

March 10, 1931.

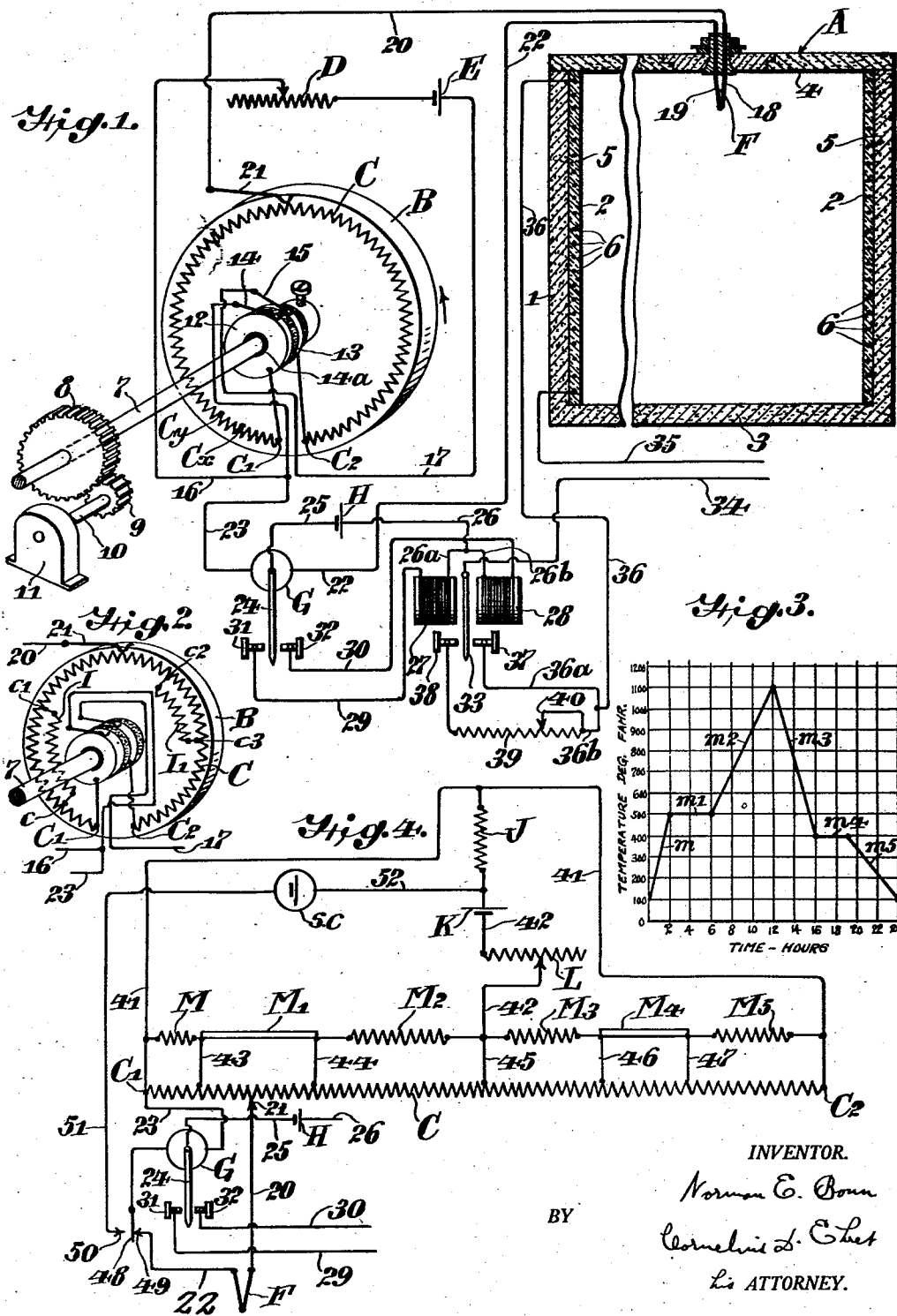
N. E. BONN

1,795,753

PROGRAM CONTROLLING SYSTEM

Filed Nov. 3, 1926

2 Sheets-Sheet 1



March 10, 1931.

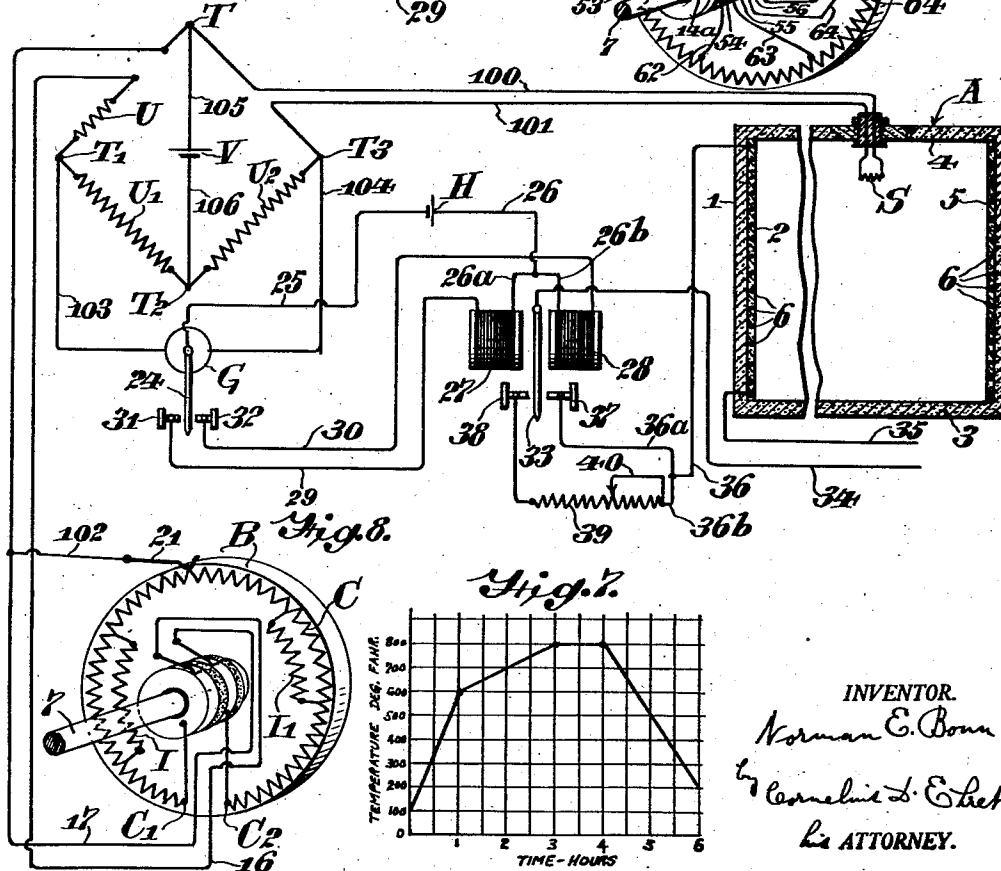
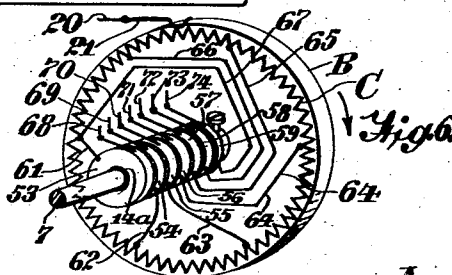
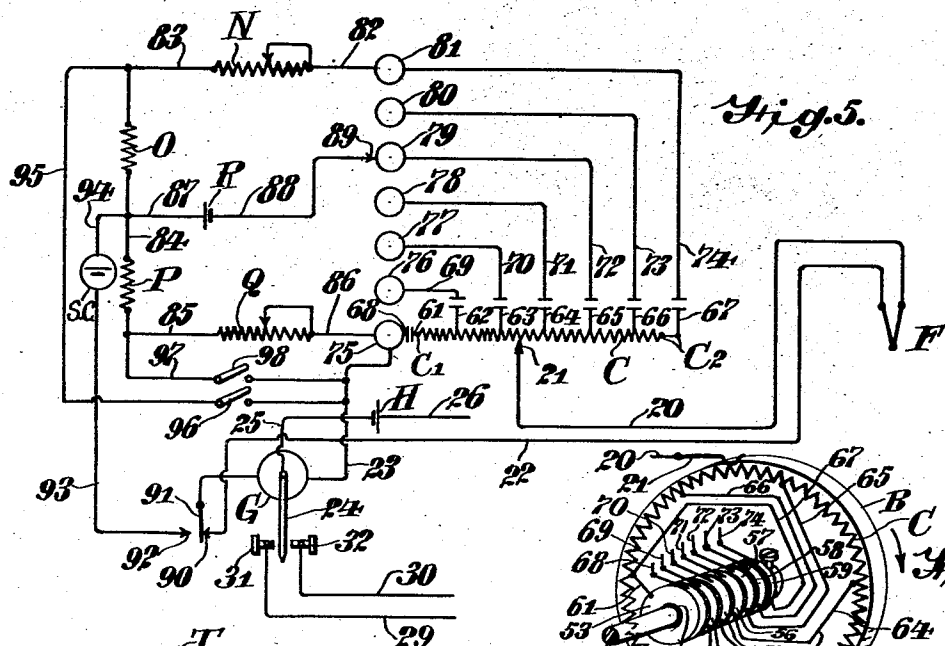
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PROGRAM CONTROLLING SYSTEM

Filed Nov. 3, 1926

2 Sheets-Sheet 2



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PROGRAM-CONTROLLING SYSTEM

Application filed November 3, 1926. Serial No. 145,998.

My invention relates to a method of and apparatus for maintaining a predetermined magnitude of a condition, as thermal, or varying the magnitude of such condition by effecting, in accordance with a predetermined program, application of an agent, as heat, of a character to change the magnitude of the condition involved.

In accordance with my invention, the magnitude of an effect is varied in accordance with the magnitude of the condition to be controlled, and simultaneously another effect is varied in accordance with a selected program, both effects coacting conjointly to control the application of the agent, and more particularly, said other effect is the electro-motive-force across a resistance whose magnitude per unit of time differs for different periods and still more particularly said resistance comprises a conductor having suitable resistance elements connected in shunt relation for developing an electro-motive-force varying in accordance with the desired program.

Further in accordance with my invention, there is provided a resistance conductor in the form of a closed loop across which is suitably and preferably adjustably connected a battery or other suitable source of energy, and more particularly, the aforesaid loop is slowly rotated with respect to a coacting fixed contact forming a terminal of the circuit influenced by the medium under control.

My invention resides in the method, apparatus and system of the character hereinafter described and claimed.

For an illustration of some of the forms my apparatus may take, reference is to be had to the accompanying drawings, in which:

Fig. 1 is a diagrammatic view of a system utilizable for substantially uniformly raising the temperature of a heating chamber.

Fig. 2 is a perspective view of an impedance constructed in accordance with my invention.

Fig. 3 is a curve showing a program of temperature changes.

Fig. 4 is a diagrammatic view of another form of my invention.

Fig. 5 is a diagrammatic view of another modified form of my invention.

Fig. 6 is a perspective view of a structure utilizable in connection with the form of my invention illustrated in Fig. 5.

Fig. 7 is a curve showing another program of temperature changes.

Fig. 8 is a diagrammatic view of a form of my invention utilizable with a Wheatstone bridge.

For purposes of illustration and without limitation of my invention, the condition to be controlled is herein illustrated as thermal in character. Accordingly, in Fig. 1, at A there is shown a chamber, enclosure, furnace, or the like, of suitable size, which may be heated by combustion of any suitable type of fuel, either solid, liquid or gaseous. In the example shown, however, and preferably, chamber A is electrically heated and, therefore, may comprise the shell 1 of sheet metal or equivalent, within which is disposed the hollow tubular heating or resistor element 2, of ceramic or the like, resting upon the bottom member 3 and closed at its upper end by the cover 4. Surrounding the member 2 within the shell 1 is a filling 5 of suitable mineral matter or other material, preferably of poor heat conductivity. Disposed within the wall of member 2 is the helically disposed resistance wire 6 traversed by current which causes the evolution of heat for heating purposes.

As one example of a field in which my invention finds application, chamber A may be assumed as having relatively large dimensions and containing a number of automobile bodies whose freshly coated or painted surfaces should be subjected to heat treatment in accordance with some predetermined program. To this end, in the form of my invention illustrated in Fig. 1, the amount of current traversing the resistance wire 6 should be so controlled or regulated as to ensure the development of the desired temperatures in chamber A. This result may be accomplished in a variety of ways. Merely by way of example, I have illustrated a control system operating on the potentiometer principle in which a departure of the chamber temperature from the desired value effects a galvanometer deflection, which in turn changes

the magnitude of the current through resistance wire 6.

In Fig. 1, B represents a disk of wood or other suitable material keyed to a shaft 7 rotated at suitable slow rate by the speed reducing gears 8 and 9, the latter being keyed to the shaft 10 driven by a clock or other governed motor 11. Upon the periphery or one face of disk B is suitably secured the resistance conductor C whose terminals C1 and C2 are connected, respectively, to the conductive rings 12 and 13 rotatable with but insulated from the shaft 7 by the insulating member 14a. Coacting, respectively, with the rings 12 and 13 are the fixed brush members 14 and 15 to which are respectively connected the conductors 16 and 17 of the potentiometer circuit including the adjustable resistance D and the battery or other suitable source of current E.

Responsive to the temperature of the chamber A is a suitable device F, herein shown as a thermo-couple comprising the wires 18 and 19 of dissimilar metals. Connected to wire 18 is a conductor 20 leading to a fixed contact or brush 21 coacting with the resistance C. Connected to wire 19 is a conductor 22 leading to one terminal of the coil of a galvanometer G, the other coil terminal being connected by a conductor 23 to the conductor 16.

The aforesaid galvanometer coil when traversed by current actuates or deflects an electrically conductive pivoted pointer or needle 24 to which is connected a conductor 25 leading to one terminal of a battery or other suitable source of current H from whose other terminal leads a conductor 26 which branches as indicated at 26a and 26b, the branched ends being connected, respectively, to terminals of the electromagnets or windings 27 and 28, whose other terminals are connected, respectively, by the conductors 29 and 30 to the respective fixed contacts 31 and 32 disposed closely adjacent the pointer 24 and on opposite sides thereof.

Pivoted between the windings 27 and 28 is an armature 33 connected by a conductor 34 to one terminal of a suitable source of current supply, not shown, from whose other terminal leads a conductor 35 connected to one end of the resistance wire 6. Extending from the other end of resistance wire 6 is a conductor 36, one branched end 36a of which is directly connected to a fixed contact 37 disposed on one side of armature 33 while the other branched end 36b is connected to a fixed contact 38 disposed on the other side of armature 33 through a resistance 39 adjustable by a shunt 40.

In operation, disk B and resistance conductor C are rotated at very slow but uniform speed and in such direction that the resistance of conductor C from its end C1 increases with time, that is, the direction of rotation is counter-clockwise, as viewed in

Fig. 1. With disk B so positioned that brush 21 is at the end C1 of resistance C, rotation of said disk may be initiated, as aforesaid, and after an interval of time, the disk and conductor C will have rotated to such position that brush 21 contacts with some point Cx on said conductor. At this time, it may be assumed that the temperature of chamber A and, therefore, of thermo couple F is insufficiently high to generate an electro-motive force that will balance that IR drop across the section C1, Cx of resistance C. Accordingly, current flows through the coil of galvanometer G in such direction that its pointer 24 is deflected toward the right, Fig. 1, into engagement with contact 32, thereby closing a circuit through winding 28, which, upon energization, attracts armature 33 and at contact 37 completes a circuit through resistance wire 6 by way of conductors 34 and 35 to evolve heat within chamber A at a relatively high rate.

The pointer 24 of galvanometer G remains in the aforesaid deflected position in engagement with contact 32 until some point Cy of resistance conductor C comes into contact with brush 21, at which time, due to the relatively rapid rate at which heat is now being supplied to chamber A, the electro-motive force of thermo-couple F has risen sufficiently to balance the IR drop across the section C1, Cy of wire C, whereupon needle 24 resumes its neutral position, thereby opening the circuit through winding 28, which releases armature 33 and permits the same to assume its neutral position to open the circuit through resistance conductor 6. In ordinary practice, however, the aforesaid balanced condition obtains only momentarily, and, hence, instead of remaining in the neutral position just described, pointer 24 moves into engagement with contact 31, thereby closing a circuit through winding 27, which, upon energization, attracts armature 33 and at contact 38 completes a circuit through resistance wire 6 by way of resistance 39.

Accordingly, current is supplied to said wire 6 at a reduced rate, and heat is evolved within chamber A at a slower rate than when armature 33 was in engagement with contact 37. Eventually, under these conditions, as rotation of disk B and resistance C continues, the IR drop across the active section of said resistance overbalances the electro-motive force developed by thermo-couple F, whereupon current is passed through the coil of galvanometer G in such direction as to again deflect pointer 24 toward the right, and armature 33 transfers the circuit through resistance wire 6 from resistance 39 to conductor 36a.

From the foregoing, it becomes apparent that the rate of temperature rise within chamber A for a given value of current depends solely upon the resistance per unit length

of the resistance wire C. If the resistance of such wire is uniform throughout its length, the rate of temperature rise will be substantially uniform, and any non-uniformity in the distribution of resistance therealong results in a corresponding non-uniformity in the rate of temperature rise within the heating chamber.

In accordance with my invention, the temperature within chamber A may be changed with time in any desired manner by suitably distributing the resistance of the wire C over or along its length. To this end, the resistance wire may be formed by utilizing a number of sections, each wound with wire of a size different from that employed for the other sections. The construction of a composite resistance wire of this character is somewhat difficult, and, therefore, it is desirable that the resistance wire be constructed from wire having a uniform size and that sections thereof be shunted by units of known resistance.

A construction of the character last noted is illustrated in Fig. 2, wherein the resistance conductor C has a section *c*, *c1* shunted by the resistance I and another section *c2*, *c3* shunted by the resistance II. With this arrangement, the temperature of the heating chamber will rise at a substantially uniform rate during the integral of time that elapses while disk B rotates from the position where contact 21 coacts with the end C1 of said wire until said contact is positioned in contacting relation with conductor C at the point *c*. During the time that disk B rotates from the last-noted position until contact 21 coacts with the point *c1* of resistance conductor C, the temperature of the heating chamber continues to rise at a substantially uniform rate (if the wire from which shunt I is wound is of uniform resistance). However, due to the lower effective resistance per unit length of section *c*, *c1*, as imposed by the shunt resistance I, the rate last mentioned at which the chamber temperature rises, will be lower than the rate first mentioned.

During the time that the disk B rotates from the position where contact 21 coacts with point *c1* until said contact coacts with the end C2 of wire C, the temperature of the heating chamber rises at one rate, as determined by the resistance wire section *c1*, *c2*, at another and different rate as determined by the section *c2*, *c3*, and again at the normal rate as determined by the section *c3*, C2.

For uniform speed of rotation of disk B, the duration of the various periods during which the temperature in the heating chamber rises, the rates of such temperature rise, and the times when the various periods are initiated and terminated may be effected as desired by suitably selecting the resistances of conductor C and shunts I and II, and connecting the latter to conductor C in the

proper regions. Obviously, any desired number of shunts having desired resistances may be utilized and the shunts may be distributed along conductor C as desired.

In the form of my invention described above, the control is such that the temperature of the heating chamber is always rising, and, therefore, at the end of the operation the heating chamber temperature is at its maximum value. Under some circumstances, it is desirable that the temperature of the heating chamber be raised to a certain value, and that thereafter a cooling period shall ensue. Moreover, it may be desirable, during certain intervals of time, to maintain the temperature of the heating chamber substantially constant.

In accordance with the last-named phase of my invention, I have diagrammatically illustrated in Fig. 4 a control system wherein the conductors 26, 29 and 30 may be assumed, in a manner similar to that described above, as controlling the application of heating current to the heating chamber, not shown, but with respect to the temperature of which the thermo-couple F is responsive. For purposes of explanation, the conductor C, of uniform resistance throughout, may be assumed as mounted on a disk similar to the disk B of Fig. 1, which is slowly rotated in any suitable manner past the fixed contact 21 engaging the said conductor C. Connected to the ends C1 and C2 of resistance wire C is the conductor 41, to which is connected a conductor 42 including the fixed resistance J, the battery or other suitable source of current K and the adjustable resistance L. Conductor 42 is extended into conductive engagement with resistance wire C in the manner hereinafter described.

In Fig. 3, there is illustrated a curve showing a program or chart of temperature changes or conditions over a twenty-four hour period. Should it be desired to control the temperature of a heating chamber in accordance with this program, the resistance conductor C of Fig. 4 and its supporting disk B should be so arranged as to rotate continuously and uniformly once and only once during a twenty-four hour period. According to the curve, there are six intervals during which the temperature either changes in value or is maintained constant. Consequently, resistance conductor C should be divided into six sections, and if six inches in length, would advance one-quarter inch during each hour. Therefore, in order to vary the temperature of the heating chamber in accordance with the program, changes in the amount of heat evolved must be effected at the beginning of the second, sixth, twelfth, sixteenth and nineteenth hour from the beginning of the cycle. To this end, conductive taps 43, 44, 45, 46 and 47 are conductively secured to resistance wire C at distances, re-

spectively, of 0.5, 1.5, 3.0, 4.0 and 4.75 inches from its end C1. Assuming that the resistance conductor C is 30 ohms, that the potentiometer current is 10 milliamperes, and that 30 microvolts is the uniform increment per degree in the thermal electro-motive-force of thermo-couple F, the resistances of the various shunts may be tabulated as follows:

Section	Temp. change	Volts required	Current	Res. required	Actual res. of section	Shunt	Remarks
C1-43	400	.012	.01	1.2	2.5	2.31	
43-44	0	0	.01	0	5.0	0	Short cct.
44-45	600	.018	.01	1.8	7.5	2.37	
45-46	700	.021	.01	2.1	5.0	3.62	
46-47	0	0	.01	0	3.75	0	Short cct.
47-C2	300	.009	.01	.9	6.25	1.05	

Accordingly, the section C1-43 of resistance conductor C is bridged by the coil M, of 2.31 ohms resistance, which is connected to conductors 41 and 43. The section 43-44 is tied together or bridged by the short-circuiting bar or rod M1 connected to conductors 43 and 44, and the sections 44-45 and 45-46 are bridged, respectively, by coils M2 and M3, respectively, having resistances of 2.37 and 3.62 ohms, and connected, respectively, to the conductors 44 and 45 (the latter being connected to conductor 42 of the potentiometer circuit) and 45 and 46. The section 46-47 is tied together or bridged by the short-circuiting bar M4 connected to conductors 46 and 47 and section 47-C2 is bridged by the coil M5 having a resistance of 1.05 ohms and connected to the conductors 47 and 41.

During the first two hours of operation, while conductor C rotates from the position where contact 21 coacts with the end C1 of conductor C until said contact engages the point connected to tap-off conductor 43, the IR drop, as determined by coil M, to be balanced against the electro-motive-force developed by thermo-couple F is increasing, and, hence, the temperature of the heating chamber rises, as designated by section *m* of the curve of Fig. 3. During the next four hours, conductor C rotates from the position where contact 21 engages tap-off conductor 43 to such position that said contact engages the point of conductor C connected to tap-off conductor 44. During this period, due to the presence of the bar M1, there is no further increase in the IR drop of conductor C, and, hence, the temperature of the heating chamber remains constant, as indicated by section *m1* of the curve of Fig. 3. During the next six hours, conductor C rotates from the position where contact 21 engages tap-off conductor 44 to the position where contact 21 engages conductor 45. During this period, the IR drop, as determined by coil M2, to be balanced against the electro-motive-force developed by thermo-couple F is again increas-

ing, and, therefore, the temperature of the heating chamber rises, as designated by section *m2* of the curve of Fig. 3.

Since tap-off conductor 45 is connected to conductor 42, which is one terminal of the potentiometer battery K whose other is conductor 41 connected to the end C1 of resistance conductor C, the maximum IR drop to be balanced by the electro-motive-force of thermo-couple F is developed when contact 21 coacts with the portion of conductor C to which tap-off conductor 45 is connected. At this time, the temperature of the heating chamber has reached its highest value, and thereafter the temperature must remain constant or decrease in value. As indicated in Fig. 3, during the next two hours of operation the temperature of the heating chamber falls somewhat rapidly, since the rate of the IR drop, as determined by coil M3, to be balanced against the electro-motive-force developed by thermo-couple F is decreasing somewhat rapidly. Accordingly, the temperature of the heating chamber falls, as designated by section *m3* of the curve of Fig. 3. During the next three hours, while resistance conductor C rotates from the position where contact 21 engages tap-off conductor 46 to such position that said contact engages tap-off conductor 47, the IR drop, to balance against the electro-motive-force developed by thermo-couple F, remains constant due to the presence of the bar M4. During this period, the temperature of the heating chamber remains constant, as designated by the section *m4* of the curve of Fig. 3. During the next five hours, resistance conductor C rotates from the position where contact 21 engages tap-off conductor 47 to such position that said contact engages the end C2 of said resistance conductor. During this period, the rate of the IR drop, as determined by coil M5, to be balanced against the electro-motive-force developed by thermo-couple F, is again decreasing, and hence the temperature of the heating chamber falls, as designated by section *m5* of the curve of Fig. 3.

It will be observed that one terminal of the potentiometer battery K is connected by conductor 41 to both ends C1 and C2 of the resistance conductor C. It results, therefore, that said terminals of resistance wire C are at the same potential, and, therefore, with this form of invention, the ends C1 and C2 may be mechanically connected together, whereby resistance conductor C forms a closed circle or loop. Accordingly, the program may be repeated as many times as desirable without stopping to turn the resistance conductor by hand. This feature is of particular importance in certain industrial processes where a certain sequence or program should be repeated continuously.

In the example shown, the terminal of the potentiometer battery K, to which the con-

ductor 42 is connected, is shown as permanently connected to resistance conductor C midway of its ends, and it is due to this feature, together with the uniform speed of rotation of the resistance conductor C, that the highest temperature in the heating chamber was reached at the time the program was one-half completed. Obviously, however, said terminal 42 may be connected nearer either end of resistance conductor C, as found desirable, thereby causing the temperature of the heating chamber to reach maximum value either before or after the program is one-half completed. To this end, it may be desirable to provide an adjustable connection between conductor 42 and the resistance conductor C.

In Fig. 4 there is supplementarily illustrated a well-known arrangement for determining the correct strength of current through the potentiometer resistance C from the source K. As herein shown, conductor 22, which is connected from one wire of thermo-couple F to one terminal of the galvanometer coil G, has interposed therein the movable switch element 48 and adjustable contact 49. A second contact element 50, likewise co-actable with switch element 48, is connected by a conductor 51 to one terminal of a standard cell S. C., whose other terminal is connected by a conductor 52 to one terminal of the potentiometer battery K. To determine correct strength of the current through resistance wire C from the source of current K, the resistance L is adjusted to such value that when the movable switch element 48 is in engagement with contact 50, the coil of galvanometer G will not deflect, indicating that the fall of potential through the resistance J due to the current from the source K is equal and opposite to the electro-motive force of the standard cell S. C.

In the forms of my invention heretofore described, the resistance conductor has been described as shunted with various resistances permanently connected in circuit and capable of performing a single definite program. Such an arrangement is suitable for many industrial applications, but is insufficiently flexible for others, inasmuch as more than one program may not readily be performed with a single instrument. To meet a condition of the character last noted, I have illustrated in Figs. 5 and 6 a form of my invention having provision for readily modifying the shunt characteristics of the resistance wire in such manner that any desired type of program may be effected.

As particularly illustrated in Fig. 6, there is secured to the shaft 7 driven at uniform slow speed in a clockwise direction the conductive rings 53, 54, 55, 56, 57, 58 and 59, insulated from each other and from the shaft 7 by the insulating member 14a. Likewise disposed on the shaft 7 is a disk B, which, as described above, may carry on its periphery or

on one face the resistance conductor C. Conductors 61, 62, 63, 64, 65, 66 and 67, connected to and equidistantly spaced along resistance conductor C, extend and are respectively connected to the conductive rings 53, 54, 55, 57, 58 and 59. Contacting respectively with the aforesaid conductive rings are individual brush elements to which are respectively connected the conductors 68, 69, 70, 71, 72, 73 and 74, terminating, respectively, in binding posts or other terminals 75, 76, 77, 78, 79, 80 and 81, Fig. 5, located on a suitable panel, not shown, or elsewhere, as desirable.

Branching from terminal 81 is a conductor 82 connected to one terminal of an adjustable resistance N, to whose other terminal is connected a conductor 83 connected to one terminal of the fixed resistance O, whose other terminal is connected by conductor 84 to one terminal of another fixed resistance P, whose other terminal is connected by a conductor 85 to one terminal of an adjustable resistance Q, whose other terminal is connected by a conductor 86 to the binding post or terminal 75. Connected to conductor 84 between the fixed resistances O and P is a conductor 87 connected to one terminal of the potentiometer cell or other source R, whose other terminal is connected to a conductor 88 terminating in the contact 89, which may be placed in conductive engagement with any of the binding posts 75, 76, 77, etc. In the form of my invention illustrated in Fig. 5, the conductor 23 leading from one terminal of the coil of galvanometer G is in effect connected to the end C1 of resistance conductor C, since it leads to the terminal 75, which is connected to said end of conductor C through conductor 68, its thereto-connected brush, conductive ring 53 and conductor 61.

Interposed in the conductor 22 leading from thermo-couple F is the fixed contact 90 and movable switch element 91. A second fixed contact 92, likewise co-actable with the movable contact 91, is connected by a conductor 93 to one terminal of the standard cell S. C. whose other terminal is connected by the conductor 94 to the conductor 84 between the fixed resistances O and P. Branching from the conductor 83 between the adjustable and fixed resistances N and O is a conductor 95 connected to conductor 23 and having a switch element 96 interposed therein. Branching from conductor 85 between the adjustable and fixed resistances Q and P is the conductor 97, likewise connected to conductor 23 and having the switch element 98 in circuit therewith.

It may be assumed, for purposes of illustration, that the resistance conductor C of Figs. 5 and 6 has a length of six inches, a resistance of nine ohms and the rotative speed thereof is one revolution in six hours. It may also be assumed that resistance conductor C has been divided into six equal sections and

that the wires 61, 62, 63, etc., form the terminals of such sections. For a potentiometer current of 0.01 amperes, a uniform increment in the thermal electro-motive-force per degree Fahrenheit of 0.00003 volts, and with the sections not shunted, the rate of temperature change within the heating chamber is

$$\frac{0.01 \times 1.5}{0.00003} = 500 \text{ degrees per hour.}$$

- 10 From the foregoing data, the resistances of shunt coils for changing the temperature within the heating chamber at different rates, such as 400, 300, 100 and 0 degrees per hour, may be tabulated as follows:

Rate— deg. per hr.	Volts re- quired	Current	Res. re- quired	Actual res.	Shunt	Remarks
500-----	.015	.01	1.5	1.5	none	
400-----	.012	.01	1.2	1.5	6.0	
300-----	.009	.01	0.9	1.5	2.25	
200-----	.006	.01	0.6	1.5	1.0	
100-----	.003	.01	0.3	1.5	.375	
0-----	.003	.01	0.0	1.5	0	Short circuit

- 25 If desired, the various resistance coils may be marked in terms of rates of temperature change, so that an unskilled operator may readily select a desired program. For example, should it be desired to maintain the temperature of the heating chamber in correspondence with the curve illustrated in Fig. 7, it will be necessary:—

1. To raise the temperature of the heating chamber from 100 degrees F. to 600 degrees F. in one hour.
2. To further raise the temperature to 800 degrees F. in two hours.
3. To maintain the heating chamber at 800 degrees F. for one hour.
4. To cool the heating chamber to 200 degrees F. in two hours.

- During the first hour, or while the resistance conductor C rotates from the position where contact 21 co-acts with its end C1 until said contact co-acts with the point on said resistance conductor to which conductor 62 is connected, the rate of temperature rise is 500 degrees F. per hour, and since, as stated above, this is the rate of temperature change as imposed by resistance conductor C alone, no shunt is required between binding posts 75 and 76. During the next two hours, or while the resistance conductor C moves from the position where contact 21 co-acts with resistance conductor C immediately adjacent conductor 62 to the point where said contact co-acts with the portion of said resistance conductor immediately adjacent contact 64, the rate of temperature rise is to be 100 degrees per hour. Accordingly, a coil marked "100 degrees per hour" should be connected between binding posts 76 and 77, and another similar coil should be connected between binding posts 77 and 78. During the fourth hour, or while resistance conductor C is mov-

ing from the position where contact 21 co-acts therewith immediately adjacent conductor 64 until said contact co-acts with the resistance conductor immediately adjacent contact 65, no change in temperature is to take place, and, therefore, binding posts 78 and 79 should be short-circuited. During the fifth and sixth hours, or while resistance conductor C is moving from the position where contact 21 co-acts therewith immediately adjacent conductor 65 to a position where said contact co-acts with the ends C2 of said resistance conductor, the rate of temperature change shall be 300 degrees F. per hour, and, therefore, a coil marked "300 degrees per hour" should be connected between binding posts 79 and 80, and a similar coil should be connected between binding posts 80 and 81.

According to the curve of Fig. 7, the temperature of the heating chamber shall start decreasing with the beginning of the fifth hour, and, therefore, the movable terminal 89 of the potentiometer battery R is conductively related to the binding post or terminal 79. The two branches of the potentiometer circuit are then separately adjusted by moving switch element 91 from engagement with contact 90 and placing it into engagement with contact 92. Thereafter, switches 96 and 98 are closed in succession and resistances N and Q adjusted until the current in each potentiometer branch is equal to 0.01 ampere. The system is now in condition to effect a heating program of the character indicated in Fig. 7.

It will be observed that cooling of the heating chamber may be initiated as desired by conductively relating the movable contact 89 of the potentiometer battery with any desired binding post or terminal 76 to 80, inclusive. However, each new position to which the aforesaid contact 89 is moved necessitates adjustment of the resistance of the potentiometer branches as indicated above.

In Fig. 8, there is illustrated a modified form of my invention wherein a balancing action is effected by utilizing a Wheatstone bridge. As shown, a device S, as a resistance thermometer, responsive to the temperature of chamber A and whose resistance, in the example shown, increases proportionately with its rise in temperature, is included by the conductors 100 and 101 in one arm of the bridge, while in a corresponding arm of the bridge is connected a suitable device whose resistance is varied in accordance with the desired program. Merely by way of example, such device is herein illustrated as of the character disclosed in Fig. 2, and, therefore, comprises the fixed brush 21 from which branches a conductor 102 connected at T to the conductor 100, to which also is connected the conductor 17 leading to the end C2 of resistance C. Conductor 16, branching from the end C1 of resistance C, may be con-

5 nected to one terminal of a fixed resistance U, whose other terminal is connected at T1 to a conductor 103 leading to one terminal of the coil of galvanometer G. In the other
10 arms of the bridge are the resistances U1 and U2, adjacent terminals of which are joined at T2. The other terminal of resistance U1 is connected to conductor 103 at T1, while the other terminal of resistance U2 is con-
15 nected at T3 to the conductor 101, from which connection branches a conductor 104 leading to the other terminal of the coil of galvanometer G. From the respective terminals of a battery or other source of current V are
20 connected the conductors 105 and 106 connected, respectively, to the points T and T2.

With the arrangement illustrated in Fig. 8, when the resistance of the bridge arm containing the resistance thermometer S in-
25 creases in value above that of the corresponding arm containing the shunted resistance conductor C, the bridge is unbalanced and current flows through the coil of galvanometer G in such direction that its pointer 24
30 is deflected toward the left, whereby, as described above in connection with Fig. 1, the resistance 39 is included in the circuit of resistance coil 6 to decrease the amount of heat evolved in chamber A. Similarly, when
35 the resistance of the bridge arm containing thermometer S decreases in value below that of the corresponding arm containing shunted resistance conductor C, current flows through the galvanometer coil G in reverse direction
40 and pointer 24 is moved toward the right to transfer the circuit through the coil 6 from resistance 39 to conductor 36a, thereby increasing the amount of heat evolved in chamber A.

45 It follows, in view of the foregoing explanation of my invention, that it is fundamentally important that in the heating chamber the ratio of the energy supply to the energy loss be such that with the galvanometer pointer 24 in engagement with contact 32, the temperature rises at a rate higher than the highest rate demanded by the program, and that with the galvanometer pointer
50 in engagement with contact 31, the heating chamber cools at a faster rate than the quickest rate of cooling required by the program.

It will be seen, therefore, that in the present improved method of temperature-control, wherein the control of temperature conditions is carried on substantially in accordance with a predetermined program, heat
55 is applied at two different rates alternately, one rate providing for heat-application greater than that required to follow exactly the program, the other rate providing for heat-application less than that required to follow exactly the program. In other words, in the present improved method of temperature-control substantially in accordance with
65 a predetermined program, heat is applied at

different rates alternately, any rate providing for heat-application either greater than or less than that required to follow exactly the program.

It will be seen further that in the present
70 improved control system, the method of control consists in producing through the thermo-couple F an electrical effect in the potentiometer circuit which varies in magnitude
75 in accordance with the magnitude of a condition such as the temperature condition in chamber A, in utilizing the resistance C to produce an electrical effect in the potentiometer circuit varying in magnitude in accordance with a program which is predetermined
80 by the resistance per unit length of resistance C, and jointly utilized the two effects through galvanometer G, relay 27-28 and associated parts to control the magnitude of said condition.

In the present improved control system, further, the relay 27-28 and associated parts
85 constitute means operable to effect controlling action of the system in either sense, that is, to effect either an increase or a decrease
90 of temperature conditions in chamber A. The galvanometer G and associated parts constitute means for governing the relay means 27-28. The thermo-couple F is responsive to
95 variations in a condition to which the control system is subjected, such as the temperature condition of chamber A, and the resistance apparatus C-21 and associated parts constitute means operable conjointly with the
100 means or thermo-couple F to control governing action of the governing means or galvanometer G.

The relay 27-28 and associated parts constitute, in another sense, governing means
105 for the heat-applying means or resistance wire 6, the galvanometer G and associated parts constitute means responsive to conditions of current-unbalance in the potentiometer circuit operable upon occurrence of
110 such conditions to effect governing action of the governing means or relay 27-28 and associated parts for wire 6.

Although the foregoing description of my invention relates somewhat specifically to arrangements for heating a chamber electrically, it shall be understood that the heating
115 chamber may be heated by combustion of suitable fuel, and that the galvanometer or equivalent may be utilized, for example, to control the speed of a device feeding solid
120 fuel or to open or close a valve in a conduit traversed by liquid or gaseous fuel.

It shall also be understood that in lieu of the arrangement described, the resistance conductor C may be maintained in a stationary
125 position and that motion at suitable rate may be imparted to the contact 21 co-acting therewith.

The term "resistance" in the specification and claims is used in a broad sense and is
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intended to include impedance where the latter term might more properly be applied in systems other than those disclosed but which embody the invention as claimed.

5 What I claim is:

1. A control system comprising a potentiometer circuit including a conductor in the form of a closed loop, a source of potential connected thereacross, and a contact adjustable circumferentially of said loop connected to said source, a circuit connected to said loop including a contact adjustably co-acting therewith, and means for effecting relative movement between said loop and said second-
15 named contact.

2. A control system comprising a potentiometer circuit including resistance in the form of a closed loop and whose magnitude per unit of time differs for different periods, a circuit connected to said loop including a contact adjustably co-acting therewith, and means for effecting relative movement between said loop and contact.
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3. A control system comprising a potentiometer circuit including a resistance in the form of a closed loop and a second resistance bridging a section of said loop, a circuit connected to said loop including a contact adjustably engageable with the bridged section and with a section of the resistance loop beyond the bridged section, and means for effecting relative movement between said loop and contact.
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4. A control system comprising a potentiometer circuit including a resistance in the form of a closed loop, a second resistance bridging a section of said loop, and means for connecting the terminals of another loop section together, a circuit connected to said loop including a contact adjustably engageable with the bridged section and with a section of the resistance loop beyond the bridged section, and means for effecting relative movement between said loop and contact.
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