Drawing Figures









PRIOR ART
FIG. 1

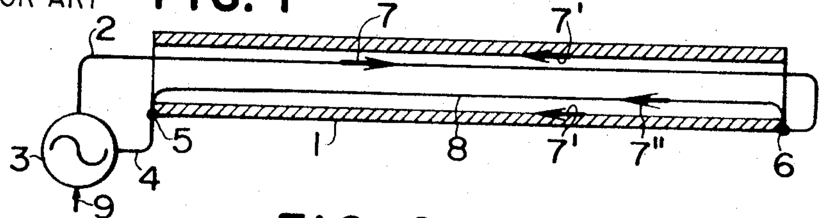
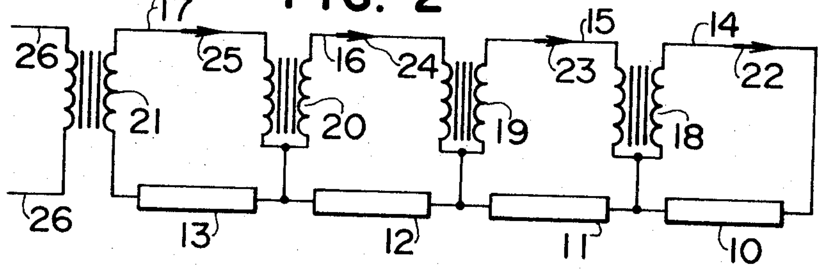


FIG. 2



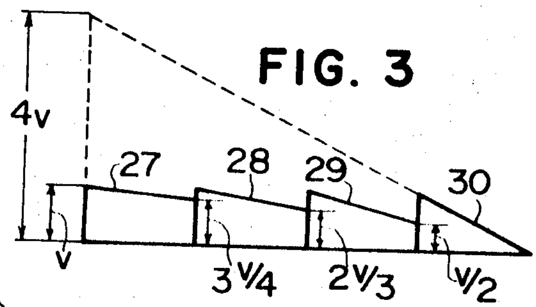


FIG. 3

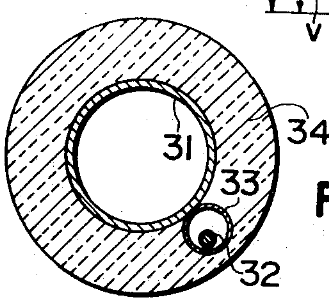


FIG. 4

FIG. 5

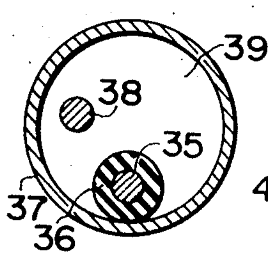


FIG. 6

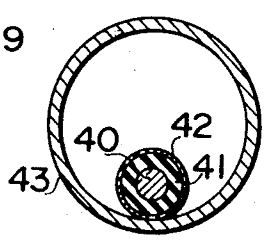
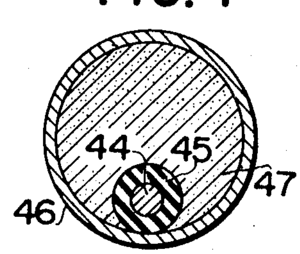


FIG. 7



ELONGATED HEAT-GENERATING APPARATUS PROVIDING FOR A REDUCTION IN THE HIGHEST VOLTAGE TO BE APPLIED

BACKGROUND OF THE INVENTION

The present invention relates to an elongated electrically heat-generating apparatus to be used as a heat source for, e.g. a pipeline which requires heating or temperature-maintenance such as a long-distance pipeline for transporting heavy fuel oil, in which apparatus the highest voltage of its circuit is limited to as a value as possible, and the electric power necessary therefor is provided from one electric source.

Although the present invention can be applied to any heat-generating apparatus in which an elongated, electrically resistant body is used as a heat-generating body, it will be herein illustrated in reference to a heat-generating apparatus utilizing skin effect current which is applicable particularly advantageously in the present invention.

The heat-generating apparatus utilizing skin effect current referred to herein comprises a ferromagnetic pipe and an insulated electric wire passing through the inside of the pipe, one end of said insulated wire being connected to one end of said ferromagnetic pipe remote from an a.c. source, the other ends of said insulated wire and said ferromagnetic pipe being both connected to the a.c. source, and the wall thickness of said ferromagnetic pipe being greater than twice the depth of skin of the a.c. flowing therethrough. Such a heat-generating apparatus utilizing skin effect current is described in my U.S. Pat. No. 3,293,407 which is assigned to the assignee of the present application.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention along with its background will be illustrated referring to the accompanying drawings for the better understanding.

FIG. 1 shows a cross-sectional view of a known heat-generating pipe utilizing skin effect current to which the present invention can be applied; FIG. 2, a schematic view of circuit for illustrating the principle of the heat-generating apparatus of the present invention; FIG. 3, a schematic view of the voltage distribution of the heat-generating apparatus of the present invention; FIG. 4, a cross-sectional schematic view of a pipeline to which the heat-generating apparatus of the present invention is applied for heating it; and FIGS. 5, 6 and 7, cross-sectional views of heat-generating pipes utilizing skin effect current to which the present invention is applied.

DETAILED DESCRIPTION OF THE PRIOR ART

In FIG. 1, which illustrates the prior art pipe heating systems, a ferromagnetic pipe 1, e.g. a steel pipe, is shown and 2 shows an insulated electric wire passing through the inside of said ferromagnetic pipe, one end of said wire being connected to one terminal of an a.c. source 3, and the other end thereof being connected to one end 6 of said ferromagnetic pipe remote from the a.c. source. The other end 5 of said ferromagnetic pipe 1 near to the a.c. source is connected to the other terminal of the a.c. source 3 by means of an electric wire 4. Thus, alternating currents 7 and 7′ flow. Numeral 9 shows a power transmission line to the a.c. source 3.

Further, if necessary, a short-circuit electric wire 8 for shorting the inside of the pipe can be used, through

which an alternating current 7″ flows. The effectiveness of such a short-circuit electric wire 8 is described in my detail in U.S. Pat. No. 3575581, also assigned to the assignee of this application.

The point of the effectiveness of the short-circuit electric wire 8 in the present invention is that the quantity of heat to be generated in the whole of the heat-generating apparatus utilizing skin effect current, can be thereby adjusted.

Now, in the circuit of FIG. 1, if the resistivity of the ferromagnetic pipe is $\rho(\Omega\ \mathrm{cm})$, the specific permeability is μ, and the frequency of the power source is f(Hz), the so-called depth of skin, S (cm) is expressed as follows:

$$S = 5030\ \sqrt{\rho/(\mu f)} \tag{1}$$

With this S, if the wall thickness of the above-mentioned ferromagnetic pipe 1 is t(cm), the length is l(cm), and the inner diameter is d (cm), and further if there is the following relationship between them,

$$t > 2S,\ l >> d \tag{2}$$

then the current 7′ flowing through the ferromagnetic pipe 1 flows concentratedly only through the inner skin portion of the ferromagnetic pipe 1, and substantially no voltage appears on the outer surface of the ferromagnetic pipe. Accordingly, even if the outer surface of the ferromagnetic pipe is shorted by a low impedance conductor, substantially no current flows therethrough, and also even if a conductive substance to be heated is contacted with the outer surface, substantially no flow of current to the substance is observed. Due to such safety, the ferromagnetic pipe can be utilized as a heat-generating pipe.

In such a heat-generating apparatus, the heat generated along the inner skin portion of the heat-generating pipe amounts to 80 – 90 percent of the total heat, and the remainder is generated in the insulated electric wire 2. Accordingly, if both the ends 5 and 6 of the heat-generating pipe 1 are short-circuitted by a short-circuit electric wire 8, passing through the inside of the pipe as seen in FIG. 1, then a part of the current 7 (shown in 7″) flows through the short-circuit electric wire to reduce the apparent resistance of the heat-generating pipe. Thus, if the current 7 is maintained at the same value, the heat to be generated is reduced. The voltage necessary for such a heat-generating pipe utilizing skin effect current, is 300 – 700 V if an alternating current of 50 – 60 Hz is used for the electric source, a steel pipe having an inner diameter of 1 – 3 cm is used as the ferromagnetic pipe, and an a.c. of 100 – 200A is passed through the insulated electric wire. Thus, if the length of the heat-generating apparatus as shown in FIG. 1 is 40 km, at least 12 KV is necessary for the voltage of the electric source 3. However, it is practically very difficult to use an insulated electric wire to which a voltage of 12 KV is applied, in the inside of such a heat-generating pipe 1, since the insulating material of the wire must be resistant to a high temperature simultaneously with the high voltage.

SUMMARY OF THE INVENTION

The object of the present invention is to provide an apparatus in which a much lower voltage than 12 KV is utilized, for the insulated electric wire, in the above-mentioned case.

The present invention resides in an elongated heat-generating apparatus which comprises an elongated electrically heat-generating body, and conductors connecting both the terminals of said body to an electric source, said body and said conductors being both divided into at least two sections and a transformer being inserted at each divided point thereof, the input side of said transformer being connected to a section near to said source, while the output side being connected to an adjacent section remote from said source, the output voltage of said transformer being as near as possible to the highest voltage allowed for the section on the output side, the capacity of said transformer corresponding to the loads obtained by substracting, from the total load of all the sections, the sum of the loads of all the preceding sections nearer to said source, and the resistance of each section corresponding to the quantity of heat required to generate in each section.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Now, the present invention will be illustrated referring to FIG. **2** and following drawings.

In FIG. **2**, a heat-generating pipe (a ferromagnetic pipe) and an insulated electric wire as seen in FIG. **1**, are both divided into four sections, **10 – 14**; **11 – 15**; **12– 16**; and **13 – 17.** It is now assumed for easy understanding that the length of the heat-generating pipe is divided into four equal sections and the resistance of the heat-generating pipe in each section is uniform in the longitudinal direction of the pipe although such equal length and such uniformity of resistance are not always necessary, and in some cases, unequal length and non-uniformity of resistance would be preferable.

The heat-generating body **10** in FIG. **2** can be considered to correspond to the heat-generating pipe **1** in FIG. **1**; the electric wire **14**, to the electric wire **2**; the transformer **18**, to the electric source **3**; and the current **22**, to the current **7.** It is assumed that the value of the current **22** is i; the output voltage of the transformer **18** is V and also this V is the highest allowable value; and in this case, the short-circuit electric wire of FIG. **1** is omitted. In such an apparatus, the potential difference between the insulated electric wire **14** and the heat-generating pipe, as shown by the straight line **30** in FIG. **3**, is V on the output side of the transformer **18**, while it is zero at the point remotest from the transformer **18**, that is, at the right end of the heat-generating pipe **10.** In this case, since the circuit current is i, the output capacity of the transformer **18** is V*i*.

Next, the circuit of the section on the input side of the transformer **18** will be illustrated. In this circuit, too, the voltage on the output side, of the transformer **19** is assumed to be the highest one V allowed for the insulated electric wire **15.** In order to make the quantity of heat to be generated in the heat-generating pipe **11** equal to that at the heat-generating pipe **10**, the current **23** must be 2 *i*, since the lengths of the heat-generating pipes **10** and **11** are equal as mentioned above, and the voltage on the input side, of the transformer **18** must be V/2. Thus, the output capacity of the transformer **19** is 2 V*i* which is twice the capacity of the transformer **18.** If this consideration is further applied to the circuits relative to the sections on the input side of the transformers **19** and **20**, the voltages and currents on the input and output sides, of the transformers **18, 19, 20** and **21**, and the output capacities thereof are as shown in the following table. The differences between the output capacities of the adjacent transformers are all vi.

TABLE

Number of transformer	Input side Voltage	Input side Current	Output side Voltage	Output side Current	Output capacity
18	V/2	2*i*	V	*i*	V*i*
19	2V/3	3*i*	V	2*i*	2V*i*
20	3V/4	4*i*	V	3 *i*	3V*i*
21			V	4*i*	4V*i*

In this table, the voltage and current on the input side, of the transformer **21** and not shown since they are dependent on the voltage of the transmission line **26** and this has nothing to do with the present invention.

The potential difference between the insulated electric wire **15** and the heat-generating pipe **11** is shown by the straight line **29** in FIG. **3**; the potential difference between the insulated electric wire **16** and the heat-generating pipe **12**, by the straight line **28**; and the potential difference between the insulated electric wire **17** and the heat-generating pipe **13**, by the straight line **27.** As seen from the table, the current **24** must be 3*i* and the current **25** must be 4*i*.

The dotted line in FIG. **3** shows the potential difference distribution between the insulated electric wire and the heat-generating pipe in case where the above-mentioned division is not carried out. As apparent from this figure, if the division is not carried out, the voltage of the source is 4 V which is four times that in the case of the division into four sections.

Now, in order to equalize heat-generation per unit length of each four section when the respective voltages and currents on the output side are given as above, there must exist the following relationships among each resistance per unit length, of the heat-generating circuit in each section:

$$R_{18}i^2 = R_{19}(2i)^2 = R_{20}(3i)^2 = R_{21}(4i)^2 \quad (3)$$

wherein R_{18} is the resistance per unit length, of the heat-generating circuit in the section on the output side of the transformer **18**; R_{19} is that in the section between the transformers **19** and **18**; R_{20} is that in the section between the transformers **20** and **19**; and R_{21} is that in the section between the transformers **21** and **20.**

As for the method for holding such relationships in the heat-generating apparatus utilizing skin effect current, adjustment of R_{19}, R_{20} and R_{21} (if R_{18} is fixed in the above-mentioned formula (3)) by means of a short-circuit electric wire as shown as numeral **8** in FIG. **1**, or the like, and/or adjustment by varying the diameter or material of the ferromagnetic pipe, can be exemplified.

Various modifications corresponding to the short-circuit electric wire **8** are illustrated in FIGS. **5, 6** and **7.**

According to the method of FIG. **5**, an electric wire **35** coated by an insulating layer **36**, corresponding to the electric wire **2** in FIG. **1**, is passed through the inside of a ferromagnetic pipe **37** as mentioned above, and further, a short-circuit electric wire **38** corresponding to the short-circuit wire **8** in FIG. **1** is passed through the clearance part **39** inside the ferromagnetic pipe **37.** In this case, the short-circuit electric wire **38** is not necessary to be insulated.

In FIG. **6,** an electric wire **40** coated by an insulating layer **41,** corresponding to the electric wire **2** in FIG. **1,** is passed through the inside of a ferromagnetic pipe **43,** but the insulated electric wire has further on its surface, a metallic tape shield **42** for preventing corona discharge which corresponds to the short-circuit electric wire **8** in FIG. **1.** If the metallic tape is insufficient for adjusting the resistance, a means corresponding to the short-circuit electric wire **38** in FIG. **5** can be added.

In FIG. **7,** an electric wire **44** coated by an insulating layer **45,** corresponding to the electric wire **2** in FIG. **1** is passed through the inside of a ferromagnetic pipe **46,** and further an electrically conductive metal **47** such as metallic sodium, is melt-filled (that is, filled through melting the metal) in the clearance part inside the ferromagnetic pipe, which metal has properties of melting at a relatively low temperature and not corroding the insulating layer **45** when it is filled in the clearance part, (in other words, melting at such an extent of temperature that the insulation of the insulated electric wire is not broken at the temperature), and corresponds to the short-circuit electric wire **8** in FIG. **1.**

In FIG. **4** showing a laterally cross-sectional view of a pipeline to which a heat-generating apparatus as mentioned above is applied for heating it or maintaining the temperature, numeral **31** shows a transporting main pipe; numeral **33,** a ferromagnetic pipe corresponding to the pipe **1** in FIG. **1**; numeral **32,** an insulated wire corresponding to the wire **2** in FIG. **1**; and numeral **34,** an insulating layer. The explanation as to the mutual relationship among the elements constituting the heat-generating apparatus of FIG. **4** will be unnecessary.

The present invention relative to an elongated heat-generating apparatus limiting the highest voltage as described above referring to the heat-generating apparatus utilizing skin effect current, can be also applied to an elongated electrically heat-generating body e.g. an inorganic-insulated metal sheath cable (referred to usually as MI cable), other than the heat-generating apparatus utilizing skin effect current, but the case applied to the heat-generating apparatus utilizing skin effect current is most economical.

The above-mentioned equal division is not always necessary, but, in most cases, it is most economical.

The present invention has an advantage in that the voltage applied to the insulated electric wire is much reduced by the division as seen in FIG. **3,** but has disadvantages in that transformers are required at each divided point; an insulated electric wire having a large capacity of current must be used in the heat-generating pipes excluding the final section; and means are needed to satisfy the above-mentioned formula (3) in order to prevent the increase of heat generation per unit length of each section except the final one, accompanied by the increase in the current. However, in the provision of transformers at each divided point which is most problematical among the above-mentioned countermeasures, single-layer winding transformers can be used as apparent from FIG. **2,** and hence the provision is not so much an economical burden. In the case of the above-mentioned heat-generating apparatus laid over a distance of 40 km, the present apparatus was more economical as compared with the case where a transmission line is provided along a long pipeline and feeding transformers are provided at each divided point.

In the above-mentioned consideration, the power factor of the circuit in the heat-generating pipe is assumed to be 1, but the above-mentioned consideration is not changed even when the power factor is a little worse.

What is claimed is:

1. Elongate electrical heat generating apparatus comprising:

an elongate electrically conductive heat generating body which is divided into at least two sections,

a transformer for each of said sections,

a source of alternating electric power,

circuit means including the secondary of each said transformer and also the associated section of said conductive body for passing an electric current along the length of said section,

said circuit means further including the primary of the transformer for the next said section more remote from said source for energizing said primary with the current passing through the associated section,

each said transformer providing across its secondary winding substantially the same predetermined voltage,

said transformer secondaries further providing different respective current amplitudes with each such secondary for a section of said conductive body nearer said source providing a current amplitude greater than that provided for the next more remote section,

and means for providing different electrical resistances for the respective said circuit means associated with said transformer secondaries to provide a predetermined heat output per unit length for each said section.

2. The heat generating apparatus of claim **1** wherein each said section of said conductive body comprises a section of ferromagnetic pipe,

said circuit means including an insulated electric wire passing through the inside of the respective associated pipe section,

the end of said wire nearer said source being connected through the secondary of the transformer associated with the respective section to the end of the pipe nearer said source and the other end of said wire being connected through the primary of the transformer associated with the next more remote section to the other end of said pipe,

the wall thickness of said pipe being greater than twice the skin depth of the alternating current.

3. A heat-generating apparatus according to claim **2,** wherein the ferromagnetic pipe, in at least one section other than the section remotest from said a.c. source, is short circuited by a conductor passing through the inside of said ferromagnetic pipe and connected to the opposite ends of said pipe to provide thereby said means providing different electrical resistance for said sections.

4. A heat-generating apparatus according to claim **3,** wherein the insulated wire passing through the inside of the ferromagnetic pipe in at least one section has a metallic tape shield thereon and the metallic tape shield is utilized as the short circuiting conductor.

5. A heat-generating apparatus according to claim 3, wherein the short circuiting conductor comprises an electrically conductive metal which is melt-filled inside said ferromagnetic pipe, said metal having a melting temperature at which the insulation of the insulated electric wire passing through the inside of the ferromagnetic pipe is not damaged.

* * * * *