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The Thermostat or Heat Governor
An Outline of its History

BY

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(Read at the Science Museum, London, Feb. 13th, 1946).

Since the beginning of the 18th Century, the evolution of heat and its control have presented a succession of problems which have had to be overcome before the machines and apparatus to which they were related could give reliable service. In many instances manual control is not only impracticable but impossible and to deal with undesired temperature changes, a variety of heat-governing devices have been evolved which are known to-day under the general name of thermostats. The word was coined in 1830 but the idea of using a medium or device capable of responding to variations in the temperature of the environment and thereby of exercising a control, giving an indication or raising an alarm, is about a century older. The earliest example that can be found of such a device is the so-called " gridiron " clock pendulum devised in 1726 by John Harrison best known for the chronometer he invented.

Harrison, although by trade a carpenter, knew something of metals, and to avoid the inaccuracy due to the effect of temperature variations on the metal clock components he produced a pendulum of variable length (Fig. 22), the variable elements being of brass which expands more readily than the steel of which the remainder of the pendulum was composed. Expansion of the brass bars A draws the pendulum bob upwards and thus counteracts the expansion of the central bar as the surrounding air becomes warmer. Thus the pendulum acts as a governor to maintain the clock movement at a constant rate irrespective of temperature variations.

In 1761, Harrison went further and produced the first bi-metallic device, developments of which are in use for certain purposes at the present day. Harrison's device (Fig. 23) which he described as a " compensation curb " was designed to alter the effective length of the balance spring of his chronometer in proportion to the expansion or contraction caused by variations of atmospheric temperature. This " compensation curb " consisted of two strips of metal, having different expansion ratios, riveted together.

In the 18th century and in the early part of the 19th, progress in the development of automatic heat governors was slow, largely because there were no instruments or apparatus in use (apart from clocks and watches) which necessitated that control within fine limits of temperature which it is the purpose of an automatic governor to impart. Also, at a time before precision machine tools were available, the manufacturing difficulty was formidable and any heat governors which were made had to be produced singly by hand by highly skilled craftsmen. For these reasons, it is doubtful whether devices evolved during the late 18th and early 19th centuries ever got into use, although possibly a few experimental models were given practical trials. No record can be found of any industrial applications of heat responsive control or indicating devices until the second half of the 19th century.

When the different expansion ratios of metals were first observed cannot be ascertained but it is submitted that Harrison, not being a metallurgist, was making use of existing knowledge when he devised the arrangements shown in Figs. 21 and 23. The knowledge of Harrison's

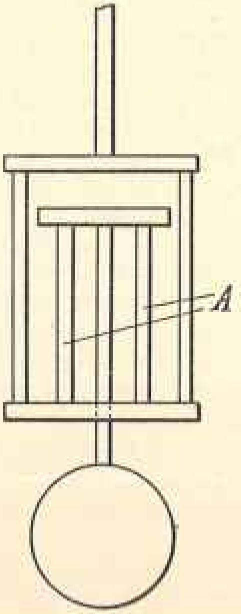


Fig. 22. Diagram of Harrison's gridiron pendulum, 1726.

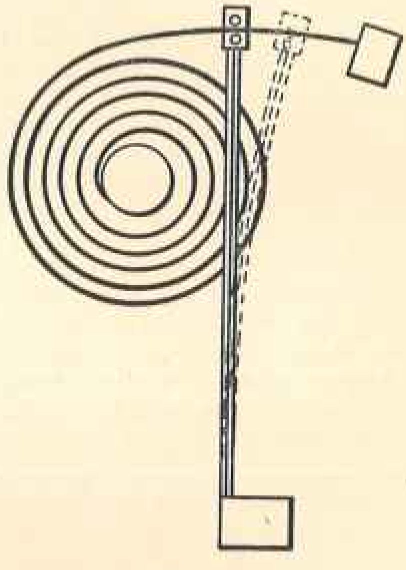


Fig. 23. Diagram of Harrison's compensation curb, 1761.

devices seems to have spread for in 1777 Bonnemain of Paris described the use of such a device for the control of temperature in buildings and also for the control of egg incubators. Bonnemain's heat governor consisted of a compound metallic element formed by a bar of iron screwed to one of brass and enclosed in a leaden tube terminating in a brass ring. For the control of room temperature, the heat governor was inserted in a boiler, having flow and return pipes, by which hot water was circulated through the rooms of a building. The distortion of the composite metallic bar as the water in the boiler reached a predetermined temperature was utilised to operate through linkage and close the ashpit door which acted as a damper. Alternatively, the composite metallic element could be exposed to the heat within an incubator chamber and was arranged, when a predetermined temperature was exceeded, to pull on a wire and close or partially close the ashpit door of the heating furnace and thereby reduce the temperature of the incubator and maintain it at the predetermined degree.

The next development of the heat governor was on entirely different lines and was known as the balance thermometer. It was invented by James Kewley in 1816 (British Patent No. 4086) (Fig. 24) and consisted of a tube A—B poised horizontally on an axis *m* with a bulb X at one end filled with mercury and a bulb Z at the opposite end filled with alcohol. The tube was held in a support *i* in which it was adjustable by slackening and tightening a screw *d*. A scale of temperatures enabled the tube to be adjusted until it balanced. Change of temperature thereafter

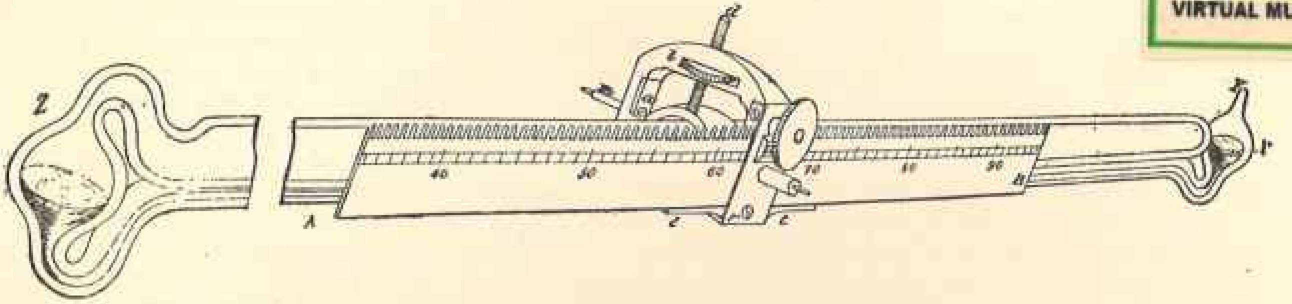


Fig. 24. KEWLEY'S BALANCE THERMOMETER 1816.
(From his Patent specification).

would affect, albeit unequally, both liquid charges to unbalance the tube; its rocking movement was utilised to actuate a device to increase or decrease the heat of an apartment or a greenhouse. In the words of the inventor, the balance thermometer " may be used as a first moving power to answer many useful purposes; so as to put delicate machinery, with which mechanics are well acquainted, into motion; for the purpose of ringing an alarm bell in the case of accidental fire; for regulating the temperature in hospitals, hothouses, and the like where a regular temperature may be desirable."

The honour of naming the heat governor the " Thermostat," and of indicating wider industrial applications for it than had previously been suggested, belongs to Dr. Andrew Ure (1778—1857). He gained his degree of Doctor of Medicine at Glasgow in 1801 and became Professor of Chemistry and Natural Philosophy in the Andersonian Institution in 1802. He removed to London in 1830 and was appointed Analytical Chemist to the Board of Customs in 1834. He was the author of a number of scientific and philosophical Works; his *Dictionary of Arts, Manufactures and Mines* published in 1839 ran into several editions both in this Country and in the United States of America. Dr. Ure's claim to fame as regards the subject of this paper is concerned, is based on a patent granted to him in 1830 (No. 6014) entitled " An apparatus for regulating Temperature in Vaporization, Distillation and other Processes." In the Specification several forms of automatic temperature control apparatus are described and shown, an example being illustrated in Fig. 25. A is the bi-metallic element (although the drawing shows three connected strips), flexing of which under increasing temperature rocks the levers B—C—D to raise the damper E. At the same time a pointer F gives a temperature indication on a scale. Ure describes the heat responsive element A as a bar or ruler of platina, iron or steel united to a bar or ruler of zinc by solder or by numerous rivets. He then goes on to say:—

" The said compound bar and apparatus . . . . constitutes a self-acting instrument for regulating or controuling temperature, which I propose to call a heat governor; and it also serves to fix the heat of a medium at a definite degree amid causes of ever-fluctuating temperature, for which reason I also propose to call it a thermostat." Thus was born the name which has since been applied to a great variety of devices whose object is to respond to temperature variations as well as to indicate or record. Ure lectured on his thermostat before the Royal Society of which he had been elected a Fellow in 1822; his Lecture need not be quoted here as it follows substantially the description contained in his Patent Specification.

Altogether Ure was granted five Patents in one of which, No. 6016/1830 he described an air-heating stove with a thermostatic control. There is no record of Ure's thermostat ever getting

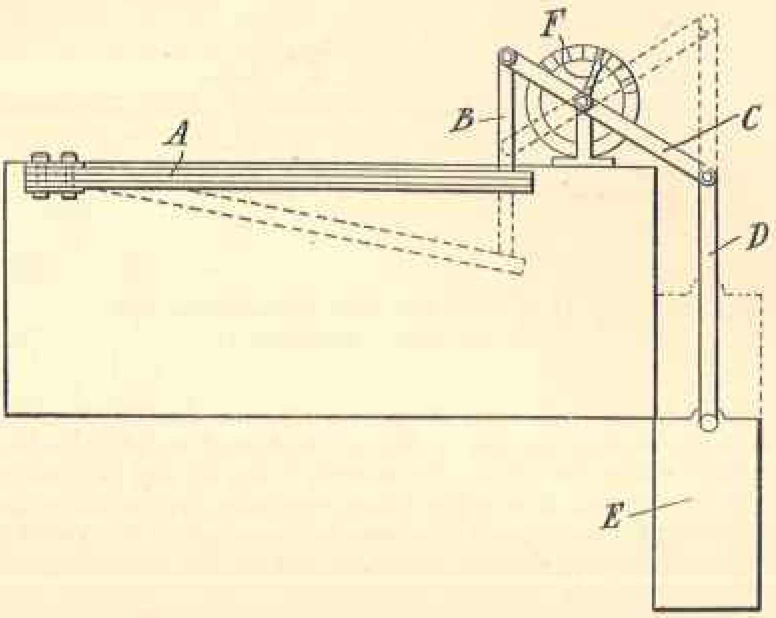


Fig. 25. URE'S THERMOSTAT, 1830.
(From his Patent specification).

into industrial use, and it is doubtful whether it would have had any success in practice because the rivetting together of the two metal strips is unsatisfactory and it was not until a method of firmly uniting them by heat treatment was found that the bi-metallic strip became a dependable component for a heat governor.

After Ure's invention, thermostat development in this country was very slow, but during the middle years of the 19th century a number of inventions devoted to it were evolved in the United States of America, a young country then seething with creative energy and the spirit of discovery both in the geographical and mechanical fields. During that period the United States led the world in the evolution of labour-saving machinery and automatic devices, many of which, although modified by the experience gained in use and by the application of additional scientific knowledge, underlie the construction of machines and instruments which have become the commonplaces of life at the present time. It is from the United States therefore, that the next examples of thermostat development are drawn. They were all evolved between 1830 and 1876. Owing to the lack of indexes to United States Patents prior to 1876 it has not been possible, except in one instance, to assign an exact date to them.

Arnott's thermostat (Fig. 26) operated on the thermometer principle and consisted of a U-tube containing mercury and terminating at one end in an arm adapted to be inserted in a combustion chamber. In the opposite end of the tube is a float connected by a rod with a vertically movable frame in turn connected to a valve so that as the temperature in the combustion chamber varies the mercury rises, lifts the float and thereby varies the degree of opening of the valve.

Tomkin's automatic damper shown in Fig. 27 comprises a pivoted damper mounted within a flue or chimney within which a bi-metallic spring of copper and iron is also fixed at one end. As the spring bends under increase of temperature it bears upon and partially closes the damper, whose spindle projects to the exterior of the flue and carries an indicating needle. A weight or other device restores the damper to the vertical neutral position shown when the pressure of the bi-metallic device is relaxed.

The discovery of practical applications of electricity during the first half of the nineteenth century produced a number of inventions wherein electricity was used as the motive power. Dr Sternberg's electro-magnetic regulator for controlling the heat of rooms broke new ground in the design of thermostats in that variations of temperature were caused to complete or interrupt an electrical circuit. His thermostat comprises a thermometer into which extends an adjustable platinum wire. As the mercury rises in the thermometer tube, it touches the wire and completes an electric control circuit which energizes an electromagnet for moving a damper in the heating apparatus in a direction to diminish the heat emission. Conversely, as the temperature falls, the electrical circuit is broken and the damper resumes its former position.

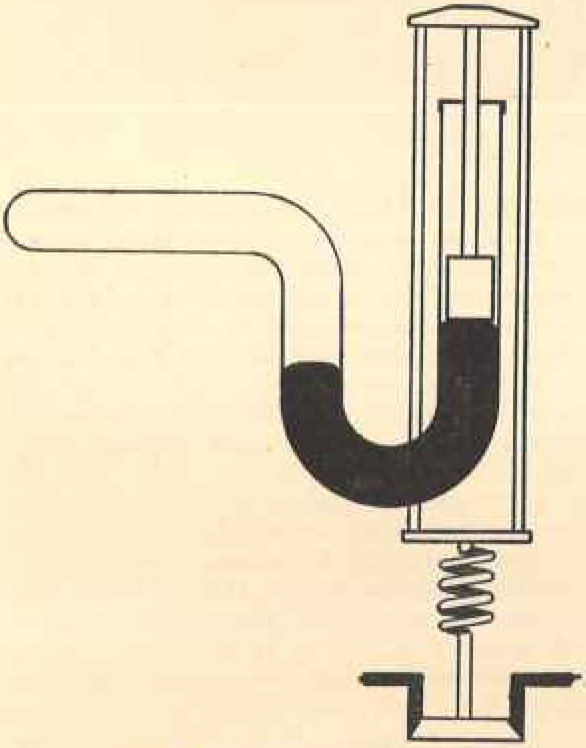


Fig. 26. Arnott's thermostat.

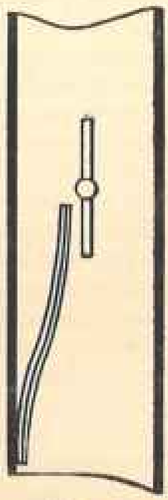


Fig. 27.
Tomkin's thermostatic flue damper.

Wilson's thermostat (Fig. 28) for steam heating apparatus is of the bi-metallic strip type with a valve element carried at the free end of the strip adapted to control the steam inlet, the arrangement being such that as the steam temperature increases, the bi-metallic strip, stated to be of brass and steel, flexes and tends to move the valve member on to its seating and thereby reduce the flow of steam until normal conditions are restored.

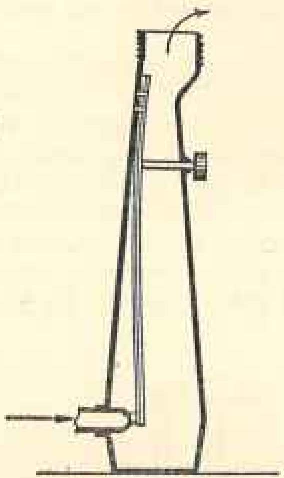


Fig. 28. Wilson's thermostat.

Guest's electrical thermostat (British Patent No. 1225/1874). This apparatus was actually an electrical fire alarm and is not a thermostat in the true sense of the term in that it was not designed to exercise any control over the source of heat which caused it to operate. It has been included because throughout the patent specification the Inventor calls his device a thermostat and because under that name it was described in contemporary technical literature. Several forms of the arrangement were described by Guest. One of these included a rod of hard rubber arranged so that its expansion under heat influence released mechanism to complete an electrical alarm circuit. In another form Guest employed an arrangement which included a thermometer type of tube wherein the rise of the mercury made contact at a pre-determined point with a wire to establish an electrical circuit and give the alarm.

About 1880 evidence first appears of the thermostat beginning to get into practical use but the form used was unlike any of those so far described. It was invented by Charles Edward Hearson after visiting a poultry farm and being impressed by the hit-and-miss method adopted in some experiments being carried on for the artificial incubation of eggs, Hearson applied himself to the problem and ultimately found the solution of maintaining the critical temperature level in an incubator by the thermostat which is shown in Fig. 29. It consists of a capsule formed from two sheets of metal sealed together at their edges and enclosing a piece of absorbent material such as blotting paper saturated with gasoline or any liquid which boils at the temperature at which the interior of the apparatus is required to be kept. Hearson obtained a Patent No. 5141/81 for the incubator and thermostat. This thermostat is applied to the hot-water jacket of an incubator and when the water in the jacket reaches the predetermined temperature level the fluid in the capsule boils, the capsule expands and thereby raises a rod to rock a lever arranged to lift a damper from a chimney and thus divert some of the hot gases from their normal path through the water jacket. As the temperature of the jacket falls, the capsule contracts and allows more heat to be applied to the water jacket. The thermostat is one of the simplest ever employed and what is more, it was a practical success. The firm of Charles Hearson & Co. Ltd. have continued to manufacture incubators controlled by these thermostats to the present day. In the history of thermostats the name of Charles Hearson takes an honoured place for he was one of those inventors who, faced with a practical difficulty, work and experiment until they find a solution which is simple, sure in operation and easy to manufacture. With the incubator capsule Hearson founded what has become a great industry; his firm was the first in this country

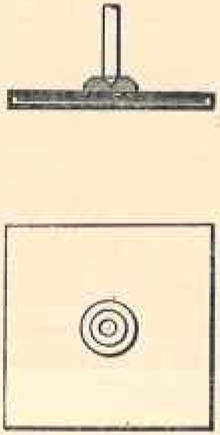


Fig. 29. Hearson's capsule thermostat, 1880.

to manufacture and apply thermostats on a wide scale. To popularise his incubator, Hearson took a shop in Regent Street. This is referred to in H. G. Wells' *Magic Shop* in which book he says that the shop stood next door to " the place where the chicks run about just out of patent incubators." Hearson's activities and powers of invention did not stop at poultry incubators for about 1895 he evolved the first thermostatic bacteriological incubator which overcame once and for all the difficulties previously experienced by biological experimentalists in maintaining their cultures at a constant temperature.

By the end of the 19th century, the thermostat had passed the experimental and novelty stage and in the ways already described had got into practical use. One of the difficulties experienced had been in finding a way of constructing the bi-metallic strip whereby the softer metal component would not buckle under repeated heating and thereby render the device increasingly inaccurate and finally inoperative. At this point it is convenient to refer to William Wilkinson of Shustoke, Warwickshire, manufacturer of bi-metals, the third in direct succession of his family to be so engaged, their combined periods of work on this subject having extended over a century.

In the course of a long letter addressed to the Author by Mr. Wilkinson, he stated that the method of making bi-metals used today originated in the sweating together of some silver and copper coins at a fire at Soho Foundry, Birmingham. Mr. Wilkinson further stated that among the earliest thermostatic uses for his bi-metals (known under his Registered Trade Mark " Thermoflex ") was the application to control the temperature in railway coaches in the United States by the Thomson-Houston Co., and to control the pressure in gas lamps.

Mr. Wilkinson sent for exhibition a sample of rivetted bi-metal in which the brass strip was much buckled and distorted between the rivets and it was this that brought me to the conclusion that Ure's thermostat, as described in his patent specification, would not have worked in practice or if it did, it would soon have become inaccurate and useless. The substitution of the method whereby the two metals forming a bi-metallic strip are caused to adhere the one to the other in place of rivetting solved the difficulties and enabled strips to be produced whose deflection can be accurately calculated for any given temperature change and which will maintain that characteristic for an indefinite period. The production of the "Thermoflex" Bi-metals by Mr. Wilkinson has been an important factor in the evolution of a number of modern thermostatic instruments.

About the year 1900, the Cambridge Instrument Company introduced a thermostatic regulator to control the temperatures in steam-heated vessels where there is available a supply of water or air at constant pressure. The thermostat is of what is known as the rod and tube type and is shown in Fig. 30. It consists of a brass tube A, which is immersed in the liquid under

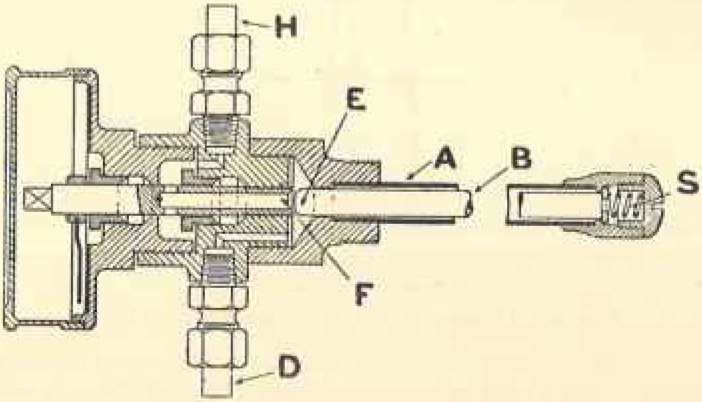


Fig. 30. Rod and tube thermostat, 1900.

temperature control. One end of a substantially inextensible rod[1] B is held by a spring S against the end of the tube, while the other end E is free to press upon or recede from a conical valve seating F, thus controlling the passage of water or compressed air from the pipe D (connected to the supply) to the pipe H (connected to the diaphragm chamber of the steam valve). The brass tube A expands with increase, and contracts with decrease of temperature, whereas the rod B does not appreciably change in length. When the temperature in the tank rises, therefore, the rod is withdrawn from the valve seating F allowing more water or air to pass through to the diaphragm, increasing the pressure and causing the steam valve to close. Conversely, when the temperature falls, the water or air supply is reduced and the steam valve opens. This arrangement has been applied to the control of the temperature in hot-water systems (Fig. 31) calorifiers, dye-vats, milk pasteurising tanks and steam cooking and drying chambers. It has also been employed in brewing, refrigerating and chemical plants and to control the temperatures of autoclaves in indiarubber manufacture.

The next development in heat governors which took place was in the automatic control of electric furnaces. In or about the year 1908, C. E. Foster evolved the arrangement shown in Fig. 32. The apparatus to be controlled was a relatively small electric resistance furnace and

[1] A metal commonly employed for this purpose is the nickel-steel alloy known under the Registered Trade Mark "Invar."

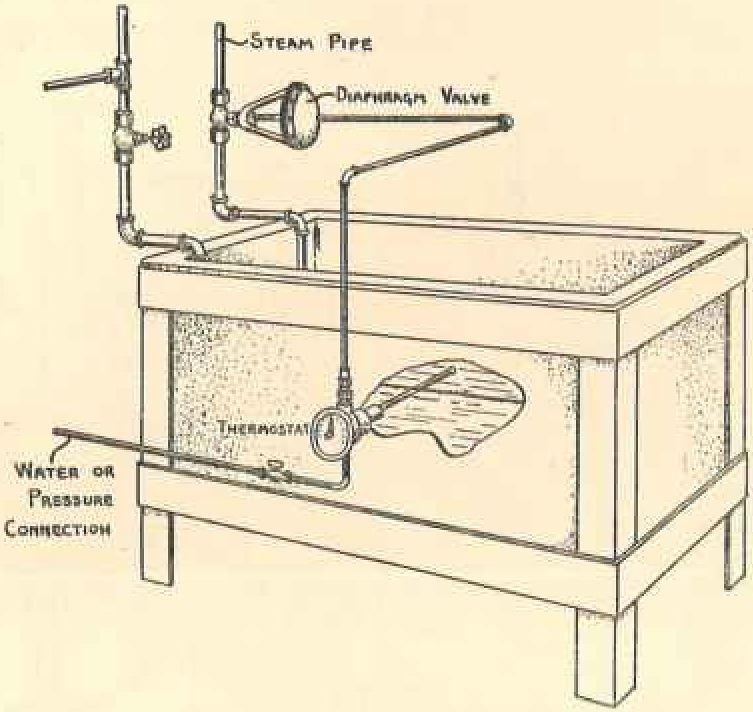


Fig. 31. Thermostat-controlled hot-water system.

the control was effected by varying the series resistance in the circuit of that furnace. The natural thermal stability of the furnace only demanded from the automatic control a gradual adjustment to deal with such variables as the rate of cooling from the outside of the furnace and changes in the voltage of the supply. Therefore, the system of control which can be briefly called " step-by-step " was successfully applied.

Use was made of a quasi-continuous recorder operating from a thermo-couple and it was the " thread recorder " invented by Sir Horace Darwin which was one of the earliest, if not the earliest, examples of this type of recorder. In the Figure (a) is a side view of the moving coil of a millivoltmeter, which is suspended, (b) being the upper and (c) the lower suspension. A recording arm (d) is attached to the suspension in such a way as to allow of the periodic depression of its outer end which is furnished with a knife edge (e). Below the plane of the normal excursions of the recording arm an inked thread (f) is stretched parallel to the axis of a drum (g) which carries a chart. A presser bar (h) is arranged periodically to descend and thus to nip the inked thread between the knife edge (e) and the chart on the drum (g) leaving a dot thereon.

For the purpose of control, the presser bar (h) has mounted upon its lower edge, but insulated therefrom, a contact (j) and another contact (k) shown in the small end view on the left of the sketch. The knife edge (e) is made alive to the relay circuit through the arm (d) and the upper suspension (b). The other arm to the relay circuit is carried to one or other of the contacts (j) or (k). These contacts are positioned just above and just below the position of the recorder arm at the desired temperature so that, when the temperature departs from the desired figure

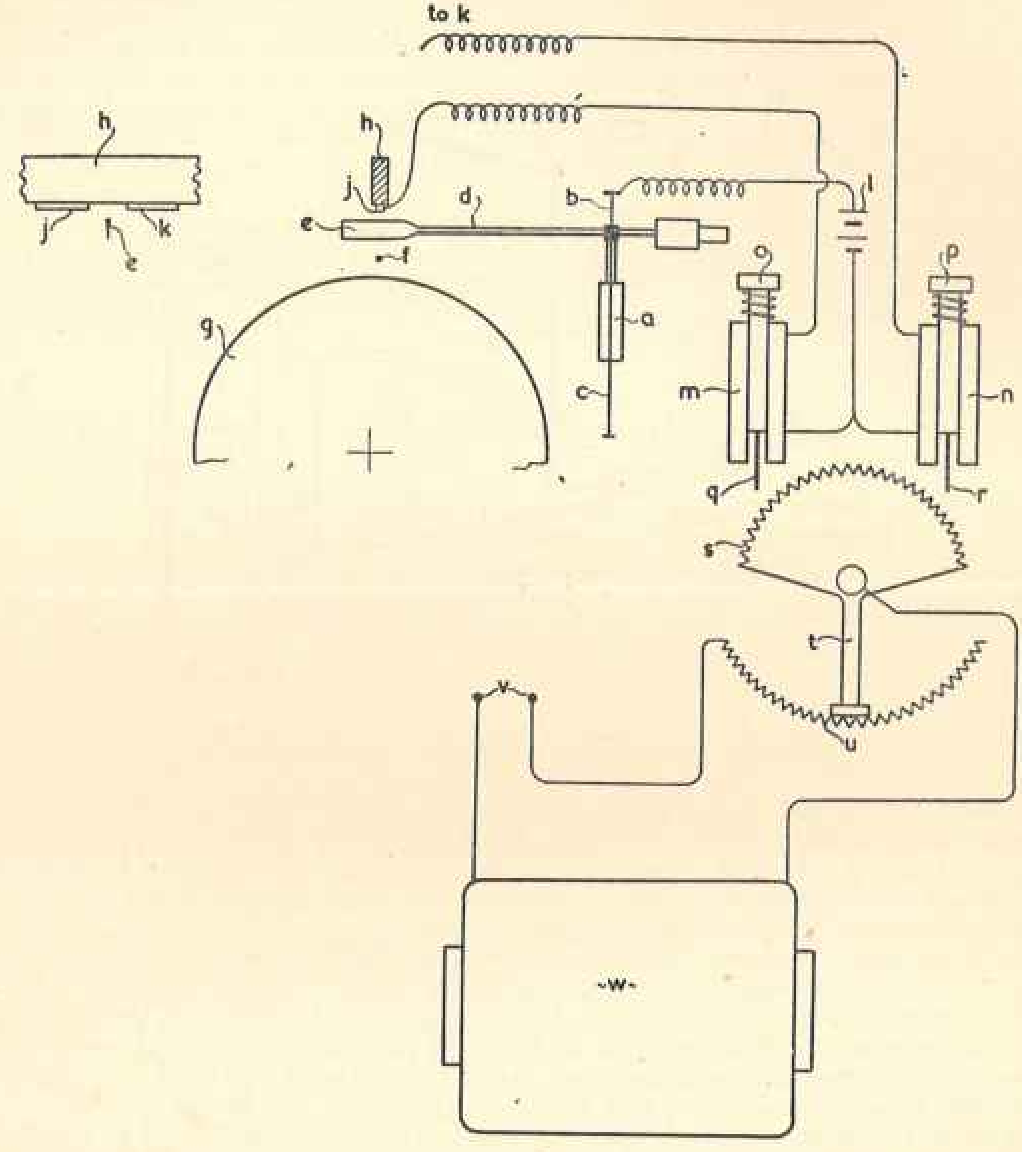


Fig. 32. Diagram of Foster's electric furnace control, 1908.

the next depression closes one or other of the relay circuits. The latter is fed by the battery (l) and includes solenoids (m) and (n) alternatively. Dealing with (m), the solenoid embraces a magnetic plunger (o) retained by a spring in an upward position. On the closing of the circuit the plunger (o) is drawn downwards and a tongue (q) engages a ratchet (s), the motion resulting in a small rotational movement of the ratchet (s). Similar action takes place in the reverse direction with the other solenoid (n). The ratchet (s) is attached to the arm (t) making contact upon the resistance (u) thus varying the amount of resistance in the circuit from the supply (v) through the winding of the electrical furnace (w).

This arrangement has later been widely adopted with variations when using the method of periodic depression. At the time the device was made and put into service, industry was not

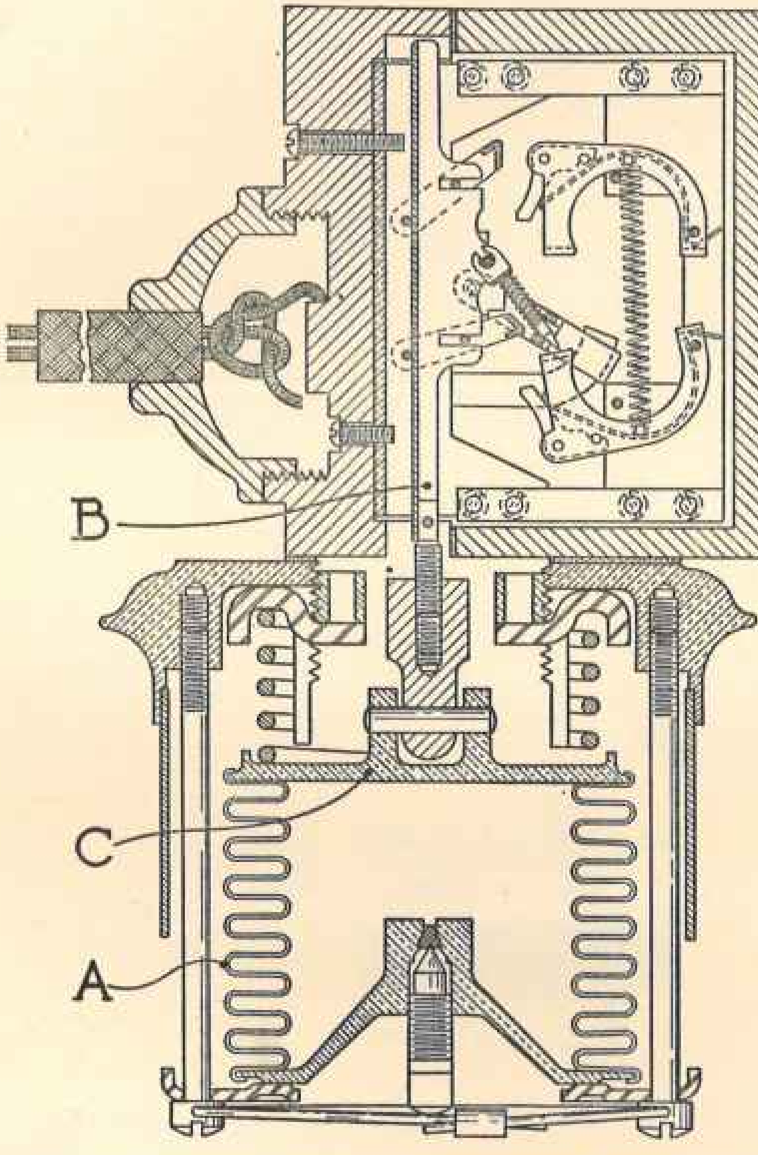


Fig. 33. Kelvinator thermal bellows-operated switch, 1914.

really ripe to adopt automatic control and it is believed that many years elapsed before the method was resurrected or re-discovered for general use.

Another industry wherein the maintenance of a predetermined temperature is of high importance is that of refrigeration, and many difficulties had to be overcome in the early days of transporting frozen meat. Kelvinator Ltd. state that its American Company first started experimenting with automatic electric refrigerators in 1914, a thermostat being used to effect the automatic control. This Company, which first started business in this country in 1926, was one of the first, if not the first manufacturer to apply thermostats to automatic refrigerators both in the United States of America and in this country. A sectional drawing of the 1923 model thermostat produced by this Company is shown in Fig. 33. This thermostat includes a metallic bellows A charged with a fluid whose pressure varies considerably with temperature fluctuations so that the bellows expands and contracts as the temperature rises and falls. Its

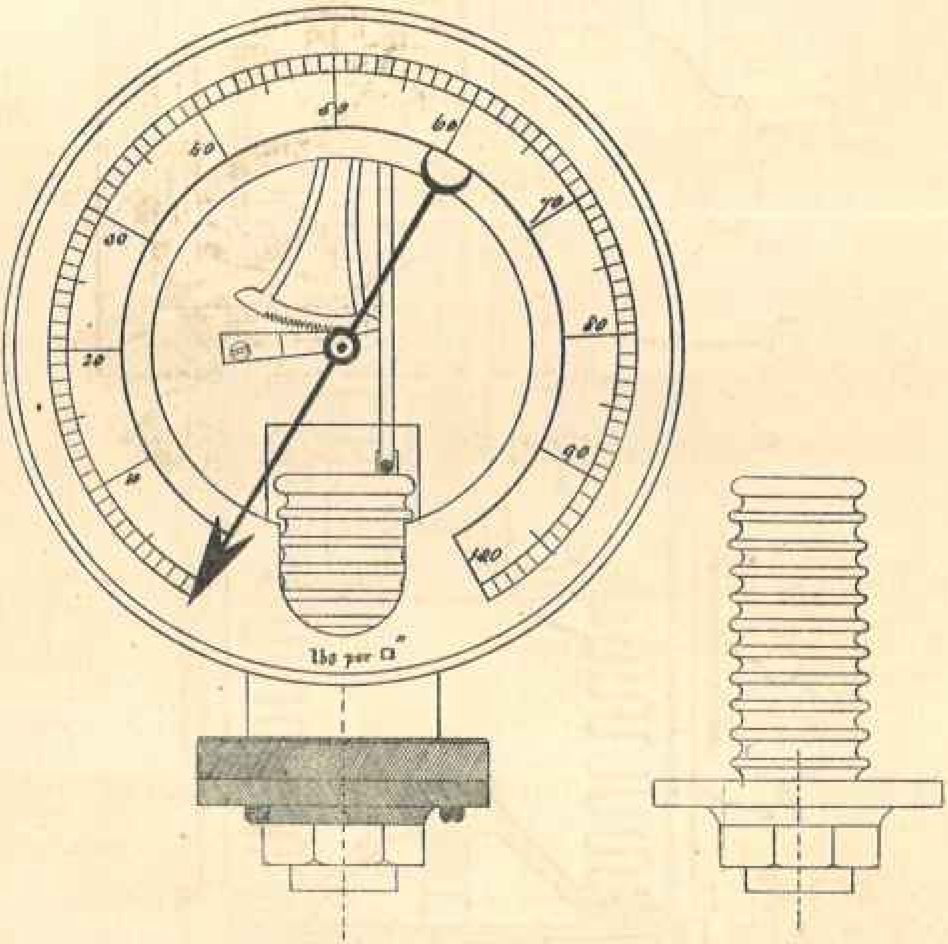


Fig. 34. Wright's corrugated tube for pressure gauge, 1885.

movements are transmitted through a rod B connected to the movable bellows end plate C, the said rod operating the switch elements to make and break the electrical circuit. This arrangement is the earliest I can find wherein the metallic bellows is embodied in an apparatus sold to the public.

The metallic bellows as used today is the outcome of long development which originated with the invention of the aneroid barometer by Lucien Vidie, a Frenchman, in 1844. The history of the development of these corrugated capsules as far as they were applied to barometers and pressure gauges is given in "The History of Pressure Responsive Elements" by L. B. Hart published in the *Journal of Scientific Instruments*, March 1944. From this history there emerge two patents whose disclosures are material to the present record. The first is C. F. Wright's Patent No. 3221/1885 illustrated in Fig. 34. The invention is a seamless, corrugated tube for use as a motive power for pressure gauges, vacuum gauges and barometers but there is no mention of its application to thermostats.

Vidie's original metallic bellows had corrugations of rectilineal cross section, an arrangement that restricted flexibility and was liable to break at the angles. Wright's seamless corrugated tube was, in principle, a great advance on the previous form of bellows although it is doubtful whether Wright's tube could have been made with machines available in 1885, as later experience has shown it to be a matter of some difficulty to produce accurately made seamless metallic bellows and special machines and processes have had to be invented for the purpose.

The second patent for a corrugated metal bellows is Johnson's No. 11548/1903 granted for an invention communicated by W. M. Fulton, Professor of Meteorology in the University of Tennessee. This is shown in Fig. 35 and was designed by employing curved corrugations

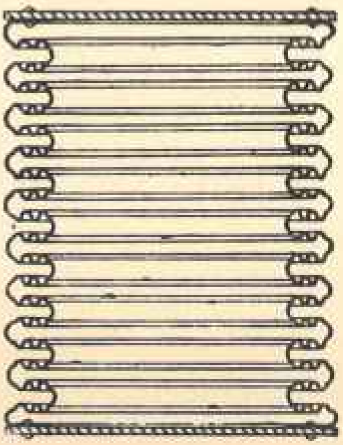
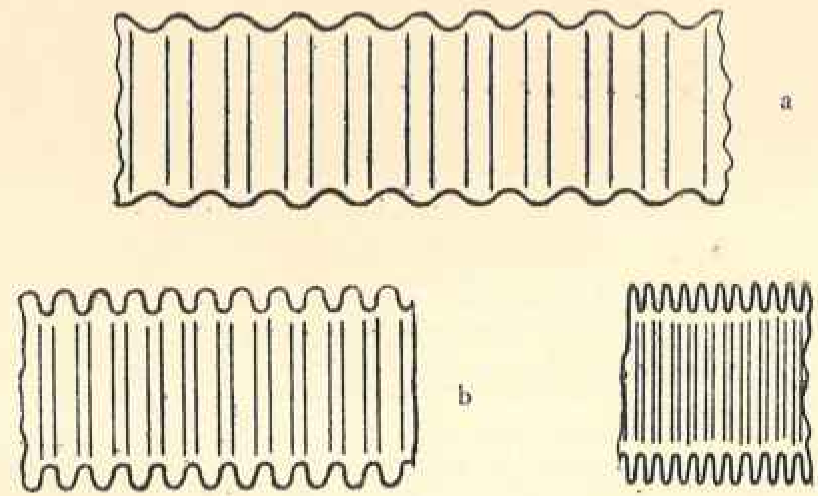


Fig. 35. Fulton's corrugated metal bellows, 1903.
(From his Patent specification).

to get over the difficulty of breakage at the angles. The invention was stated to be applicable to hermetically-sealed gas or vapour-charged vessels capable of expanding or contracting in response to variations of temperature and among the uses indicated are those of controlling heating apparatus by operating a valve or damper. No evidence can be found that this device was put into practical use but Fulton's invention prepared the way for the thermostats which began to come into public use in the third decade of the present century.

The employment in thermostats of the flexible metallic bellows gives greater sensitivity and more instantaneous response to small temperature variations than is possible with thermostats of the bi-metal type which, however, still have numerous applications where instantaneous response is not essential. The thermal bellows used at the present day are either liquid, vapour or gas charged, the charge being varied according to the medium in which the device is to operate but for ordinary purposes a charge of carbon dioxide gas is often used. It is a frequent practice not to expose the bellows directly to the variable temperature but to connect it by a capillary tube with a phial exposed directly in the area whose temperature variations are to be controlled. The axial expansion and contraction of the flexible metallic bellows can be utilised directly to operate mechanical or electrical controlling devices but generally the bellows movement is so small and its power so slight that some amplifying mechanism is necessary. Frequently, the bellows is arranged to close and open switch contacts to complete or interrupt a circuit for actuating a solenoid device which effects the actual controlling operation such as opening and closing a valve member or a shutter.

The flexible metallic bellows now used largely in thermostat constructions are commonly made from seamless tubes in which the corrugations are produced by successive operations. The result of these operations is that the metal is folded and not stretched thereby ensuring that uniform thickness of metal is retained in the finished bellows. These operations are performed by mounting the tube over a mandrel rotated at a speed of several hundred revolutions a minute. The tube fits loosely over the mandrel which is provided with a grooved roller with which co-operates a roller mounted externally to the tube and moved towards the internal roller while the tube is rotated to produce the corrugations one by one. The first of such operations produces successively a number of wide shallow corrugations shown in Fig. 36a; the second



a b c

Fig. 36. Diagrams to illustrate operations of making metallic bellows.

operation deepens the corrugations as shown in Fig. 36b at which stage the tube is slightly flexible; and the third operation further deepens the corrugations until the tube has the cross-section shown in Fig. 36c when it is as flexible as a spring. These operations can be performed wholly under manual control but a machine has recently been perfected whereby the entire series of operations is performed automatically thereby imparting to the finished bellows standard proportions and predictable characteristics. The ends of the finished bellows have rigid end plates affixed thereto with such connecting means as are necessary for the particular instrument of which the bellows is to form a part.

Another method of forming the bellows which is also in use is by hydraulic pressure. This method was invented by Walter Baker Clifford of Boston U.S.A. and was patented by him in this country on 25th October 1928 (British Patent No. 324134). By his method the metallic bellows are formed by placing a cylindrical tube within a series of appropriately spaced collapsible dies. One end of the tube is sealed and fluid pressure applied through the other end and exerted internally of the tube. The pressure causes the tube to be expanded and bulged between the dies and when the spacing elements are removed the tube tends to collapse to bellows form. The operation is completed by applying endwise contracting pressure to the tube while maintaining the internal fluid pressure.

About the year 1920, the control of heat in electric furnaces again engaged the attention of inventors and at that time the Cambridge Instrument Company evolved the instrument illustrated in Fig. 37. This instrument comprises a moving coil C fitted with a pointer N adapted

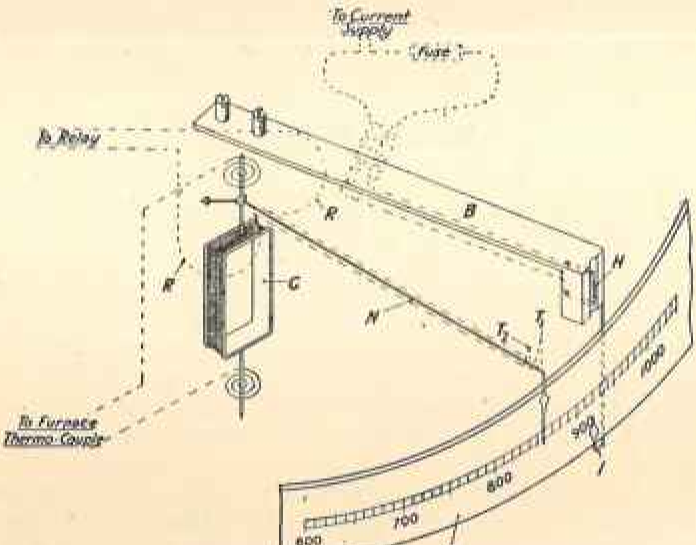


Fig. 37. Cambridge Instrument Co's furnace thermostat.

to move over a scale S and carrying at its extremity a differential thermo-couple T_1, T_2 which is connected electrically to a robust moving coil relay. A small electrically-heated coil H is mounted on the movable arm B which is set by hand to the point on the scale at which it is desired to control the temperature, this point being marked by an index I carried by the arm. The actual control is effected when the thermo-couple T_2 comes opposite the heater H, as the electromotive force then generated actuates the relay to close an electrical circuit and operates mechanism which controls the supply of heat to the furnace. The second thermo-couple T_1 comes in front of the heater as the furnace cools and causes the relay to break contact so that the supply of heat to the furnace is increased.

The domestic gas oven has been a familiar feature in most homes since the beginning of the present century but for many years its control was effected merely by the user adjusting the position of the gas inlet cock, a method which, not infrequently, led to disastrous results in cooking. The first commercially successful application of thermostatic control to such ovens was the " Regulo " introduced in the years 1922-3 by Radiation Limited. That Company has supplied the accompanying diagram Fig. 38 of the standard type of thermostatic control used. The

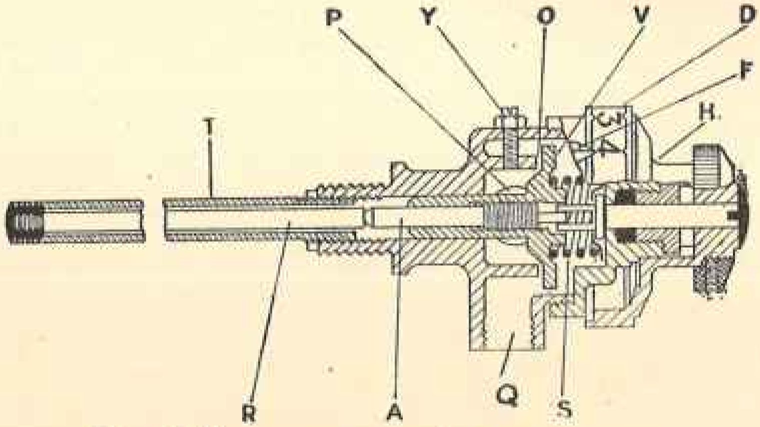


Fig. 38. Thermostatic control for gas stove.
(Courtesy of Radiation Ltd.)

thermostat is of the rod and tube type consisting of a rod R of non-expanding metal disposed within a tube T of brass or other readily expansible metal, both rod and tube being connected at one end. The other end of the rod abuts against a spindle A which carries the valve member V, a spring S maintaining the spindle A and rod R in contact and tending to seat the valve member by closing the opening O between the valve member and its fixed seating. A rotational hand setting knob H carries a dial D on which a series of numbers is marked and when this is rotated it causes spindle A to turn and owing to its screw threaded connection to the valve member, this member is initially positioned nearer to or further away from its seating, thereby determining the particular temperature to be maintained in the oven. As the heat in the oven increases, the tube T expands and draws the rod R away from the end of spindle A so that the spring S can move valve member V nearer to its seating and thereby restrict the flow of gas between inlet P and outlet Q to the oven. A by-pass arrangement Y prevents the danger of the gas supply to the oven being entirely cut off if the valve member becomes seated. The device provides a simple means to enable a housewife to set the control in accordance with a given scale for any variety of food being cooked as, once set, the device maintains the exact temperature necessary without the necessity for any supervision.

In the year 1925, the late Capt. Matt Payne turned his attention to the manufacture of thermostats. He was first interested in the thermostats used on refrigerators which were complex, expensive and largely of foreign origin. By adopting the seamless metallic bellows and manufacturing them in this country Payne founded an industry, The British Thermostat Co. Ltd. which was later to develop and manufacture thermostats applicable to a variety of industrial, mechanical and aeronautical purposes. As the credit of founding in this country an industry devoted entirely to the development and manufacture of thermostats belongs to Capt. Payne, a note on the man himself is appropriate at this stage. He had been in his earlier life a mining engineer and later became a Consultant to the War Office and certain industrial concerns on mechanical traction. He was that unusual combination, the inventor and man of business. His scientific and mathematical knowledge, his powers of organization, initiative and foresight gave to this Country an experimental and productive organisation ready to equip British aircraft with heat-controlling instruments which contributed materially to the Allied air victories in the Second World War. Payne was not in the class of great inventors, but was rather an adaptor to practical uses of the inventions of others which he knew how to apply to the best advantage. He was a genial man who knew how to inspire others to give of their best and was always ready with practical advice when a personal or technical difficulty arose. He passed away in 1937 at the plenitude of his powers leaving as his monument the great industry he created, but for his personal qualities his memory is cherished by those who were fortunate enough to know him and to work with him.

Two arrangements evolved by Payne will suffice to indicate the practical side of his work. The first is for controlling the cooling system of an internal combustion engine and is illustrated diagrammatically in Fig. 39. It comprises a flexible metallic bellows A charged with a

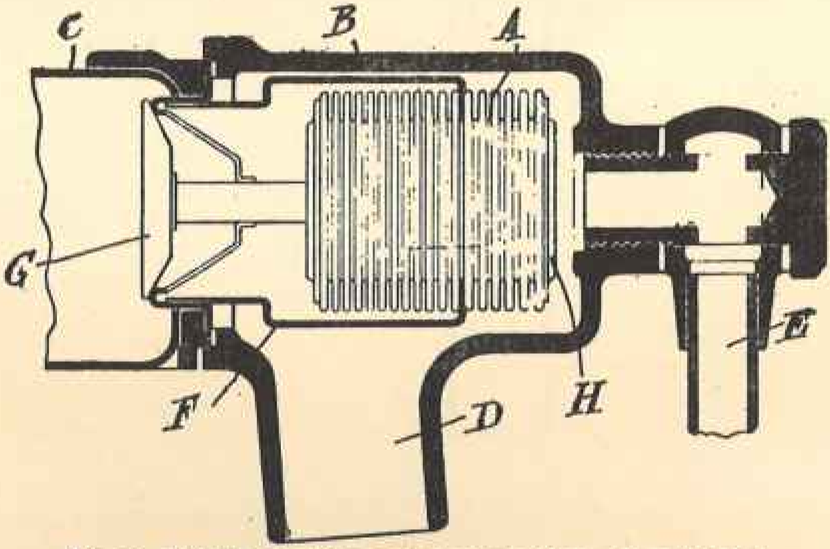


Fig. 39. Payne's internal combustion engine control, 1925.
(From his Patent specification).

volatile liquid and disposed in a chamber B having connections C to the upper end of a radiator; D to the engine cooling jacket; and E to a by-pass conduit whose other end is connected to the return conduit from the radiator. The bellows is mounted in a fixed support F and carries valve members G and H at its ends. As the temperature of the coolant fluid rises, the bellows expands so that valve member H is seated and valve member G opens to compel all the coolant fluid to pass through the radiator. As the temperature of the coolant fluid falls, valve member G is seated and valve member H opened to divert the coolant through the by-pass pipe (British Patent No. 435568).

The second arrangement is for the control of room temperatures and is shown in Fig. 40.

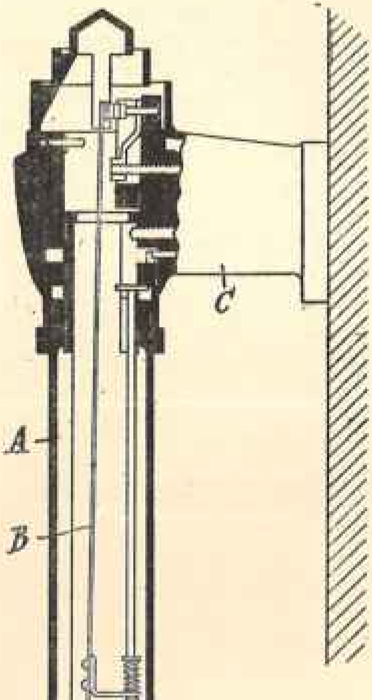


Fig. 40. PAYNE'S ROOM TEMPERATURE CONTROL, 1925.
(From his Patent specification).

It comprises a tube A through which air can freely circulate. The tube contains a bi-metallic strip B whose lower end is fixed and connected permanently to an electrical circuit. The upper end of the strip B carries an armature and co-operates with a permanent magnet fixed in the wall of the tube to effect rapid and definite make and break action. The flexing of the strip B thus completes or interrupts a heating circuit as required. The tube is supported by a bracket C to space the tube from the wall so that the strip B is influenced by the general temperature of the room rather than by the temperature of the wall surface (British Patent No. 481277).

It is impossible in a survey of this kind to describe all the many varieties of thermostats which technical development has brought into use during the past decade. There are many variations of all the types described in practical application as well as others evolved by recently acquired knowledge. For example, photo-electric tubes have now been pressed into service for thermostatic control, their use being described in the following extract from the *Mechanical World* for 20th April, 1945.

" The emitted light from annealing hardening and tempering furnaces is a measure of the temperature. The emitted light can be directed on to a photo-electric cell; the photo-electric current is amplified by radio valves and indicated or recorded on a meter which is calibrated in terms of temperature. The current may also operate a relay to control the supply of fuel to the furnace."

The development of thermostats goes on uninterruptedly and its latest chapter on their use in the second great World War has yet to be written; when that time comes another phase of man's attempt to utilise natural phenomena to do his work with a precision and a promptitude which he unaided cannot command will be revealed.

In conclusion I acknowledge with gratitude my indebtedness to all the firms whose names have been mentioned, who have given freely of their knowledge of the origins of their manufactures and have in many cases supplied me with drawings and diagrams.

The paper was illustrated by drawings Figs. 22 to 40 projected by the epidiascope.

Figs. 35 and 39 are reproduced by permission of the Controller, H.M. Stationery Office from Pat. Specns. Nos. 11548/03, 435568 and 481277 respectively.

Discussion.

Dr. H. W. Dickinson, referring to the date when expansion of metals was first observed, said that Mr. Jenkins had referred him to an experiment made before the Accademia dei Lincei in 1644 with a metal ring and a ball of the same diameter; when cold, the ball passed through the ring, when hot, it would not. The date when the ratios of expansion of different metals were first observed was obscure. Mr. Wilkinson mentioned the sweating of two metals after a fire at Soho Foundry, but this did not prove anything about curving under heat of a strip of the two metals. Matthew Boulton began making Sheffield plate (i.e. silver on copper) at Soho Manufactory in 1762 and curving of this plate by heat might have been noticed and given rise to the application.

Mr. R. J. Forbes stated that P. van Musschenbroek measured the expansions of different metals in 1720.

Mr. D. Chilton thought Harrison must have had knowledge of the thermal coefficients of expansion of metals. It was the individual rods of his pendulum that varied in length and compensated one another for temperature.

Mr. Ramsey, in reply, said he would welcome information on the expansion of metals in early days. The fire mentioned showed that two metals could be sweated together but that was not the invention of the thermostat although it prepared the way for the production of a bi-metal.

Correspondence.

Dr. Dickinson wrote that James Short, F.R.S.,[2] who knew both George Graham and John Harrison, stated that Graham *c.* 1715, thinking that inaccuracies in time-keeping by clocks was due to the effect of changes of temperature in the length of the pendulum, instituted experiments on brass, steel, iron and silver. He found the differences so minute that it afforded him no hope of succeeding and he gave up the experiments. Some time later, finding that mercury had a very great ratio of expansion, he invented the mercury pendulum. In 1725 Harrison made experiments on wires of different metals. In 1726 he finished the clock with a gridiron pendulum. In 1729 he made his first chronometer. Therefore until we get to know more, we must credit Harrison with being the first to use expansion of metals for practical purposes.

Mr. J. A. Chaldicott, Member, wrote: The following notes concerning thermostatic devices manufactured by the Cambridge Instrument Company are of particular interest in view of the dates involved and those quoted in Mr. Ramsey's paper :—

(a) British Pat. Spec. No. 13,524 of 1908 comprises a communication from the Hohmann and Maurer Manufacturing Co. of Rochester, N.Y., which was submitted for patenting by the Cambridge Scientific Instrument Co., Ltd. The patent relates to a thermostatic regulator very similar to that described by Mr. Ramsey for the control of temperature in steam-heated vessels where a supply of water or air is available at constant pressure. It seems probable that the pattern described in the paper would have been manufactured by the Cambridge Scientific Instrument Co., under licence from the American firm, subsequent to the granting of this patent.

(b) British Pat. Spec. No. 194,597 of 1923 is concerned with a type of galvanometer unit evolved for the control of heat in electrical furnaces by W. H. Apthorpe and the Cambridge and Paul Instrument Co., Ltd. The original design of 1923 was subsequently modified and then took the form described in Mr. Ramsey's paper; this later pattern is described and illustrated on pp. 4 and 5 of a Catalogue with the title "Cambridge Automatic Temperature Regulators, List No. 150," published by the Cambridge Instrument Co., Ltd., in 1925.

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[2] *Phil. Trans.* XLVII, 1752, p. 517.