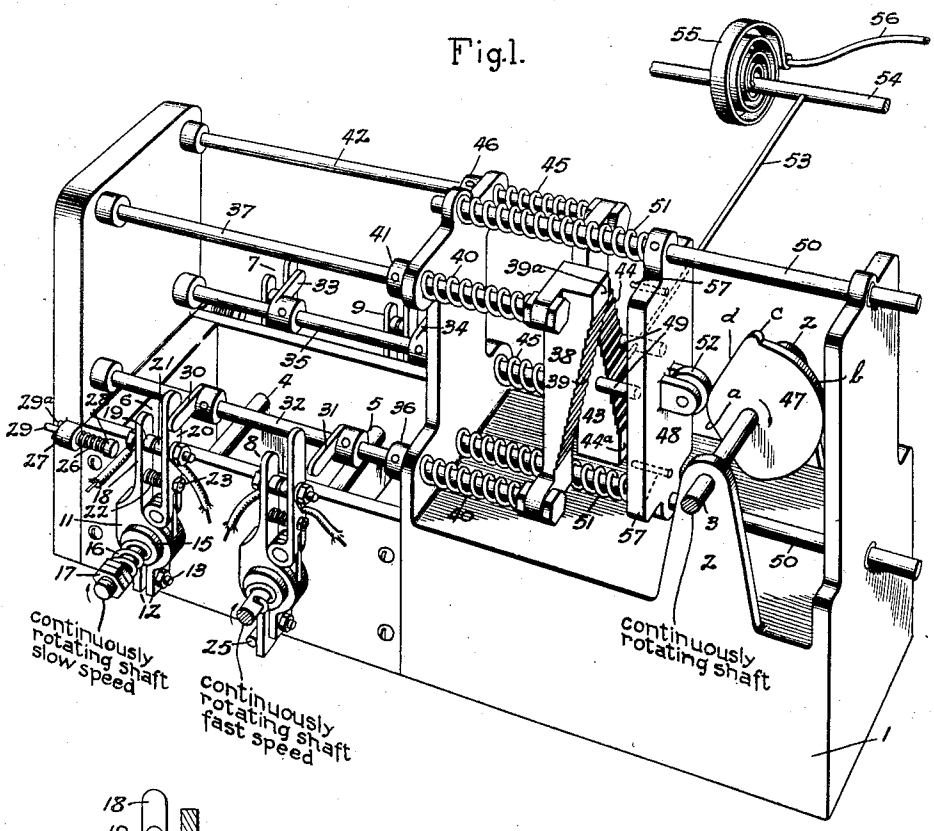
May 5, 1931. R. M. HARDGROVE 1,804,336

AUTOMATIC CONTROL SYSTEM

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Fig.1.



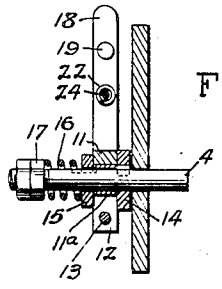
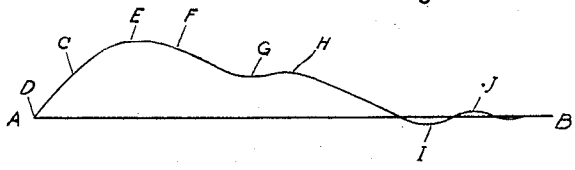


Fig.2.

Fig. 9.



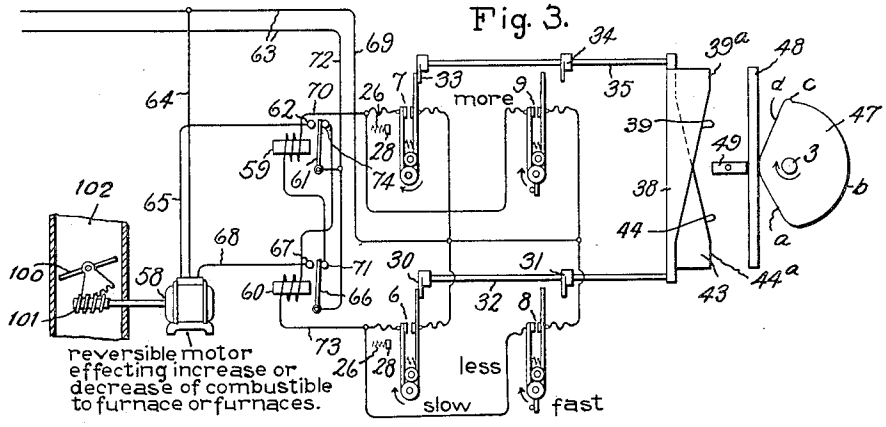
Inventor:
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by
His Attorney.

May 5, 1931. R. M. HARDGROVE 1,804,336

AUTOMATIC CONTROL SYSTEM

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Fig. 3.



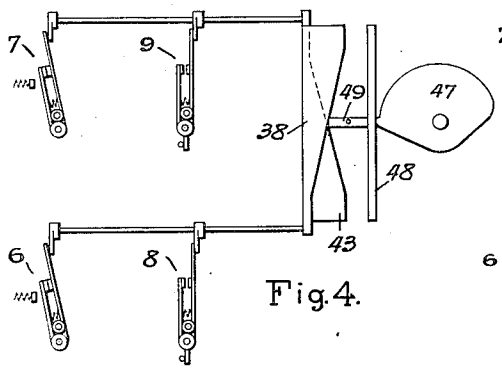


Fig. 4.

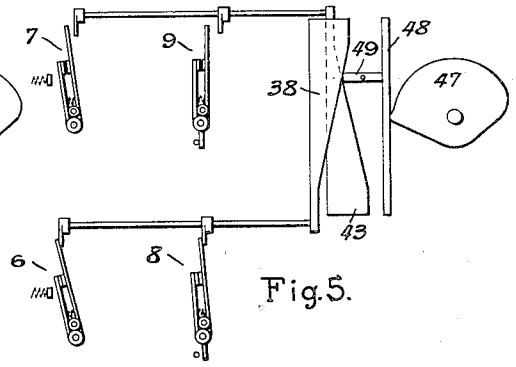


Fig. 5.

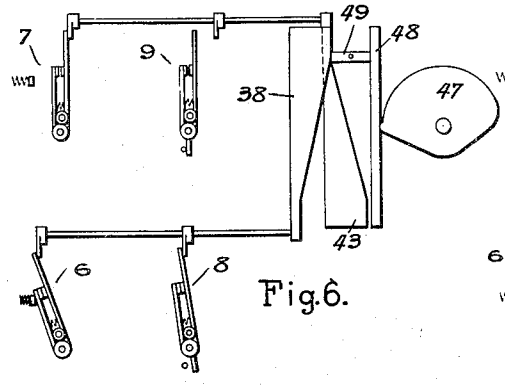


Fig. 6.

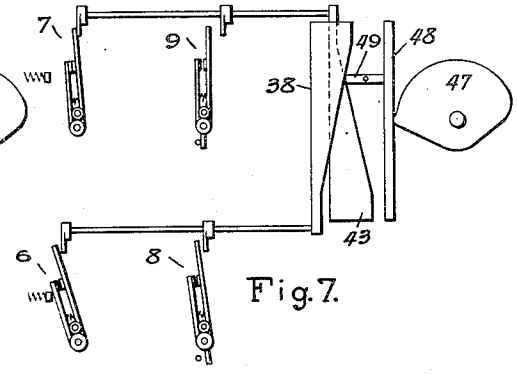


Fig. 7.

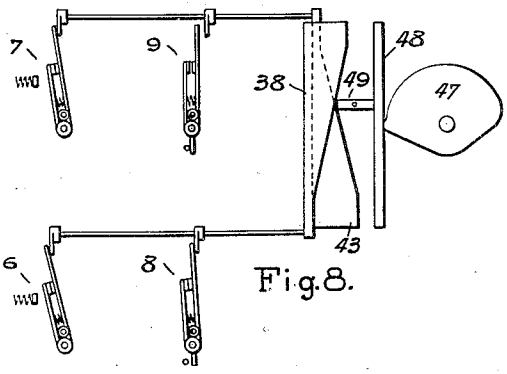


Fig. 8.

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Patented May 5, 1931 1,804,336

UNITED STATES PATENT OFFICE

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AUTOMATIC CONTROL SYSTEM

Application filed December 10, 1927. Serial No. 239,201.

This application is a continuation in part of my application, Serial No. 125,556, filed July 28, 1926.

The present system relates to automatic control systems wherein changes in the value of a factor which it is desired to maintain at a predetermined value effects adjustments of an operating condition or conditions appurtenant to such factor in a manner to restore the factor to the desired value. An important application of my invention is in connection with the automatic control of combustion in boiler furnaces and it is this application which I have chosen to specifically illustrate and describe. It is to be understood, however, that the invention is not limited necessarily to such application.

In connection with the operation of a boiler furnace or boiler furnaces used for generating steam, it is known to provide a control means responsive to an operating condition of the boiler furnace or boiler furnaces, for example, a control means responsive to the steam pressure or to the steam flow, and utilize such control means in effecting adjustment of the fuel and air to the furnace or furnaces so as to supply fuel and air in quantities such as are required to carry the load on the boiler or boilers. In the operation of a boiler furnace or boiler furnaces, changes in the steam pressure from a normal value may be taken as indicative of changes in the demand for steam, an increase in steam pressure indicating a decrease in the demand for steam and a decrease in steam pressure indicating an increase in the demand for steam, and it is the more usual arrangement to make the control means responsive to steam pressure.

A control means of the type referred to is termed usually a master controller or a primary controller, and my invention relates more particularly to such a control means.

In the regulation of a boiler furnace or boiler furnaces by a control means responsive to steam pressure the condition is met with that when a fuel and air adjustment has been made by the control means due to a change in steam pressure, a certain time elapses before the effect of the adjustment is registered on the steam pressure. As a result of this, the difficulty exists that in such a control system there is likely to occur over-regulation or "hunting", which means an unsatisfactory operating condition.

The object of my invention is to provide an improved control means or master controller for use in a system of the above referred to type which in a satisfactory manner takes care of the operating conditions met with, and for a consideration of what I believe to be novel and my invention, attention is directed to the accompanying description and the claims appended thereto.

In the drawings, Fig. 1 is a perspective view of a somewhat diagrammatic nature of a control means embodying my invention; Fig. 2 is a detail sectional view, and Figs. 3 to 9 are diagrammatical views illustrating the operation of the control means.

Referring to the drawings, 1 indicates a frame provided with arms 2 in which is mounted a continuously-rotating shaft 3; also mounted in suitable bearings in the frame is a continuously-rotating shaft 4 and a continuously-rotating shaft 5. Shaft 4 rotates at a speed slower than does shaft 5 and for convenience shaft 4 is referred to as the slow speed shaft and shaft 5 is referred to as the fast speed shaft. Shafts 3, 4 and 5 may be rotated by any suitable means, the only essential being that they be continuously rotated at the desired uniform speed. In order to simply the drawing a specific driving means for the shafts is not shown but instead legends have been applied to the drawing. In actual practice, the shafts may be driven with advantage by an electric motor, the motor being connected to shaft 3 either directly or through suitable reduction gearing and shaft 3 being in turn connected to shafts 4 and 5 through suitable reduction gearing. Shaft 3 rotates at a speed substantially higher than shafts 4 and 5. The directions of rotation of the respective shafts is indicated in the drawing by arrows.

Mounted on slow speed shaft 4 are two circuit closers 6 and 7 which may be termed secondary circuit closers and mounted on

fast speed shaft 5 are two circuit closers 8 and 9 which may be termed primary circuit closers. These circuit closers are all alike. Their primary characteristic is that they are frictionally mounted on the shafts in a manner such that while they tend to turn with the shafts, still they may be turned relatively to the shafts when a turning force is supplied to them. Each circuit closer comprises a split hub 11 mounted on a sleeve or liner 11^a through which the shaft loosely extends, the hub being provided with a pair of depending ears 12 through which a bolt 13 extends and by means of which the two parts of the hub may be drawn together to clamp the hub to the sleeve. The hub is frictionally connected to the shaft by being held between a shoulder 14 fixed on the shaft (see Fig. 2) and a washer 15 which is splined on the shaft so as to be free to move axially thereon and which is pressed against the hub by a spring 16 located between washer 15 and a nut 17 on the end of the shaft. By adjusting nut 17, the frictional connection between the hub and the shaft may be given a desired value. Rigidly connected to hub 11 is an arm 18 provided with an electrical contact 19 and pivotally mounted on the hub is an arm 20 provided with an electrical contact 21 adapted to engage contact 19. Arm 20 is biased to a position wherein contact 21 is out of engagement with contact 19 by a spring 22, the movement of arm 20 being limited by a head 23 on the end of a bolt 24 which passes loosely through an opening in arm 20 and through spring 22 and is fixed on arm 18.

With the foregoing arrangement, it will be seen that when contact arm 20 of any one of the circuit closers is moved toward the left as viewed in Fig. 1, contact 21 will first be brought into engagement with contact 19 after which the circuit closer as a whole will be turned on its shaft against the action of the friction tending to cause it to rotate with the shaft. Primary circuit closers 8 and 9 are provided with stops 25 which serve to limit the extent to which the circuit closers may be moved by shaft 5. Mounted in the path of movement of secondary circuit closers 6 and 7 are spring return devices each comprising a spring 26 located between an ear 27 on the side of frame 1 and a head 28 on the end of a rod 29 which extends through an opening in ear 27. Movement of rod 29 toward the right is limited by a pin 29^a. The circuit closers 6 and 8 are adapted to be actuated by fingers 30 and 31 fixed on a rod 32 mounted to slide in suitable bearing openings in frame 1 and the circuit closers 7 and 9 are adapted to be actuated by similar fingers 33 and 34 carried by a rod 35 which slides in suitable bearing openings in frame 1. The movement of rods 32 and 35 toward the right, as viewed in Fig. 1, is limited by a stop 36 fixed on each rod and adapted to engage a wall of frame 1.

Rigidly connected to the right hand end of rod 32 and to one end of a guide rod 37 is a wedge plate 38 having steps on its front surface as is indicated at 39, which terminate at the thick end of the wedge at a flat surface 39^a. Wedge plate 38 is pressed toward the right (Fig. 1) by springs 40 which surround rods 32 and 37, movement toward the right being limited by stop 36 on rod 32 and a similar stop 41 on rod 37. Similarly connected to the right hand end of rod 35 and to one end of a guide rod 42 is a wedge plate 43 having steps on its front face as is indicated at 44 and a flat surface 44^a at its thick end. It is pressed toward the right (Fig. 1) by springs 45 which surround rods 35 and 42, the movement toward the right being limited by the stop 36 on rod 35 and a similar stop 46 on rod 42. As will be seen from Fig. 1, and also as is clear from the diagrammatic view, Fig. 3, wedge plates 38 and 43 are oppositely arranged, their inclined surfaces crossing each other midway between their upper and lower ends when the wedge plates are in their extreme right hand positions.

When wedge plate 38 is moved toward the left (Fig. 1) rods 32 and 37 will be moved with it, the rods sliding through the bearing openings in the frame. Finger 30 will engage arm 20 of circuit closer 6 and move it to bring its contact 21 into engagement with its contact 19 after which circuit closer 6 will be turned as a whole on shaft 4 and in a counter-clockwise direction as viewed in Fig. 1. Also, finger 31 will engage arm 20 of circuit closer 8 and move it to bring its contact 21 into engagement with its contact 19 after which circuit closer 8 will be turned as a whole on shaft 5 and in a counter-clockwise direction as viewed in Fig. 1. Fingers 33 and 34 are similarly arranged relatively to circuit closers 7 and 9 and operate in a similar manner when wedge plate 43 is moved toward the left.

Wedge plates 38 and 43 are moved by a cam 47 fixed on continuously-rotating shaft 3, which cam operates through the intermediary of a flat plate 48 and two pins 49, one for each wedge plate. Plate 48 is carried by two guide rods 50 which slide in bearing openings in frame 1 and it is pressed toward the edge of the cam by springs 51 which surround the guide rods. On plate 48 is a roller 52 against which cam 47 operates. Cam 47 has a steep portion *a* followed by a portion *b* which increases slightly in height beginning at the point where it joints portion *a* and finally terminates in a small projection *c* followed by a rapidly receding portion *d*. The total rise in cam portion *b* may be an amount of an order equal to two steps

on wedges 38 and 43. With this arrangement, it will be seen that when cam 47 rotates and beginning with the cam in the position shown in Figs. 1 and 3, plate 48 is first pushed to the left by steep cam portion *a* after which it is moved slowly further toward the left while cam portion *b* passes by roller 52 and then finally it is given a small further movement toward the left by projection *c* after which it is permitted to return to its former position, following along cam portion *d*. When plate 48 moves toward the left, pins 49 are forced against wedge plates 38 and 43 thus moving said wedge plates toward the left to effect operation of certain of the circuit closers, 6, 7, 8 and 9 depending on the position of pins 49 relative to the front surfaces of wedges 38 and 43.

Pins 49 are moved up and down relatively to the surfaces of wedge plates 38 and 43 in accordance with the operating condition of the boiler or boilers to be controlled, and in this case taken to be the steam pressure. To this end they are shown in the present instance as being fixed to the end of an arm 53 connected to a rotatably-mounted shaft 54 to which is connected a known type of Bourdon tube 55 the interior of which is connected by a pipe 56 to the steam conduit which conveys steam from the boiler or bank of boilers being controlled. The arrangement is such that when the stem pressure increases, Bourdon tube 55 straightens somewhat thereby turning shaft 54 in a direction to raise pins 49 relatively to wedge plates 38 and 43 while when the steam pressure decreases, Bourdon tube 55 contracts thereby turning shaft 54 in a direction to lower pins 49 relatively to wedge plates 38 and 43. The extreme movements of pins 49 are limited by suitable stops against which arm 53 engages, such stops being indicated at 57 in Fig. 1. The Bourdon tube arrangement is shown only diagrammatically and it is to be understood that any suitable arrangement for accomplishing the desired result may be used.

The arrangement is such that when the desired normal steam pressure obtains, pins 49 stand midway between the ends of the wedge plates as is shown in Figs. 1 and 3.

The control means or master controller as illustrated in Fig. 1 may be used in connection with any suitable automatic boiler furnace control system. For example, it may be used in a system such as that disclosed in the application of Erwin G. Bailey, Serial No. 749,769, filed November 13, 1924. When utilized in a boiler furnace control system the arrangement is such that the one pair of circuit closers, for instance, circuit closers 6 and 8, whenever either is closed, serve to effect an adjustment or adjustments in a direction to decrease the rate of supply of a combustible or combustibles being fed to the furnace or furnaces, and the other pair of circuit closers 7 and 9, whenever either is closed serve to effect an adjustment or adjustments in a direction to increase the rate of supply of combustible or combustibles being fed to the furnace or furnaces. In either case, the extent of the adjustments varies in amount directly with the length of time the contacts are held closed. The specific arrangement used for adjusting the rate of supply of a combustible or combustibles to the furnace or furnaces forms no part of my present invention. Suitable arrangements are now known. Accordingly, I have indicated what may be taken as a suitable arrangement by the reversible electric motor 58 (Fig. 3) it being understood that when motor 58 operates in one direction it effects an adjustment or adjustments in a direction to decrease the rate of supply of a combustible or combustibles to the furnace or furnaces while when it operates in the other direction, it effects an adjustment or adjustments in a direction to increase the rate of supply of a combustible or combustibles to the furnace or furnaces. In this connection it is to be understood that by the term combustible I refer to fuel (such as coal, oil or the like) to air, or to both. As illustrated in Fig. 3 connected to and driven by the motor 58 through the medium of gearing 101 is a damper 100 capable of being positioned in the duct 102 to vary the flow of a combustible therein.

The two circuits for motor 58 are controlled by relays 59 and 60. When relay 59 is energized its armature 61 is moved into engagement with relay contact 62 thereby connecting motor 58 directly to supply lines 63 through conductors 64 and 65 to effect operation of motor 58 in a direction to increase the rate of supply of combustible or combustibles, and when relay 60 is energized its armature 66 is moved into engagement with relay contact 67, thereby connecting motor 58 directly to supply lines 63 through conductors 64 and 68 to effect operation of motor 58 in a direction to decrease the rate of supply of a combustible or combustibles. The circuits for relays 59 and 60 are interconnected so that when one relay is energized the circuit for the other relay is opened. The circuit for relay 59 may be traced as follows: upper supply line 63, conductor 69, either of the circuit closers 7 or 9 which are connected in parallel, conductor 70, winding of relay 59, back contact 71 of relay 60 and conductors 72 to lower supply line 63. The circuit for relay 60 may be traced as follows: upper supply line 63, conductor 69, either of the circuit closers 6 or 8 which are connected in parallel, conductor 73, winding of relay 60, back contact 74 of relay 59 and conductor 72 to lower supply line 63. It will thus be seen that the circuit for relay 59 includes the back contact 71 of relay 60 and the circuit for relay 60 includes the back contact 74 of relay

59 so that when either relay is energized the circuit for the other relay is opened. This renders it not possible to close both motor circuits at the same time.

A better understanding of the operation of the control device is obtained if relative numerical values are considered for the speeds of rotation of shafts 3, 4 and 5. Accordingly, values which I have found to be satisfactory in actual use are given. It is to be understood, however, that this is only by way of example and is not to be taken as a limitation of my invention.

Shaft 3 may be revolved at a speed of the order of eight revolutions per minute so that cam 47 makes a complete revolution about every eight seconds. This means that during each eight seconds plate 48 is moved by the cam to bring pins 49 into engagement with wedges 38 and 43, forcing both wedges toward the left a distance depending upon the location of pins 49 relative to the wedges and moving one or more of the circuit closers 6, 7, 8 and 9 relatively to shafts 4 and 5. Slow speed shaft 4 may be rotated at a speed of the order of one revolution in four hundred minutes, and fast speed shaft 5 may be rotated at a speed of the order of one revolution in one hundred thirty-five minutes. This means that while shaft 3 is making a complete revolution, shaft 4 makes about 1/3000 of a revolution and shaft 5 makes about 1/1000 of a revolution. The maximum movement of circuit closers 6 and 8 relative to shafts 4 and 5 is obtained when pin 49 engages the flat surface 39^a of wedge plate 38 and the maximum movement of circuit closers 7 and 9 relative to shafts 4 and 5 is obtained when pin 49 engages the flat surface 44^a of wedge plate 43. Under these circumstances, circuit closers 6 and 7 may be moved relatively to shaft 4 through a total angle of the order of 14° and circuit closers 8 and 9 may be moved relatively to shaft 5 through a total angle of the order of 7°. Fingers 31 and 34 are arranged relatively to circuit closers 8 and 9 so that (starting from the positions shown in Fig. 3) on the first or initial rotation of cam 47 fingers 30 and 33 will have moved circuit closers 6 and 7 through an angle of about 7° before fingers 31 and 34 begin to move circuit closers 8 and 9. The quick return devices comprising springs 26 and heads 28 are arranged so that they are engaged and compressed by circuit closers 6 and 7 during about the last 2° of the movement of each circuit closer.

When the steam pressure in the steam conduit or header for the boiler or bank of boilers it at its normal value, pins 49 stand midway between the upper and lower ends of wedge plates 38 and 43 as shown in Fig. 3. When the pressure increases it is assumed that the pins move upward and when the pressure decreases it is assumed that they move downward. The maximum vertical movement possible for the pins is when they are brought into line with flat surfaces 39^a or 44^a. During the operation of cam 47, pins 49 are periodically clamped between plate 48 and the surfaces of wedge plates 38 and 43 and again released. When released, the pins are free to assume a position corresponding to the steam pressure. Shaft 53 has sufficient flexibility in an axial direction to permit of the pins when clamped between plate 48 and wedge plates 38 and 43, moving with the plate. If the steam pressure changes at a time when the pins are clamped between the plate 48 and the wedge plates, the Bourdon tube 55 may take the distortion.

Fig. 3 shows diagrammatically the positions of the various parts when the steam pressure is at normal value and before cam 47 has made a revolution, it being assumed that circuit closers 8 and 9 have been brought into engagement with stops 25 and that circuit closers 6 and 7 have been brought into engagement with fingers 30 and 33. Pins 49 stand midway between the upper and lower ends of wedge plates 38 and 43. When cam 47 turns in the direction indicated by the arrow in Fig. 3, plate 48 is moved fairly rapidly toward the left by cam section *a* first bringing pin 49 into engagement with wedge plates 38 and 43, and then effecting movement of the wedge plates toward the left. The movement of the wedge plates toward the left is then continued slowly by portion *b* of cam 47 and is given a final push toward the left by the small projection *c* on the cam. Following this, the wedge plates are permitted rapidly to return to their initial positions by the receding portion *d* of the cam. The arrangement is such that under these conditions circuit closers 6 and 7 will have been closed and in addition to that moved in a counter-clockwise direction on shaft 4 a distance of about 7°. Circuit closers 8 and 9 will not have been affected as fingers 31 and 34 are spaced from them a distance such that they will not quite have reached these circuit closers. The positions of the parts at the time projection *c* engages plate 48 is illustrated in Fig. 4.

As soon as contact fingers 30 and 33 move away from the circuit closers 6 and 7, the circuit closers open immediately and begin to move very slowly back toward their initial positions being carried along by slow speed shaft 4. Before they will have moved far, however, cam 47 will have again operated to force wedge plates 38 and 43 toward the left. On this second operation of the cam nothing will happen except that circuit closers 6 and 7 will be momentarily closed by the projection *c* and will be moved again relatively to shaft 4 a distance corresponding to that which they have been carried around by shaft 4 during the time

they have been released by fingers 30 and 33. In view of the fact, however, that shaft 4 makes but about 1/3000 of a revolution while shaft 3 makes 1 revolution, it will be clear that circuit closers 6 and 7 will have been carried back but a very short amount, and an amount about equal to that which they were moved initially by cam projection *c*.

When the control device is in operation, cam 47 rotates continuously. What may be considered the normal positions of the circuit closers when the steam pressure is at normal value is substantially their positions, as shown in Fig. 4, circuit closers 8 and 9 being held by their stops 25 and circuit closers 6 and 7 being operated on by fingers 30 and 33 at the extreme end of their movements as described in the preceding paragraph.

It will thus be seen that as cam 47 continues to rotate, assuming pins 49 remain in the same position, cam projection *c* causes repeated substantially simultaneous closings of circuit closers 6 and 7 but of very short duration. Each time circuit closers 6 and 7 close either relay 59 or relay 60 will be energized tending to operate motor 58 in either one direction or the other. The two relays are set alike and as only one can operate at a time because their circuits are interconnected, it results in actual practice that over a period of time each is operated about the same number of times. The net effect is that the continuous simultaneous closing of the circuit closers 6 and 7 results in no appreciable adjustment of motor 58 in either direction.

Assume now that the system is in operation, motor 58 being connected to operate and representing the controlled mechanism and cam 47 and shafts 4 and 5 being in operation. Assume also that the steam pressure is at normal value so that pins 49 stand in the central positions shown in Fig. 4. Under these circumstances, as just explained, circuit closers 6 and 7 will be closed simultaneously at regular intervals for an instant but will have no appreciable effect on motor 58. Assume now that there is an increase in the steam pressure which indicates a decrease in demand for steam and hence requires that the rate of supply of combustible or combustibles to the furnace or furnaces be decreased somewhat. Increase in steam pressure causes pins 49, when released by plate 48 to be raised by Bourdon tube 55 a certain distance so that when the pins are again moved forward by cam 47 and plate 48, the one pin 49 will engage its wedge plate 38 at a higher step on the stepped wedge surface 39 and the other pin 49 will engage its plate 43 at a lower step on the stepped wedge surface 44. This is illustrated in Fig. 5.

As a result, wedge plate 38 will be moved in advance of wedge plate 43. Also, wedge plate 38 will be moved a greater distance than before while wedge plate 43 will be moved a lesser distance than before. Because of this, the movement of wedge plate 38 will be sufficient to effect the closing of both circuit closers 6 and 8 while on the other hand, the movement of wedge plate 43 now will not be sufficient to effect the closing of circuit closer 7 because during one revolution of cam 47 circuit closer 7 will not have been carried back by rotating shaft 4 a distance sufficient to make up for the lesser amount which wedge plate 43 is moved. Assuming the pressure has changed enough to move pins 49 several steps along the wedges as is shown in Fig. 5, then the circuit closers 6 and 8 will be closed by cam portion *a* and will be held closed while cam portions *b* and *c* are effective. The closing of circuit closers 6 and 8 closes the circuit of relay 60, effecting operation of motor 58 in a direction to decrease the rate of supply of combustible or combustibles to the furnace or furnaces.

As soon as the portion *d* of cam 47 is reached wedge plates 38 and 43 start back toward their initial positions, releasing circuit closers 6 and 8. Both circuit closers will open immediately, thus opening the circuit on relay 60 and stopping motor 58. Also both circuit closers will be carried back toward their former positions by the rotation of shafts 4 and 5, the circuit closer 8 being carried back more rapidly on account of the faster turning of shaft 5. On the next rotation of cam 47 (and assuming the steam pressure remains at the new value) circuit closers 6 and 8 will be again engaged and closed, the circuit closer 8 being engaged first because it will have been moved back further by the rotation of its shaft 5 than will circuit closer 6 by the rotation of its shaft 4. The arrangement is such that circuit closer 8 will have been carried back during the interval it is released an amount just slightly more than that which it was moved by cam portion *c*. On this next revolution of cam 47, therefore, circuit closer 8 will be engaged and closed by cam portion *b* just in advance of cam portion *c* and will be held closed until portion *c* has moved past it, the circuit closer being at the same time again turned on its shaft in a counter-clockwise direction. During the interval circuit closer 8 is closed, which interval is of short duration, a small additional adjustment of motor 58 in a direction to decrease the rate of supply of combustible or combustibles to the furnace or furnaces will take place. If as a result of the initial adjustment or the initial adjustment followed by one or more repeat adjustments of short duration the steam pressure stops increasing and starts to return toward normal value, then pins 49 will move back toward their

former positions and no further adjustment will take place in this direction. On the other hand, if, following the first adjustment referred to above, the steam pressure continues to rise bringing the pins 49 to a still higher step on wedge plate 38 and a still lower step on wedge plate 43 then circuit closers 6 and 8 will be again closed after the manner just described to effect a further adjustment or adjustments of motor 58. Fig. 5 illustrates a condition of operation wherein pins 49 have been raised a number of steps by increase in steam pressure and as will be noted circuit closers 6 and 8 are both closed. Assume now that the pressure continues to rise bringing the one pin 49 into line with flat surface 39ª. Under these circumstances, the maximum turning movement is imparted to circuit closers 6 and 8, circuit closer 6 being brought into engagement with the spring-pressed head 28 and the spring being compressed during the latter part of the movement, for example the last 2 degrees of movement. This is illustrated in Fig. 6.

As a result of this as soon as finger 30 releases circuit closer 6, it is moved back by the spring-pressed head 28 through 2 degrees. Now when cam 47 makes another revolution, circuit closer 6 will be closed while being moved through a distance represented by that which it is returned by the spring device plus the small amount which it was carried back due to the rotation of shaft 4. This represents an appreciable time and it will effect a predetermined adjustment of motor 58. Thus it will be seen that when the steam pressure has varied a predetermined amount, there will be a substantial constant adjustment of motor 58 for each revolution of cam 47.

In connection with the spring pressed head 28, the arrangement is such that it begins to become effective as the pin 49 reaches the step on the wedge adjacent to the flat portion 39ª and becomes fully effective as soon as the flat portion is reached. Thus when the pressure has varied a predetermined amount, the spring pressed head begins to be effective and increases in its action until when pin 49 reaches the flat portion 39ª the action becomes a maximum.

Assume now that the steam pressure having reached a maximum value as shown in Fig. 6, adjustments have taken place to such an extent that the furnace has responded and the steam pressure begins to decrease. Assume also that it has decreased until pins 49 have reached the position shown in Fig. 7, this being a position about the same as that which they occupied in Fig. 5. Now, when cam 47 moves forward wedge plate 38 will be operated a lesser amount than previously. As a result of this, neither circuit closer 6 nor circuit closer 8 will be closed because of the fact that they have not had time to be carried back by rotating shafts 4 and 5 an amount equal to the decrease in the movements of wedge plate 38. On the other hand, wedge plate 43 will be moved a distance greater than before and a distance such that its finger 33 will engage and close circuit closer 7. This is due to the fact that during the previous period of operation, circuit closer 7 has been carried by its shaft back to the region in which finger 33 was previously moving. In this connection it is to be noted that since circuit closer 7 has no stop, it will be moved back continuously by shaft 4 as long as it is not engaged by finger 33. As a result, therefore, circuit closer 7 will be closed and effect operation of motor 58 in a direction to increase the rate of supply of combustible or combustibles to the furnace or furnaces. By this means, the rate of decrease of the steam pressure is checked, so to speak; that is to say, forces are put into operation tending to prevent the steam pressure decreasing at a too rapid rate.

This operation of the mechanism whereby after the steam pressure has departed from normal and due to adjustments which have been effected, the pressure is moving back toward normal, adjustments in the opposite direction are effected to prevent a too rapid return of the pressure toward normal, (a thing likely to result in the pressure passing beyond normal in the other direction) is an important feature of my invention. By it the result is obtained that as the pressure returns toward normal, the rate of return as the pressure approaches normal is gradually decreased so that when normal pressure is reached the rate of return approaches zero which means that the pressure will not go beyond or will have a tendency not to go beyond normal in the other direction.

The cycle of operation is illustrated by the diagram in Fig. 9 wherein the straight line A—B represents normal pressure and the line C represents a curve followed by the steam pressure in departing from and returning again to normal. Beginning at a point D where the steam pressure is normal and following line C it will be seen that the steam pressure is increasing quite rapidly. As a result circuit closures 6 and 8 will be actuated upon successive revolutions of cam 47 after the manner already described to effect successive adjustments of motor 58 in a direction to decrease the rate of supply of combustible or combustibles to the furnace or furnaces. During this period circuit closers 7 and 9 will not be closed since circuit closer 9 is held by its stop 25 and circuit closer 7 is located in a region not now reached by finger 33 upon successive actuations of wedge plate 43. However, circuit closer 7 will be traveling back slowly toward finger 33 due to the rotation of shaft 4. At point E the steam pressure, due to the adjustments which have

been made, ceases to rise and is about to turn back toward normal. At this point there will be successive actuations of the wedge plates upon the same step which as already explained results in the closing of circuit closers 6 and 8 for very short periods, the circuit closer 8 being closed for the longer period and effecting small adjustments of motor 58 in a direction to decrease the rate of combustible supply. The pressure now starts back toward normal and at point F for example, the pins 49 will have lowered to a point on the wedge plates such that the movement of wedge plate 38 is decreased to an extent that fingers 30 and 31 do not reach circuit closers 6 and 8 while the movement of wedge plate 43 is increased to an extent such that finger 33 does reach circuit closer 7 and effects a long closure of it. Circuit closer 7 is in a position to be reached by finger 33 because during the period of increasing pressure it has been traveling back continuously with shaft 4. The closing of circuit closer 7 will effect an adjustment of motor 58 in a direction to increase the rate of combustible supply even though the steam pressure is still well above normal. As a result, therefore, there is a tendency to retard the rate of approach of the steam pressure toward normal. Retarding adjustments of motor 58 will continue as the steam pressure continues to decrease. At point G it is assumed that the decrease in the steam pressure has been checked definitely and that it tends now to increase slightly as indicated at point H and to become stabilized at this point. This may have been due, for example, to a small change in load on the boiler or boilers causing a small change in pressure. Under these circumstances, circuit closer 7 will be closed and also the circuit closers 6 and 8. However, since circuit closer 8 is on the fast speed shaft 5 it will be returned further during a revolution of cam 47 than will either of the circuit closers 6 and 7. Circuit closer 8 will be closed first therefore, and will be the controllng circuit closer out of the three. It will effect small adjustments of motor 58 in a direction to decrease the rate of supply of combustible thus again turning the pressure toward normal but at a slow rate. Beyond point H the pressure is indicated as approaching normal gradually and when normal pressure is reached further decrease in pressure may cease. However, in some instances the decrease in pressure may not cease when normal pressure is reached and at point I it is indicated as having passed slightly beyond normal. When this happens, circuit closer 9 (and also circuit closer 7) will be closed to effect an adjustment of motor 58 in a direction to increase the rate of combustible supply and turn the pressure back toward normal. And if the pressure then moves back above normal as is indicated at J, then circuit closer 8 (and also circuit closer 6) will be closed to effect an adjustment of motor 58 in the other direction. The pressure then will have a tendency to hover back and forth around normal, finally settling down at normal pressure or approximately normal pressure.

With my construction, it is not possible for the steam pressure in returning toward normal value to become stabilized at a value other than normal pressure value. This is illustrated by the operation just described in connection with the points G and H on the diagram. When the pressure was definitely checked at the point G on its downward journey there would be a tendency for it to become stabilized at this point were it not for the arrangement of the circuit closers on the slow and fast shafts. At this time circuit closers 6, 7 and 8 were being closed but since circuit closer 8 was on fast shaft 5 while circuit closers 6 and 7 were on the slow shaft, circuit closer 8 became the controlling circuit closer of the three and gave the control a definite turn toward normal value again.

This condition of operation is illustrated in Fig. 8, where it will be seen that circuit closers 6 and 7 are both positioned so they are being closed by fingers 30 and 33, and that circuit closer 8 is also being closed by finger 31. On the other hand, however, circuit closer 9 is not being closed because it is held by its stop 25 out of range of the finger 34.

In the foregoing description of the operation a condition of increasing steam pressure was assumed. Upon decrease in steam pressure which indicates increase in the demand for steam, the operation is similar to that described, except that it takes place in opposite directions.

In accordance with the provisions of the patent statutes, I have described the principle of operation of my invention, together with the apparatus which I now consider to represent the best embodiment thereof, but I desire to have it understood that the apparatus shown is only illustrative and that the invention may be carried out by other means.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. A control system for use with heating apparatus having a factor appurtenant to the heating apparatus which, during operation of the apparatus, tends to vary from a predetermined value for maintaining said factor at the predetermined value, comprising means positioned in accordance with variations of said factor from the predetermined value, means which when operated tends to restore said factor to its predetermined value, and control means through which said first-named means effects operation of said second-named means, said control means comprising

mechanism for effecting movements of said second-named means in each direction, means whereby as said factor approaches its predetermined value after having departed from such value, said mechanism will be operated to effect movement of said second-named means in a direction tending to cause departure of said factor from its predetermined value and in amounts depending upon the rate at which such factor is approaching its predetermined value whereby as the factor approaches its predetermined value its rate of approach will be decreased.

2. A control system for use with heating apparatus having a factor appurtenant to the heating apparatus which, during operation of the apparatus, tends to vary from a predetermined value for maintaining said factor at the predetermined value, comprising means positioned in accordance with variations of said factor from the predetermined value, means which when operated tends to restore said factor to its predetermined value, control means through which said first-named means effects operation of said second-named means, said control means comprising mechanism for effecting movements of said second-named means in each direction, means whereby as said factor approaches its predetermined value after having departed from such value, said mechanism will be operated to effect movement of said second-named means in a direction tending to cause departure of said factor from its predetermined value whereby as the factor approaches its predetermined value its rate of approach will be decreased, and means which serves to prevent said factor from becoming stabilized at a value other than the predetermined value.

3. A master controller comprising contact means which when actuated serves to effect an operation in one direction, contact means which when actuated serves to effect an operation in the other direction, means tending to rotate said contacts in one direction, an actuator for each contact which when moved into engagement with its contact turns said contact in a direction opposite to that in which it tends to rotate, each actuator comprising a wedge-shaped member, the two wedge-shaped members being oppositely-arranged, and means adapted to engage both actuators to move them simultaneously.

4. A master controller comprising two sets of contacts, means tending to rotate one set of contacts at a given rate and in a given direction, means tending to rotate the other set of contacts at a different rate but in the same direction, actuators for effecting closing of said sets of contacts and rotation of them in a direction opposite to said given direction, and movable means which is positioned to move said actuators variable distances.

5. A control system for use with heating apparatus having a factor appurtenant to the heating apparatus which, during operation of the apparatus, tends to vary from a predetermined value for maintaining said factor at the predetermined value, comprising reversible mechanism which when operated effects changes in said factor, electric contact means which when actuated effects operation of said reversible mechanism in one direction, electric contact means which when actuated effects operation of said reversible mechanism in the other direction, a wedge-shaped actuator for each contact means, said actuators being located side by side with the wedges oppositely disposed, and means for moving said wedge-shaped actuators comprising a member which is positioned in accordance with the value of said factor.

6. In a boiler control system, reversible mechanism for regulating the supply of combustible or combustibles to a boiler installation, a set of primary contacts, a set of secondary contacts, each set comprising a contact for effecting operation of the reversible mechanism in each direction, means which tends to rotate continuousuly said sets of contacts but at different speeds, actuators for said contacts, and means responsive to an operative condition of the boiler installation for moving said actuators.

7. In a boiler control system, reversible mechanism for regulating the supply of combustible or combustibles to a boiler installation, means responsive to an operating condition of the boiler installation for effecting operation of said mechanism to increase or decrease the rate of combustible supply to the installation, and means whereby when after a departure from normal operating condition, normal operating condition is again approached, said reversible mechanism is operated in a direction tending to again effect departure from normal operating condition whereby the approach toward normal operating condition is retarded.

8. In a boiler control system, reversible mechanism for regulating the supply of combustible or combustibles to a boiler installation, means responsive to pressure of vapor generated in said installation for operating said reversible mechanism to increase the combustible supply upon decrease in vapor pressure and to decrease the combustible supply upon increase in pressure, and means whereby after said mechanism has been operated upon a departure of the pressure from normal value to cause the pressure to return toward normal value said mechanism will be operated in a direction tending to again cause the pressure to depart from normal value whereby the approach of the pressure toward normal value will be retarded.

9. In a control system, the combination of a reversible mechanism, electric contact means which when actuated effects move-

ment of said mechanism in one direction, electric contact means which when actuated effects movement of said mechanism in the other direction, means for actuating said contacts simultaneously comprising oppositely arranged, overlapping, wedge shaped members, and means for preventing said contacts from being connected simultaneously to said reversible mechanism.

10. In a control system, the combination of a reversible mechanism, electric contact means which when actuated effects movement of said mechanism in one direction, electric contact means which when actuated effects movement of said mechanism in the other direction, means for actuating said contacts simultaneously comprising oppositely arranged, overlapping, wedge shaped members, and interlocking relays for preventing said contacts from being connected simultaneously to said reversing mechanism.

11. In a control system, the combination of a reversible mechanism, electric contact means which when actuated effects movement of said mechanism in one direction, electric contact means which when actuated effects movement of said mechanism in the other direction, oppositely arranged, overlapping, wedge shaped members which when moved effect closing of said electric contact means, means which engages both said wedge shaped members to move the same, said means being movable relatively to said members, and a continuously rotating cam for imparting periodic movement of said last named means.

12. In a control system, the combination of a reversible mechanism, a continuously rotating shaft, contacts mounted on said shaft in frictional engagement therewith whereby the contacts tend to turn with the shaft but may be moved relatively to the shaft, oppositely arranged, overlapping, wedge shaped members which when moved close said contacts and turn them relatively to the shaft and in a direction opposite to that in which the shaft rotates, and means movable relatively to the inclined surfaces of said wedge shaped members which engages the wedge shaped members and moves them in a direction to close said contacts.

13. In a control system, the combination of a reversible mechanism, a continuously rotating shaft, contacts mounted on said shaft in frictional engagement therewith whereby the contacts tend to turn with the shaft but may be moved relatively to the shaft, oppositely arranged, overlapping, wedge shaped members which when moved close said contacts and turn them relatively to the shaft and in a direction opposite to that in which the shaft rotates, means movable relatively to the inclined surfaces of said wedge shaped members which engages the wedge shaped members and moves them in a direction to close said contacts, and means for preventing said contacts from being connected simultaneously to said reversible mechanism.

14. In a control system, the combination of a reversible mechanism, electric contact means which when actuated effects movement of said reversible mechanism in one direction, electric contact means which when actuated effects movement of said mechanism in the other direction, a continuously rotating shaft to which said contact means are frictionally connected and which tends to turn them in one direction, a second continuously rotating shaft which turns at a speed different from that of the first named continuously rotating shaft, secondary electric contact means frictionally connected to said second continuously rotating shaft, said secondary electric contact means being connected in parallel with said primary electric contact means, and periodically actuated means which tends to close said contacts and rotate them in a direction opposite to that in which the shafts tend to rotate.

15. A control system for use with apparatus having a factor which, during operation of the apparatus, tends to vary from a predetermined value, for maintaining said factor at the predetermined value, comprising adjustable means which when operated tends to restore said factor to its predetermined value, control means for effecting movements of said adjustable means, means responsive to the rate of departure of the factor from the predetermined value, said last-named means effecting variations in the magnitude of said movements, and selective means effective as said factor approaches the predetermined value after having departed from such value for operating said control means to effect movement of said adjustable means in a direction tending to cause departure of said factor from its predetermined value and in amounts depending upon the rate at which said factor is approaching its predetermined value whereby as the factor approaches its predetermined value its rate of approach will be decreased.

16. A control system for use with apparatus having a factor which, during operation of the apparatus, tends to vary from a predetermined value, for maintaining said factor at the predetermined value, comprising means positioned in accordance with variations of said factor from the predetermined value, adjustable means which when operated tends to restore said factor to its predetermined value, control means through which said first-named means effects operation of said adjustable means, said control means comprising mechanism for effecting movements of said adjustable means in each direction, means responsive to the rate of departure of the factor from the predetermined

value, said last-named means effecting variations in the magnitude of said movements, and selective means effective as said factor approaches the predetermined value after having departed from such value for operating said control means to effect movement of said adjustable means in a direction tending to cause departure of said factor from its predetermined value and in amounts depending upon the rate at which said factor is approaching its predetermined value whereby as the factor approaches its predetermined value its rate of approach will be decreased.

17. A control system for use with apparatus having a factor which, during operation of the apparatus, tends to vary from a predetermined value, for maintaining said factor at the predetermined value, comprising adjustable means which when operated tends to restore said factor to its predetermined value, control means for effecting movements of said adjustable means, means responsive to the rate of departure of the factor from its predetermined value, said last-named means effecting variations in the magnitude of said movements, means effective upon departure of said factor a predetermined amount from the predetermined value and limiting the successive movements of said adjustable means to a constant magnitude, and selective means effective as said factor approaches its predetermined value after having departed from such value for operating said control means to effect movement of said adjustable means in a direction tending to cause departure of said factor from its predetermined value and in amounts depending upon the rate at which said factor is approaching its predetermined value whereby as the factor approaches its predetermined value its rate of approach will be decreased.

18. A control system for use with apparatus having a factor which, during operation of the apparatus, tends to vary from a predetermined value, for maintainig said factor at the predetermined value, comprising means positioned in according with variations of said factor from the predetermined value, adjustable means which when operated tends to restore said factor to its predetermined value, control means through which said first-named means effects operation of said adjustable means, said control means comprising mechanism for effecting movements of said adjustable means in each direction, means responsive to the rate of departure of the factor from the predetermined value, said last-named means effecting variations in the magnitude of said movements, means effective upon departure of said factor a predetermined amount from the predetermined value and limiting the successive movements of said adjustable means to a constant magnitude, and selective means effective as said factor approaches the predetermined value after having departed from such value for operating said control means to effect movement of said adjustable means in a direction tending to cause departure of said factor from its predetermined value and in amounts depending upon the rate at which said factor is approaching its predetermined value whereby as the factor approaches its predetermined value its rate of approach will be decreased.

In witness whereof, I have hereunto set my hand this 8th day of December, 1927.

RALPH M. HARDGROVE.