Oct. 11, 1955 P. L. BETZ 2,720,615

THERMOELECTRIC GENERATORS

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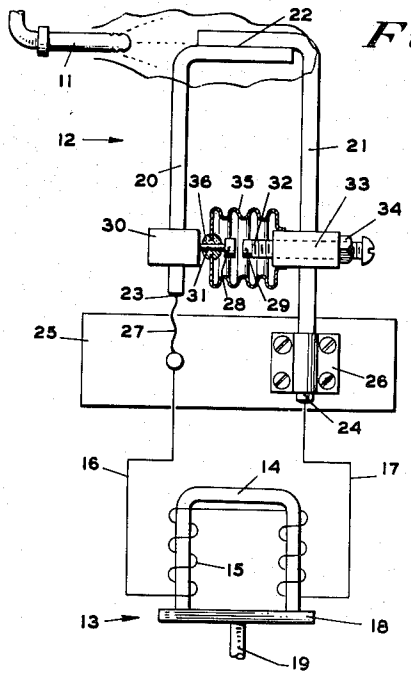


Fig. 1.

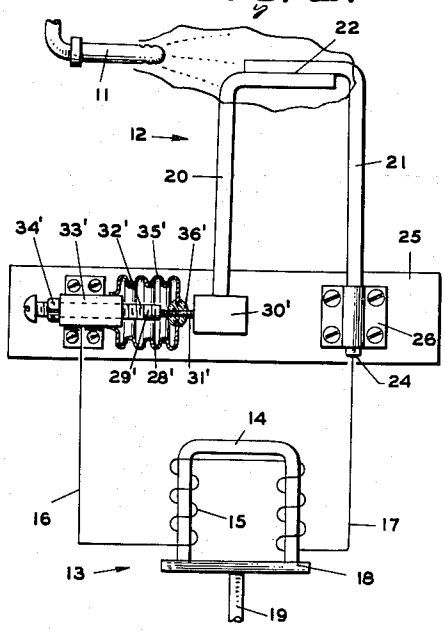


Fig. 2.

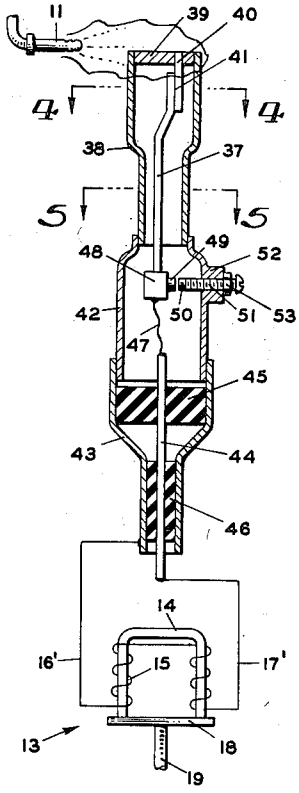


Fig. 3.

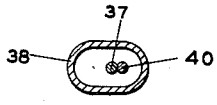


Fig. 4.

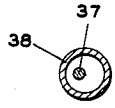


Fig. 5.

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Fig. 6.

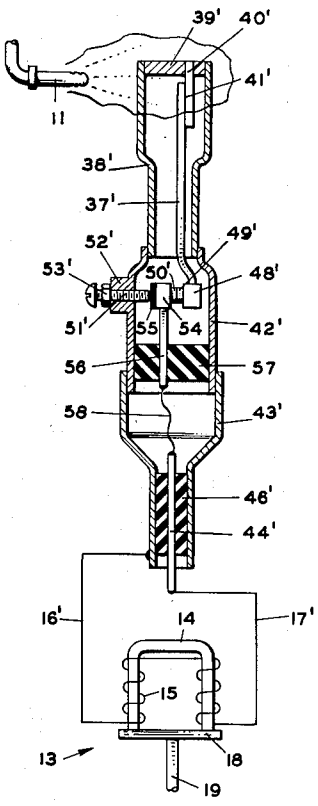


Fig. 7.

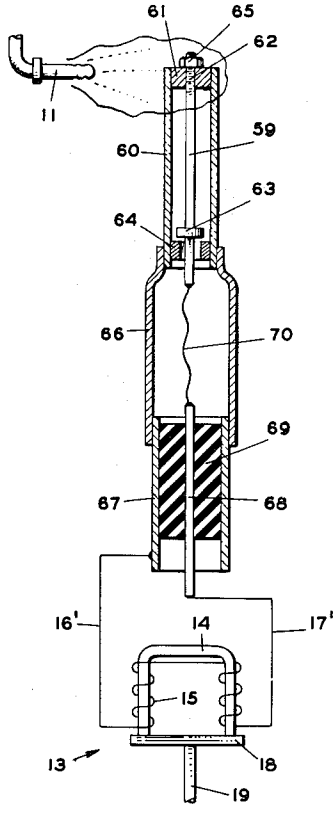


Fig. 8.

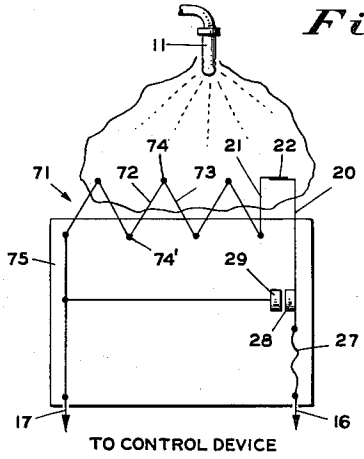
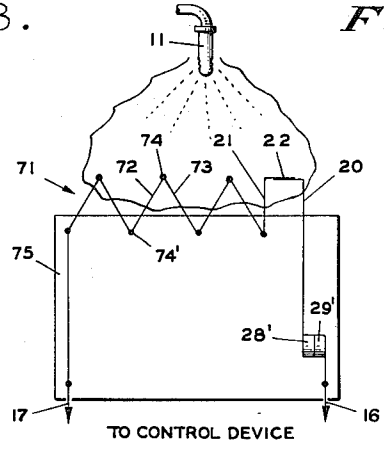


Fig. 9.



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THERMOELECTRIC GENERATORS

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Application December 9, 1952, Serial No. 324,990

20 Claims. (Cl. 317—133.5)

This invention relates to thermoelectric generators suitable for use with safety or other devices for controlling fuel burners, and one aspect thereof is directed particularly to improvements in such generators which decrease the time required for operation of the associated device following extinction of the flame which activates the generator. The present invention has useful characteristics in other respects than rapid decrease in electrical output upon cooling, and is therefore adapted to other applications than those involving the direct control of fuel burners.

By way of example, thermoelectric generators and their associated safety devices for gas burners of the character heretofore commercially available are, in general, restricted to use in installations where reasonably prompt operation of the safety device is acceptable following extinction of the burner flame applied to the thermoelectric generator. With these devices, operation usually occurs in about 50 to 60 seconds after flame failure; and in many appliances, such as water heaters and residential heating furnaces, as well as in some commercial applications, a time delay of this magnitude between flame failure and safety operation is not objectionable. However, there are many commercial types of gas burning apparatus, and certain domestic installations, to which thermoelectric safety devices have not been applied because of the need for faster operation than is obtainable with such devices as previously developed.

It is therefore one of the principal objects of the present invention to provide improved forms of thermoelectric generators which are capable of effecting more rapid operation of the associated thermoelectrically controlled devices following interruption of heating than can be achieved by use of the thermoelectric generators of the prior art.

In conventional safety control systems for gas burners, a thermoelectric generator, such as a thermocouple, is positioned closely adjacent to a pilot burner that is associated with a burner to be controlled so that the hot junction of the thermocouple is subjected to the heat of the pilot flame, and its cold junctions are connected to the energizing winding of an electromagnetic safety device which, when energized by the thermoelectric current produced by the generator, holds an armature in attracted position. The armature is connected to a valve or other control mechanism which is thereby maintained in running position to permit the flow of gas to the controlled burner. In such an installation, when the pilot flame is extinguished, the hot junction of the thermoelectric generator cools by radiation, conduction and natural convection, augmented, in some instances, by the cooling effect of the stream of unignited gas flowing from the pilot burner. Cooling of the hot junction results in a gradual, although relatively rapid, reduction in the output voltage of the generator and a consequent reduction in the thermoelectric current supplied to the winding of the electromagnetic safety device. When the output current reaches a predetermined, relatively low value,

the electromagnet releases the armature of the safety device and permits the latter and its associated control mechanism to move to safety position and cut off the flow of gas to the controlled burner. As indicated above, when using thermoelectric generators of the character heretofore available, a period of approximately 50 to 60 seconds elapses between failure of the pilot flame and operation of the safety device.

Other conventional arrangements include those in which the thermoelectric generator is heated by the flame at the burner controlled by the safety device, and those in which the flow of gas to the pilot burner as well as to the controlled burner is interrupted by the safety device upon cooling of the generator.

The improved thermoelectric generators of the present invention are characterized by the inclusion of elements having thermoexpansive or thermostatic characteristics which are employed to decrease or interrupt the output thermoelectric current of the generator and thereby effect deenergization of the control or other device more rapidly than would result from the decrease in thermoelectric current due to normal cooling of the hot junction of the generator.

The improved thermoelectric generators of the present invention may also be arranged so that the thermoexpansive or thermostatic elements will decrease or interrupt the output thermoelectric current of the generator upon heating of the thermostat above a predetermined value, in contrast with the use in which the output current is decreased or interrupted upon cooling of the generator thermostat. This arrangement is hence one in which an upper limit control action is provided. In other applications of the invention the desired characteristic may be the switching action by which the generator may be disconnected from associated circuits when the temperature of the thermostat of the generator is either above or below a predetermined value depending on the arrangement of the thermoexpansive or thermostatic elements.

One of the main objects of the invention is therefore to provide a novel form of thermoelectric generator which includes thermoelements having dissimilar thermal expansion characteristics, as well as different thermoelectric properties, and which utilizes the difference in thermal expansion of said elements for modifying the output of thermoelectric current from the generator.

A further object is to provide an improved control system for fuel burners which includes a thermoelectric generator subject to the heat produced by the flame of a main or pilot burner for supplying current to an electromagnetic control device wherein the dissimilar thermal expansion characteristics of said elements are employed for physically altering circuit conditions in the thermoelectric circuit between the generator and the control device.

Another object is to provide a thermoelectric generator embodying thermoresponsive or thermostatic means adapted to promptly decrease the effective thermoelectric current output upon discontinuance of heating of said generator, which generator also produces the less rapid but nevertheless certain normal decrease in thermoelectric current output in the event that the thermoresponsive or thermostatic means becomes inoperative.

Still another object is to provide a thermoelectric generator of novel, unitary construction in which the thermoelements serve the dual function of generating thermoelectric current and providing a thermostatic control of that current.

These, and other objects, including the provision of a quick-acting thermoelectric generator of simple, reliable construction, will appear more fully upon consideration of the following detailed description of the several different

embodiments of the invention which have been illustrated in the accompanying drawings. It is to be expressly understood, however, that these drawings are exemplary only and are not to be construed as defining the limits of the invention, for which latter purpose reference should be had to the appended claims.

In the drawings, wherein like reference characters indicate like parts throughout the several views:

Fig. 1 is a schematic representation of one form of improved thermoelectric generator embodying the invention wherein the thermostatically actuated contacts for controlling the flow of thermoelectric current are connected in parallel with the output circuit of a thermocouple having thermoelements of different thermal expansion characteristics, the generator being applied to a control system for fuel burners;

Fig. 2 is a similar schematic illustration of a modification of the system shown in Fig. 1 wherein the thermostatically actuated contacts are connected in series with the thermocouple output circuit;

Fig. 3 is a longitudinal sectional view of a closed type thermoelectric generator constructed in accordance with the present invention, certain of the parts thereof being shown in full and the associated burner and control device being illustrated diagrammatically;

Figs. 4 and 5 are transverse sectional views of the device shown in Fig. 3 taken substantially on the lines 4—4 and 5—5 in the latter figure;

Fig. 6 is a view similar to Fig. 3 showing a modified form of closed type generator wherein the thermostatically controlled contacts are in series, instead of in parallel, with the thermocouple output circuit;

Fig. 7 is a view similar to Fig. 3 showing still another form of closed type thermocouple embodying the invention wherein the thermostatically actuated contacts shunt the thermoelectric circuit to the control device upon extinction of the burner flame;

Fig. 8 is a schematic view of the generator portion of a system similar to that illustrated in Fig. 1 embodying a thermopile as the generator; and

Fig. 9 is a schematic view similar to Fig. 8 of a series arrangement of thermopile and thermostatically controlled contacts comparable to the system of Fig. 2.

In each figure of the drawings, the thermostatically actuated contacts are shown in the position occupied thereby when the control system is in its normal running condition with the burner flame fully ignited and heating the generator in normal manner.

Referring now to Fig. 1, there is shown therein a thermoelectric generator **12** positioned closely adjacent to a fuel burner **11** so as to be subject to the heat produced by the flame thereof and an electromagnetic control device **13** having a magnetizable core **14**, an energizing winding **15** adapted to receive thermoelectric current from the generator **12** through output leads **16** and **17**, and an armature **18** to which is connected an operating member **19**. Operating member **19** serves in known manner to move an associated control mechanism, such as a valve (not shown), to a released position when winding **15** is deenergized, whereby one of the following actions may be accomplished: (*a*) flow of fuel is discontinued to burner **11**, in which case burner **11** is the main burner; (*b*) flow of fuel is discontinued to a main burner (not shown) but continued to pilot burner **11**; (*c*) flow of fuel is discontinued to a main burner (not shown) and also to pilot burner **11**, this action being commonly known as 100 per cent shut-off. In the embodiment illustrated, the generator **12** consists of an open type thermocouple embodying thermoelements **20** and **21** having one end of each connected to one end of the other in overlapping relation to form a hot junction **22**, the opposite ends of the thermoelements, forming the cold junctions or output terminals **23** and **24** of the thermocouple, being connected to output leads **16** and **17**, respectively. Thermoelements **20** and **21** are joined together throughout the length of the overlapped hot junction **22** in any suitable manner, as by welding, and are made of any appropriate conductive metals having dissimilar thermal expansion characteristics as well as different thermoelectric properties, such as **18–8** stainless steel and constantan or Copel. The electromagnetic control device **13** of the associated control mechanism may conform to any of the various constructions now known to the art.

As thus far described (ignoring the overlapped character of hot junction **22** and the dissimilar thermal expansion characteristics of the thermoelements), the arrangement of Fig. 1 is of conventional construction and operates in known manner. As previously pointed out, it usually takes about 50 seconds or more after extinction of the burner flame for the ordinary thermocouple to cool sufficiently to effect operation of the control device. In order to reduce this time interval, commonly referred to as the "dropout" time, the present invention combines with the above described conventional type of control system thermoresponsive or thermostatically operated means for deenergizing the electromagnet winding of the control device more rapidly than would result from normal cooling of the hot junction of the thermocouple following flame failure.

In the embodiment illustrated in Fig. 1, thermocouple **12** is mounted on a base **25**, preferably formed of electrically insulating material, by means of a clamp **26** which rigidly fixes the cold junction end of thermoelement **21** to the base in position for connection of output terminal **24** to output lead **17**. As shown, the thermocouple is of inverted U-shape, the portion of thermoelement **20** which depends from the overlapped hot junction **22** being substantially parallel to, and free to move toward and away from, the rigidly supported portion of thermoelement **21**. The cold junction or output terminal end **23** of thermoelement **20** is connected to output lead **16** by means of a flexible conductor **27**.

With this arrangement, heating of hot junction **22** by the flame from burner **11** not only generates thermoelectric current which is supplied to the control device **13** through leads **16** and **17**, but also causes distortion in the overlapped ends of thermoelements **20**, **21** and consequent movement of the free portion of thermoelement **20** relative to the fixed portion of thermoelement **21**. If the coefficient of thermal expansion of thermoelement **20** is greater than that of thermoelement **21**, as it is assumed to be in the structure of Fig. 1, heating of hot junction **22** produces movement of thermoelement **20** away from thermoelement **21**, the amount of movement being dependent for a given temperature at hot junction **22** upon the respective coefficients of thermal expansion of the thermoelements, the length of the thermoelements and the length of their overlap at the hot junction. Cooling of hot junction **22** results in movement of the free end of thermoelement **20** toward thermoelement **21**. If the coefficient of thermal expansion of thermoelement **20** is less than that of thermoelement **21**, or if the overlap is made with thermoelement **20** above thermoelement **21**, instead of below as shown in Fig. 1 and with expansion coefficients as first described, the direction of movement upon cooling will be reversed, i. e., thermoelement **20** will move away from thermoelement **21**.

In accordance with the invention, the movement of the depending portion of thermoelement **20** relative to the substantially parallel, rigidly fixed portion of thermoelement **21** is employed to actuate a pair of electrical contacts **28** and **29** which control the flow of thermoelectric current to the output circuit of thermocouple **12**. As shown, thermoelement **20** is provided with a member **30** having an arm **31** extending toward thermoelement **21** and on which is supported contact **28**. Contact **29** is supported closely adjacent contact **28**, and is adjustable relatively to the latter, by means of a screw **32** having threaded engagement with a member **33** which is suitably mounted on thermoelement **21**. The physical connec-

tions betwen contacts **28, 29**, their respective supporting means and thermoelements **20, 21** are electrically conductive so that the contacts form part of the thermoelectric circuit; for example, members **30** and **33** may be brazed or silver soldered to thermoelements **20** and **21**, respectively, and the connections between arm **31** and member **30**, contact **28** and arm **31**, and contact **29** and screw **32** may be made in similar manner. The relative positions of contacts **28, 29** may be adjusted by threading screw **32** into or out of member **33**, a lock nut **34** being provided for fixing the screw in adjusted position. Alternatively, the screw **32** might be permanently fixed to member **33**, after adjustment, by brazing or soldering.

If desired, contacts **28, 29** may be protected against oxidation, or the presence of foreign material that might interfere with their proper operation, by surrounding the contacts with a suitable enclosure for preventing exposure thereof to the atmosphere surrounding the generator. For example, the contacts may be enclosed in a sealed metallic bellows **35** having one end brazed or soldered to member **33** and the other end embedded in a bead **36** of glass or other suitable insulating material which is fused to contact arm **31** intermediate contact **28** and member **30**.

The parts of the generator shown in Fig. 1 are so arranged and adjusted relative to one another that, when hot junction **22** is heated by the flame of burner **11** in normal manner, the resultant distortion of the overlapped portions of thermoelements **20, 21** due to their different thermal expansion characteristics causes the free portion of thermoelement **20** to move away from thermoelement **21**, to the left as viewed in Fig. 1, and to assume a position in which contact **28** is separated from contact **29**. The thermoelectric current generated by thermocouple **12** then flows to winding **15** of control device **13** through leads **16, 17** and flexible conductor **27**. Should the burner flame be extinguished, cooling of hot junction **22** distorts the overlapped portions of the thermoelements in the opposite direction and causes thermoelement **20** to move toward thermoelement **21** and close contacts **28, 29**, the structure being so designed and adjusted that closure of the contacts is effected promptly after extinction of the burner flame and before release of armature **18** with normal cooling of hot junction **22**.

When contacts **28, 29** are closed, a portion of the thermoelectric current generated by thermocouple **12** is shunted through the circuit comprising thermoelements **20, 21**, members **30, 33**, arm **31**, screw **32** and contacts **28, 29**, thereby reducing the current flowing through output leads **16, 17** to the winding **15** of control device **13**. The electrical characteristics of the two circuits are so selected that the decrease in current flow through winding **15** upon closure of contacts **28, 29** is sufficient to effect immediate release of armature **18** and movement of operating member **19** to released position. Provision of the shunt circuit thus materially shortens the dropout time of control device **13** as compared with operation of the conventional system. When burner **11** is reignited, the thermostatic action of the overlapped ends of thermoelements **20, 21** opens contacts **28, 29** quickly and within the time required for the thermoelectric current generated by thermocouple **12** to build up to a value at which the winding **15** of control device **13** is sufficiently energized to maintain armature **18** in its attracted running position.

The system illustrated in Fig. 2 is similar to that of Fig. 1 except that the contacts **28', 29'** are connected in series, rather than in parallel, with the output circuit of thermocouple **12**, and the contact supporting members are so mounted and adjusted that said contacts are closed, rather than open, when the generator is heated normally by the flame of burner **11**. To this end, member **33'** is fixed to base **25** instead of thermoelement **21** and is suitably insulated electrically therefrom, output lead **16** is connected to member **33'** instead of to the cold junction

of thermoelement **20**, and contacts **28', 29'** are so positioned that the thermostatically produced movements of contact **28'** relative to contact **29'** are opposite to those produced by the device of Fig. 1. With the arrangement shown in Fig. 2, extinction of the burner flame results in opening of contacts **28', 29'** which thereby completely interrupts the flow of thermoelectric current from thermocouple **12** to the winding **15** of control device **13** long before the hot junction **22** of the thermocouple has cooled sufficiently to effect release of armature **18** in the conventional manner.

The thermoelectric generators illustrated in Figs. 1 and 2 are of the open type in which both thermoelements are exposed to the action of combustion products from the burner flame at the hot junction. In many instances, such exposure may shorten the life of one of the thermoelements more rapidly than the other, in which case it is desirable to protect the more susceptible thermoelement. The closed type structures illustrated in Figs. 3–7 have therefore been provided for protecting the more susceptible thermoelement from exposure to combustion products by enclosing it within a hollow thermoelement made from the material that is the more resistant of the two to the action of such products.

In the device shown in Figs. 3–5, an elongated thermoelement **37** made of a material to be protected from exposure to the action of combustion products, such as constantan or Copel, is enclosed within a hollow thermoelement **38** of a different, more resistant material, such as 18–8 stainless steel, the upper end of the latter being closed by a plug **39** which may be made of the same metal as outer thermoelement **38**. Fixed to and depending from plug **39** is a relatively short thermoelement **40** which also may be of the same metal as thermoelement **38**, but must be of a different metal than thermoelement **37**, and to which is secured in overlapping relationship the upper end of inner thermoelement **37**, the overlapped portions of said elements forming an extended hot junction **41**. The junctions between inner thermoelement **37** and thermoelement **40** and between the latter, plug **39** and outer thermoelement **38** may be made by suitable welding procedures.

If desired, thermoelement **40** may be of a different material than outer thermoelement **38** and plug **39**, such different material being selected because of a more suitable thermal expansion characteristic. In this event, thermoelement **40** would form one thermojunction with plug **39** and another with thermoelement **37**. The temperature difference between these two junctions would be small due to the relatively short length of thermoelement **40**. In any event, thermoelements **37** and **40** must have dissimilar thermal expansion characteristics in order to produce the thermostatic action which is characteristic of the present invention.

Fixed to the lower open end of outer thermoelement **38**, as by brazing, is a conductive sleeve **42** to the lower end of which is connected, also by brazing, a tubular lead member **43**. Sleeve **42** serves as one of the output leads of the thermoelectric generator. A conductor **44** is fixedly positioned within tubular lead member **43** in coaxial relation therewith and electrically insulated therefrom by means of fixed spaced supporting blocks **45** and **46** of nonconducting material having forced fits within member **43**. The upper end of conductor **44** is electrically connected to inner thermoelement **37** by a flexible conductor **47** and a contact block **48** which is suitably fixed to the free, lower end of thermoelement **37**, as by silver soldering or brazing. Conductor **47** comprises the other output lead of the generator. The lower ends of tubular member **43** and the coaxially arranged conductor **44** are connected to the energizing winding **15** of electromagnetic control device **13** in any suitable manner, as by leads **16'** and **17'** which, if desired, may be arranged coaxially as continuations of member **43** and conductor **44**, respectively. With this construction, the central portions of concentric leads

43, 44 may be bent, if desired, to facilitate installation without disturbing the rest of the structure or the electrical connections between the conductive elements thereof.

Outer thermoelement 38 is illustrated as made in the form of a thin-walled tube flattened into oval shape over the upper portion of its length, as indicated in Fig. 4, plug 39 having a similar oval shape. This oval portion of thermoelement 38 provides an enclosure for extended hot junction 41 having minimum heat capacity, and serves as the hot junction end of the generator. The lower portion of thermoelement 38 may be of circular section, as indicated in Fig. 5.

In order to provide the device of Figs. 3–5 with the improved thermostatic control of the present invention, contact block 48 at the lower end of inner thermoelement 37 is provided with an electrical contact 49 adapted to cooperate with a second contact 50 which is fixed to the inner end of a screw 51 adjustably threaded through a boss 52 forming part of conductive sleeve 42. A lock nut 53 may be provided for fixing screw 51 and its contact 50 in adjusted position. Contact 50 is soldered or brazed to screw 51 and is thus electrically connected to sleeve 42. Since movable contact 49 is also electrically connected to inner thermoelement 37 through contact block 48, it will be evident that the two contacts are in parallel with the output leads of the generator represented by sleeve 42 and flexible conductor 47.

As indicated in Fig. 3, the generator structure is adapted to be mounted closely adjacent burner 11 so that the upper end thereof, which houses the hot junction 41, may be subjected directly to the heat of the burner flame. The coefficients of thermal expansion of thermoelements 37 and 40 are so selected and the overlapped hot junction 41 is so formed that when the upper end of the generator is heated, the heat conducted through plug 39 to the hot junction causes distortion of the overlapped portions of the thermoelements in such directions that the free, lower end of inner thermoelement 37 moves to the left, as viewed in Fig. 3, and assumes a position in which movable contact 49 is separated from fixed contact 50. At the same time, heating of the hot junction 41 generates thermoelectric current which flows through the circuit comprising inner thermoelement 37, contact block 48, flexible output conductor 47, conductor 44, lead 17', winding 15, lead 16', tubular lead member 43, output sleeve 42, outer thermoelement 38, plug 39 and thermoelement 40.

When the burner flame is extinguished, hot junction 41 cools rapidly and the overlapped portions of thermoelements 37 and 40 are so distorted as to deflect the lower end of thermoelement 37 to a position wherein contacts 49, 50 close, whereupon a portion of the thermoelectric current produced by the generator is shunted through the circuit comprising contacts 49, 50 and screw 51, and the current flowing through leads 16', 17' is reduced below the value required to maintain the armature 18 of control device 13 in attracted or running position. As in the case of Figs. 1 and 2, the thermal expansion characteristics of thermoelements 37, 40 are so selected and the parts of the device of Fig. 3 are so designed and adjusted that contacts 49, 50 are closed within the desired time period after the burner flame is extinguished so that the control device functions much more quickly than it would were it dependent solely upon normal cooling of the hot junction of the thermocouple for reduction of the thermoelectric current output.

The device illustrated in Fig. 6 is similar in construction to that of Figs. 3–5, but differs from the latter in that the contacts 49', 50' are so arranged as to be closed, instead of open, when the upper end of the structure is heated in normal manner by the flame of burner 11, and are in series, instead of in parallel, with the output circuit of the thermoelectric generator. To this end, contact 50' is mounted on a block 54 having an insulated back 55, block 54 being fixed to the upper end of an arm 56 of conductive material which is fixedly positioned within sleeve 42' and electrically insulated therefrom in any suitable manner, as by a supporting block 57 having a forced fit within the lower portion of sleeve 42'. The lower end of arm 56 is electrically connected to the upper end of conductor 44' by a flexible conductor 58. Sleeve 42' and flexible conductor 58 constitute the output leads of the generator. As shown, contact 50' is so positioned with respect to contact 49' that, upon application of heat to hot junction 41', the difference in thermal expansion of the overlapped portions of thermoelements 40' and 37' causes contact 49' to move into engagement with contact 50' and thereby close the circuit through which the thermoelectric current is supplied to control device 13. The position of contact block 54 and contact 50' may be adjusted in any suitable manner, as by means of adjusting screw 51' which is threaded through boss 52' of sleeve 42' and bears at its inner end against the insulated back 55 of block 54, it being understood that arm 56 is sufficiently resilient to permit the desired adjusting movement of said block.

In operation, the generator of Fig. 6 is directly comparable to that of Fig. 2 in that, when the parts are properly adjusted, normal heating of hot junction 41' provides a closed circuit for the flow of thermoelectric current to the control device through contacts 49', 50'. Upon extinction of the burner flame, contacts 49', 50' are opened promptly by the thermostatic movement of inner thermoelement 37' resulting from the cooling of hot junction 41', and thereby open the thermoelectric circuit and effect operation of the control device much more quickly than would be possible in the absence of the thermostatic control.

The further modification of the invention illustrated in Fig. 7 is similar to the devices of Figs. 1 and 3–5 in that it includes thermostatically actuated contacts which shunt the thermoelectric circuit to the control device upon flame failure, but differs from all of the previously described constructions by relying upon the net linear thermal expansion of the thermoelements for thermostatic actuation of the contacts.

As shown in Fig. 7, the thermoelectric generator comprises an inner thermoelement 59 and an outer hollow thermoelement 60 of different thermal expansion characteristics as well as different thermoelectric properties, the upper end of outer thermoelement 60 being closed by a metallic plug 61 which is fixed thereto in any suitable manner, as by welding. Inner thermoelement 59 is threaded at its upper end, as indicated at 62, for engagement with a similarly threaded, centrally positioned aperture in plug 61, and has fixed thereto adjacent its lower end a disk type contact 63 adapted to cooperate with an annular or ring type contact 64 which is fixed to the inner wall of outer thermoelement 60 at the lower end thereof just below contact 63. Contacts 63 and 64 may be brazed or silver soldered in the positions shown in Fig. 7 with respect to thermoelements 59 and 60 so as to be in good electrical contact therewith.

In assembling the structure, inner thermoelement 59 may first be inserted in outer thermoelement 60 with contacts 63, 64 in the relative positions shown in Fig. 7 and plug 61 may then be threaded onto the upper end of thermoelement 59 and positioned in the upper end of thermoelement 60. Thereafter inner thermoelement 59 may be turned with respect to plug 61 until contact 63 is brought into the desired position relative to contact 64 and be held in position by a lock nut 65 applied to the outwardly extending end of thermoelement 59 to maintain the final contact adjustment. If desired, thermoelement 59 and lock nut 65 may be welded to plug 61 after the desired adjustment has been made.

The remainder of the generator comprises a conductive sleeve 66 fixed to the lower open end of outer thermoelement 60, as by brazing, and a tubular lead member 67

connected to the lower end of sleeve **66**, also by brazing. Conductor **68** is fixedly positioned within tubular lead member **67** in coaxial relation therewith and electrically insulated therefrom by a non-conducting supporting block **69** having a forced fit within member **67**. The upper end of conductor **68** is electrically connected to the free, lower end of inner thermoelement **59** by a flexible conductor **70**, there being either electrical insulation or a suitable air gap between the portion of thermoelement **59** below contact **63** and the surrounding wall of the opening in contact **64** through which the end of said thermoelement passes. As in the previously described embodiments, the lower ends of tubular member **67** and the coaxially arranged conductor **68** are connected to the energizing winding **15** of electromagnetic control device **13** in any suitable manner, as by leads **16'** and **17'** which, if desired, may be arranged coaxially as continuations of member **67** and conductor **68**, respectively. Sleeve **66** and flexible conductor **70** constitute the output leads of the generator.

In the structure of Fig. 7, outer thermoelement **60** is made of material having a greater coefficient of thermal expansion than that of inner thermoelement **59**. Consequently, when the hot junction at **60**, **61**, **62**, **59** is heated in normal manner by the flame of burner **11**, outer thermoelement **60** undergoes a greater linear expansion than inner thermoelement **59** and thereby causes contacts **63**, **64** to separate so that the electrical output of the generator flows through sleeve **66**, tubular lead member **67**, flexible conductor **70**, conductor **68** and leads **16'**, **17'** to the winding **15** of control device **13**. Upon extinction of the burner flame, the net contraction of the thermoelements due to their different thermal expansion characteristics is such as to close contacts **63**, **64** and thereby shunt the thermoelectric current produced by the generator away from the output circuit to the control device. Should the coefficient of thermal expansion of outer thermoelement **60** be less than that of inner thermoelement **59**, the same method of operation may be obtained by simply locating contact **63** below, instead of above, contact **64**.

It will be recognized that, where linear thermal expansion of the thermoelements is employed to actuate the contacts, as in Fig. 7, the relative movement of the contacts is necessarily less for a given hot junction temperature than the movement obtainable in devices such as those shown in Figs. 1–6 where amplification of contact movement is obtained by reason of the length of thermoelement **20** (Figs. 1 and 2) and **37** or **37'** (Figs. 3–6).

Figs. 8 and 9 illustrate diagrammatically how the invention may be applied to systems wherein the thermoelectric generator consists of a thermopile instead of a single thermocouple. As shown in Fig. 8, a thermopile **71**, having a series of thermoelements **72** and **73** of suitable dissimilar metals connected together to form hot junctions **74** and cold junctions **74'**, is mounted in any convenient manner on a support **75** and is positioned closely adjacent burner **11** so that the hot junctions **74** are all subjected to the heat produced by the burner flame. At the right-hand end of the series is a thermocouple of the type shown in Fig. 1, comprising thermoelements **20** and **21** having an overlapped hot junction **22**, wherein the thermoelements perform the dual function of generating thermoelectric current and of thermostatically actuating a pair of control contacts **28** and **29**. As in the system of Fig. 1, contacts **28** and **29** are electrically connected to leads **16** and **17**, respectively, in parallel with the circuit by which the thermoelectric current generated by the thermopile is supplied to a control device (not shown), and are maintained in open position by the thermostatic action of thermoelements **20** and **21** as long as hot junction **22** is heated in normal fashion. Inasmuch as the operation of the arrangement illustrated in Fig. 8 is the same as that of Fig. 1 except for the presence of a plurality of conventional thermocouples **72**, **73**, **74** in series with thermocouple **20**, **21**, **22** embodying the thermostatic feature of the invention, a detailed description of said operation would appear unnecessary.

The device represented by Fig. 9 is similar to that of Fig. 8 except that the contacts **28'**, **29'**, are connected in series, rather than in parallel, with the output of thermopile **71**, and are so mounted and adjusted that they are closed, rather than open, when the generator is heated normally by the flame of burner **11**. The arrangement of Fig. 9 is thus directly comparable to that of Fig. 2 and operates in the same manner as the latter.

For purposes of illustration the drawings exemplify the use of the present invention to hasten the operation of an associated control device upon interruption of heating of the hot junction or junctions and of the thermostat. It is to be expressly understood, however, that the thermostats may be arranged to reduce or interrupt the thermoelectric output current when heating exceeds a predetermined value.

Other contemplated uses of the present invention include applications in which the switching action of the improved thermoelectric generator is the desired function in that the generator may disconnect itself from associated circuits when the temperature of the thermostat is above or below a predetermined temperature depending on the arrangement of the thermostat.

There is thus provided by the present invention a new and improved form of thermoelectric generator which may be used with control devices for fuel burning apparatus, as well as with other devices, and which materially decreases the time interval between interruption of heating of the generator and operation of the associated control or other device. The improvement resides primarily in the provision of thermoelements having different thermal expansion characteristics as well as different thermoelectric properties and in the combination with such thermoelements of means controlled by their thermostatic action whereby the output of thermoelectric current from the generator is either decreased or interrupted promptly after failure of the flame or other source of heat and operation of the control device is effected more rapidly than would result from the decrease in thermoelectric current due to normal cooling of the hot junction or junctions of the generator. The invention also provides structurally novel thermoelectric generators of the closed type incorporating the thermostatic control feature above mentioned.

Although several specifically different forms of the invention have been described and illustrated in detail, it is to be expressly understood that these devices are intended for purposes of illustration only, and that the inventive concept is capable of a variety of mechanical embodiments. For example, it is obvious that the thermoelectric generator may incorporate any suitable combination of thermoelements having dissimilar thermoelectric and thermal expansion characteristics, and that the generator may be used with other forms of control device, or for other purposes, than herein represented. It is equally evident that the specific character and construction of the heat source with which the generator is associated is not material as long as it simultaneously heats the hot junction of the thermocouple sufficiently to maintain an adequate output of thermoelectric current and produces the desired thermostatic movement of the control contacts. In this connection, it will be understood that the generator may be used with electrical as well as fuel burning sources of heat. It will also be recognized that the bellows enclosure of the contacts shown in Figs. 1 and 2 is not essential and may be modified or omitted, if desired, and that the linear thermal expansion principle of Fig. 7 may be employed to actuate contacts in series, as well as in parallel, with the output circuit.

Various other changes, which will now suggest themselves to those skilled in the art, may be made in the mechanical construction, arrangement, electrical char-

acteristics and use of the device without departing from the inventive concept. Reference is therefore to be had to the appended claims for a definition of the limits of the invention.

What is claimed is:

1. A thermoelectric device comprising thermoelements of dissimilar metals forming a thermoelectric generator having at least one hot junction and two free ends of dissimilar thermoelements, said one hot junction being between adjacent thermoelements having different thermal expansion characteristics as well as different thermoelectric properties, said adjacent thermoelements of different thermal expansion characteristics being so constructed and arranged as to produce relative movement between portions thereof remote from said one hot junction upon heating and cooling of said junction, output leads connected to the free ends of said thermoelements, and means actuated by the relative movement between said adjacent thermoelements for controlling the flow of thermoelectric current in said leads.

2. A thermoelectric device comprising thermoelements of dissimilar metals forming a thermoelectric generator having at least one hot junction and two free ends of dissimilar thermoelements, said one hot junction being between adjacent thermoelements having different thermal expansion characteristics as well as different thermoelectric properties, said adjacent thermoelements of different thermal expansion characteristics being so constructed and arranged as to produce relative movement between portions thereof remote from said one hot junction upon heating and cooling and said junction, means for connecting the free ends of said thermoelements with the conductors of an output circuit, and contacts adapted to control the flow of thermoelectric current to said output circuit, said contacts being actuated between open and closed positions by the relative movement between said adjacent thermoelements.

3. A thermoelectric device comprising thermoelements of dissimilar metals forming a thermoelectric generator having at least one hot junction and two free ends of dissimilar thermoelements, said one hot junction being between adjacent thermoelements having different thermal expansion characteristics as well as different thermoelectric properties, said adjacent thermoelements of different thermal expansion characteristics being so constructed and arranged as to produce relative movement between portions thereof remote from said one hot junction upon heating and cooling of said junction, output leads connected to the free ends of said thermoelements, and a pair of contacts connected in parallel with said leads for controlling the output of thermoelectric current therefrom, said contacts being actuated between open and closed positions by the relative movement between said adjacent thermoelements.

4. A thermoelectric device comprising thermoelements of dissimilar metals forming a thermoelectric generator having at least one hot junction and two free ends of dissimilar thermoelements, said one hot junction being between adjacent thermoelements having different thermal expansion characteristics as well as different thermoelectric properties, said adjacent thermoelements of different thermal expansion characteristics being so constructed and arranged as to produce relative movement between portions thereof remote from said one hot junction upon heating and cooling of said junction, output leads conneted to the free ends of said thermoelements, and a pair of contacts connected in series with one of said leads for controlling the output of thermoelectric current therefrom, said contacts being actuated between open and closed positions by the relative movement between said adjacent thermoelements.

5. A thermoelectric device comprising a pair of thermoelements of different thermoelectric and thermoexpansive properties so connected to one another as to provide a combination thermostat and thermoelectric generator having a hot junction, the first of said thermoelements having a portion free to move relatively to the second thermoelement whereby heating and cooling of said junction produces movement of the free portion of said first thermoelement relative to the second thermoelement, and a pair of contacts for controlling the output of thermoelectric current from said generator, one of said contacts being operated by the movable portion of said first thermoelement and the other contact being normally fixed with respect to said second thermoelement.

6. A thermoelectric device comprising a pair of thermoelements of different thermoelectric and thermoexpansive properties so connected to one another as to provide a combination thermostat and thermoelectric generator having a hot junction, the first of said thermoelements having a portion free to move relatively to the second thermoelement whereby heating and cooling of said junction produces movement of the free portion of said first thermoelement relative to the second thermoelement, and a pair of contacts for controlling the output of thermoelectric current from said generator, one of said contacts being actuated by, and electrically connected to, the movable portion of said first thermoelement and the other contact being normally fixed with respect to, and electrically connected to, said second thermoelement.

7. A thermoelectric device comprising a pair of thermoelements of different thermoelectric and thermoexpansive properties so connected to one another as to provide a combination thermostat and thermoelectric generator having a hot junction, the first of said thermoelements having a portion free to move relatively to the second thermoelement whereby heating and cooling of said junction produces movement of the free portion of said first thermoelement relative to the second thermoelement, and a pair of contacts for controlling the output of thermoelectric current from said generator, one of said contacts being actuated by, and electrically connected to, the movable portion of said first thermoelement and the other contact being normally fixed with respect to, and electrically insulated from, said second thermoelement.

8. A thermoelectric device comprising a pair of thermoelements of different thermoelectric and thermoexpansive properties so connected to one another as to provide a thermoelectric generator having a hot junction, the first of said thermoelements having a portion free to move relatively to the second thermoelement whereby heating and cooling of said junction produces movement of the free portion of said first thermoelement relative to the second thermoelement, a pair of contacts for controlling the output of thermoelectric current from said generator, one of said contacts being actuated by the movable portion of said first thermoelement and the other contact being normally fixed with respect to said second thermoelement, and means forming an enclosure for said contacts to prevent exposure thereof to the atmosphere surrounding the generator.

9. A thermoelectric device comprising a pair of thermoelements of different thermoelectric and thermoexpansive properties so connected to one another as to provide a combination thermostat and thermoelectric generator having a hot junction, the first of said thermoelements having a portion free to move relatively to the second thermoelement whereby heating and cooling of said junction produces movement of the free portion of said first thermoelement relative to the second thermoelement, a pair of contacts for controlling the output of thermoelectric current from said generator, one of said contacts being actuated by the movable portion of said first thermoelement and the other contact being normally fixed with respect to said second thermoelement, and a sealed bellows enclosing, and electrically insulated from at least one of, said contacts to prevent exposure thereof to the atmosphere surrounding the generator.

10. A thermoelectric device comprising at least a pair of thermoelements of different thermoelectric properties

joined to provide a thermoelectric generator having a hot junction and having their free ends separated from one another, one of said thermoelements being hollow and forming at least part of an enclosure for a second thermoelement, a pair of contacts within said enclosure, the first of said contacts being operated by said second thermoelement and a second contact being normally fixed with respect to said one thermoelement, a conductor insulated from said one thermoelement, and a conductive connection between said conductor and one of said contacts, said thermoelements also having different thermal expansion characteristics and being so connected together that the difference in thermal expansion thereof actuates said contacts upon heating and cooling of said hot junction.

11. A thermoelectric device comprising at least a pair of thermoelements of different thermoelectric properties joined to provide a thermoelectric generator having a hot junction and having their free ends separated from one another, one of said thermoelements being hollow and forming at least part of an enclosure for a second thermoelement, a pair of contacts within said enclosure, the first of said contacts being operated by and electrically connected to said second thermoelement and the second contact being normally fixed with respect to, and electrically connected to, said one thermoelement, a conductor insulated from said one thermoelement, and a conductive connection between said conductor and said first contact, said thermoelements also having different thermal expansion characteristics and being so connected together that the difference in thermal expansion thereof actuates said contacts upon heating and cooling of said hot junction.

12. A thermoelectric device comprising at least a pair of thermoelements of different thermoelectric properties joined to provide a thermoelectric generator having a hot junction and having their free ends separated from one another, one of said thermoelements being hollow and forming at least part of an enclosure for a second thermoelement, a pair of contacts within said enclosure, the first of said contacts being operated by and electrically connected to said second thermoelement and the second contact being normally fixed with respect to, and electrically insulated from, said one thermoelement, a conductor insulated from said one thermoelement, and a conductive connection between said conductor and said second contact, said thermoelements also having different thermal expansion characteristics and being so connected together that the difference in thermal expansion thereof actuates said contacts upon heating and cooling of said hot junction.

13. A thermoelectric device comprising a first thermoelement at least a portion of which is of hollow construction, a second thermoelement housed at least partially within said first thermoelement and connected at one end to the latter to form a thermoelectric generator having a hot junction, first and second output conductors for connecting said first and second thermoelements to a utilization circuit, said first and second thermoelements having different thermal expansion characteristics and being so constructed and arranged that heating and cooling of said hot junction produces relative movement therebetween, and means actuated by the relative movement of said thermoelements due to the difference in thermal expansion thereof for controlling the flow of thermoelectric current in said output conductors.

14. In a control system for fuel burners, a thermoelectric device having at least one pair of thermoelements of different thermoelectric properties connected together to provide a thermoelectric generator having a hot junction subject to the heat produced by the flame at a burner, a safety device adapted to be energized by the thermoelectric current produced by said generator, the said pair of thermoelements also having different thermal expansion characteristics and being so constructed and arranged that heating and cooling of said hot junction produces relative movement therebetween, and means actuated by the relative movement of said thermoelements due to the difference in thermal expansion thereof for controlling the flow of thermoelectric current from said generator to said safety device.

15. In a control system for fuel burners, a thermoelectric device having output terminals and at least one pair of thermoelements of different thermoelectric properties connected together to provide a thermoelectric generator having a hot junction subject to the heat produced by the flame at a burner, a safety device adapted to be energized by the thermoelectric current produced by said generator, a circuit connecting the output terminals of said thermoelectric device to said safety device, and a pair of contacts for controlling the flow of thermoelectric current in said circuit, one of said contacts being operated by one of said pair of thermoelements and being movable by the latter relatively to the other contact, said one thermoelement having a different coefficient of thermal expansion from the other thermoelement whereby heating and cooling of said thermoelements produces movement of said one contact relative to the other contact.

16. In a control system for fuel burners, a thermoelectric device having output terminals and at least one pair of thermoelements of different thermoelectric properties connected together to provide a thermoelectric generator having a hot junction subject to the heat produced by the flame at a burner, a safety device having an energizing winding connected to the output terminals of said thermoelectric device, the said pair of thermoelements also having different thermal expansion characteristics, and means controlled by the difference in thermal expansion of said thermoelements for decreasing the flow of thermoelectric current from said generator to said winding upon extinction of the burner flame.

17. In combination, a source of heat, a thermoelectric device having output terminals and at least one pair of thermoelements of different thermoelectric properties connected together to provide a thermoelectric generator having a hot junction subject to the heat produced by said source, a safety device connected to the output terminals of said thermoelectric device and adapted to be energized by the thermoelectric current produced by the generator when the heat source is producing heat, the said pair of thermoelements also having different thermal expansion characteristics, and a pair of contacts actuated by the relative movement of said thermoelements due to the difference in thermal expansion thereof for deenergizing said safety device when the heat source ceases to produce heat.

18. In combination, a source of heat, a thermoelectric device having output terminals and a pair of thermoelements of different thermoelectric properties connected together to provide a thermocouple having a hot junction subject to the heat produced by said source, a safety device connected to the output terminals of said thermoelectric device and adapted to be energized by the thermoelectric current produced by said thermocouple when the heat source is producing heat, the thermoelements of said thermocouple also having different thermal expansion characteristics, and means comprising a pair of contacts actuated by the relative movement of said thermoelements due to the difference in thermal expansion thereof for decreasing the flow of thermoelectric current from said thermocouple to said safety device when the heat source ceases to maintain the hot junction of said thermocouple within a desired temperature range.

19. In combination, a source of heat, a thermoelectric device having output terminals and a pair of thermoelements of different thermoelectric properties connected together to provide a thermocouple having a hot junction subject to the heat produced by said source, a safety device connected to the output terminals of said thermoelectric device and adapted to be energized by the thermo-

electric current produced by said thermocouple when the heat source is producing heat, the thermoelements of said thermocouple also having different thermal expansion characteristics, and means comprising a pair of contacts actuated by the relative movement of said thermoelements due to the difference in thermal expansion thereof for opening the thermoelectric circuit between said thermocouple and said safety device when the heat source ceases to maintain the hot junction of said thermocouple within a desired temperature range.

20. In combination, a source of heat, a thermopile having output terminals and a plurality of pairs of thermoelements connected together to provide a plurality of thermocouples having hot junctions all subject to the heat produced by said source, the thermoelements of at least one of said pairs having different thermal expansion characteristics, a safety device connected to the output terminals of said thermopile and adapted to be energized by the thermoelectric current produced thereby when the

heat source is producing heat, and means comprising a pair of contacts for controlling the flow of thermoelectric current from said thermopile to said safety device, said contacts being actuated by the relative movement of said one pair of thermoelements due to the difference in thermal expansion thereof.

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