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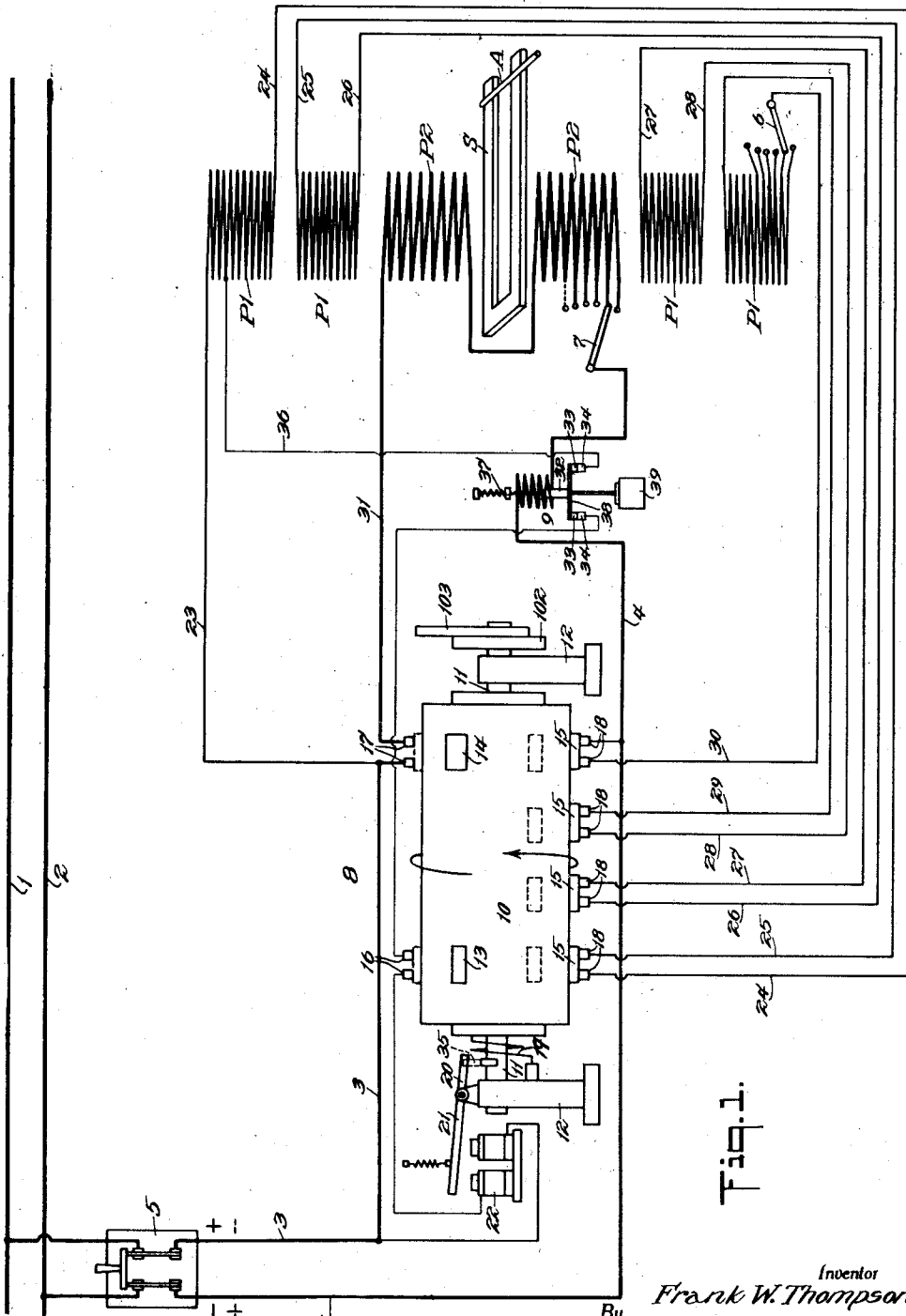
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1,695,302

ELECTRIC HEATER

Filed April 12, 1922

7 Sheets-Sheet 1



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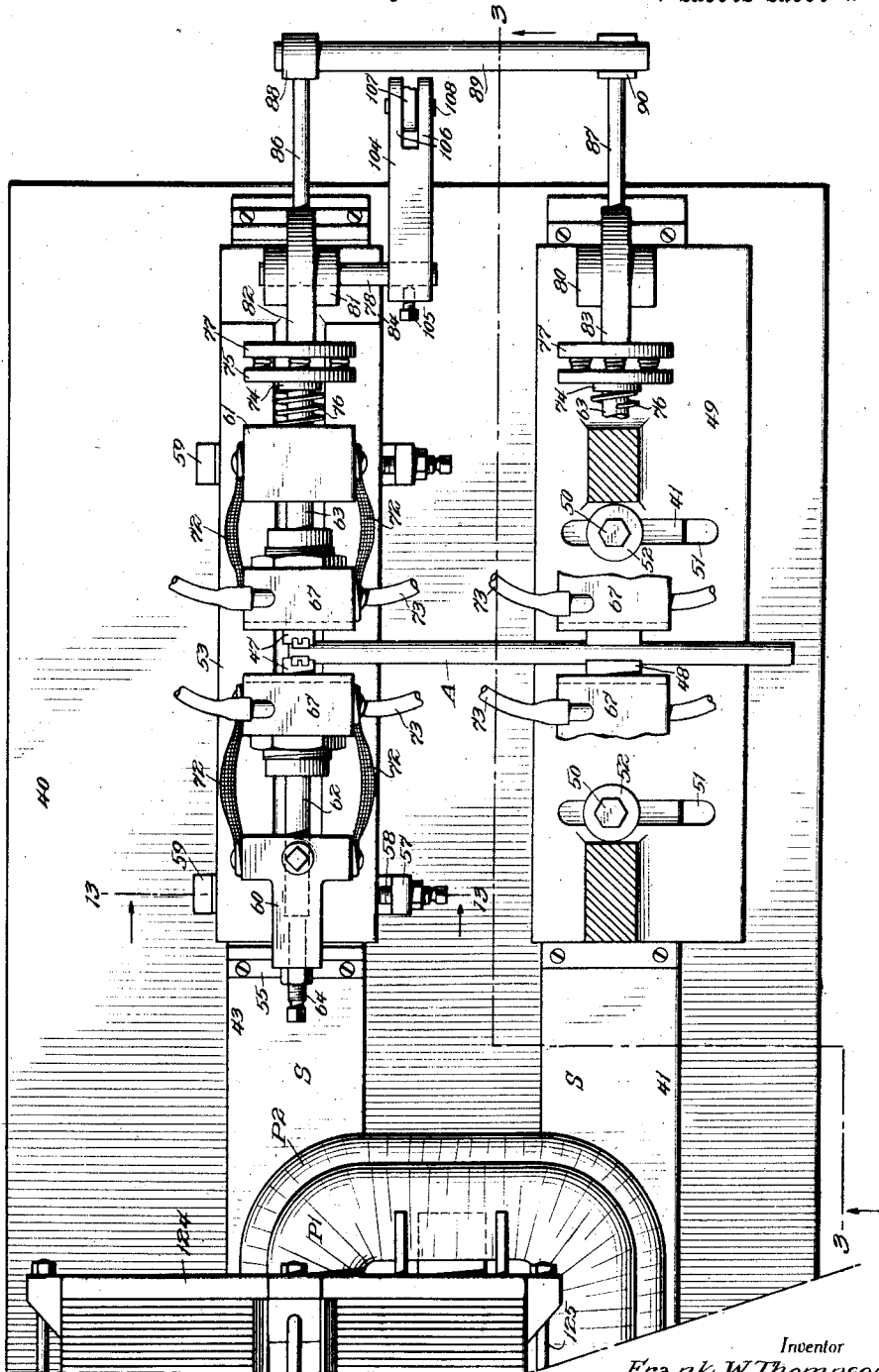
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Fig. 2.



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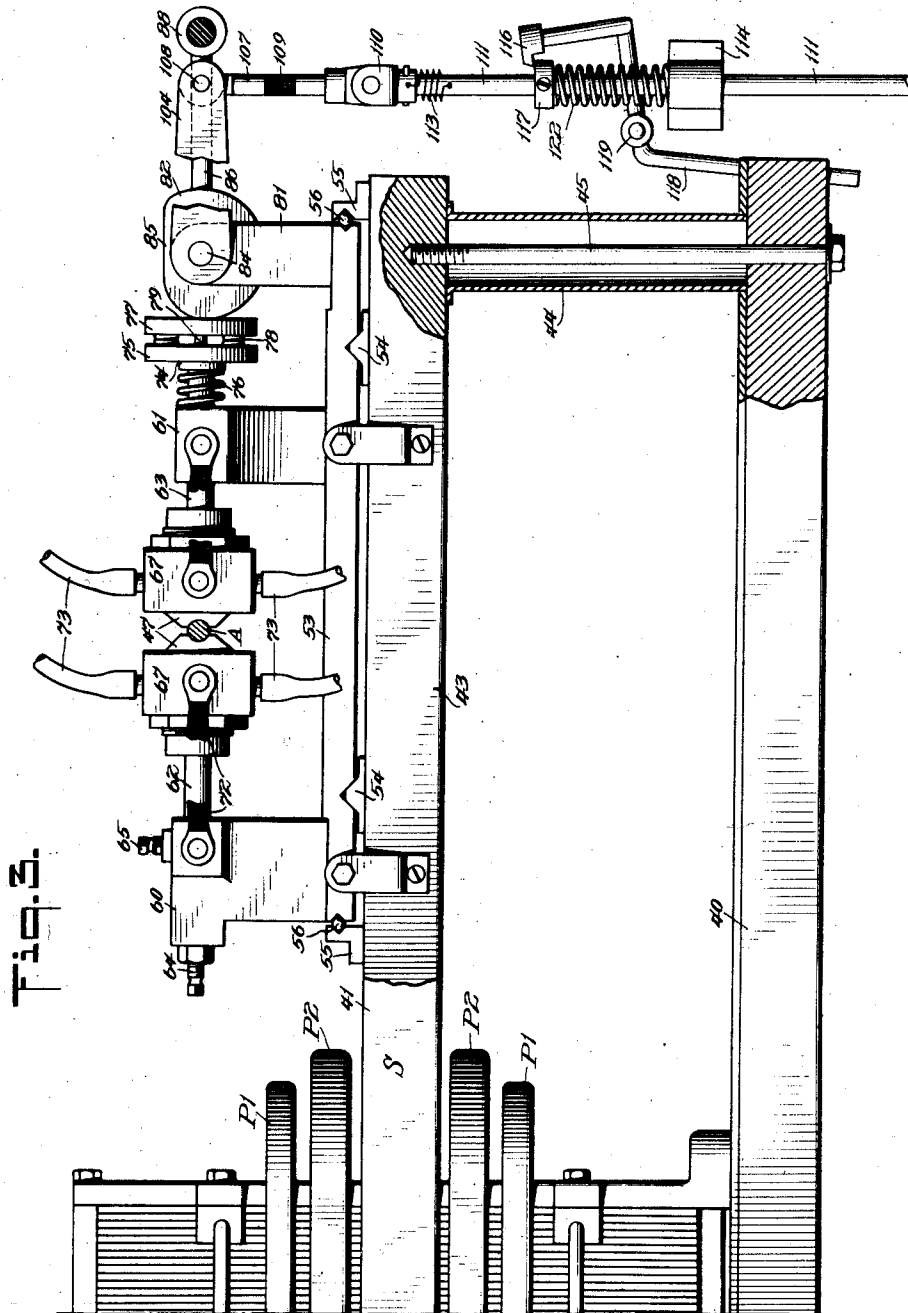
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7 Sheets-Sheet 3



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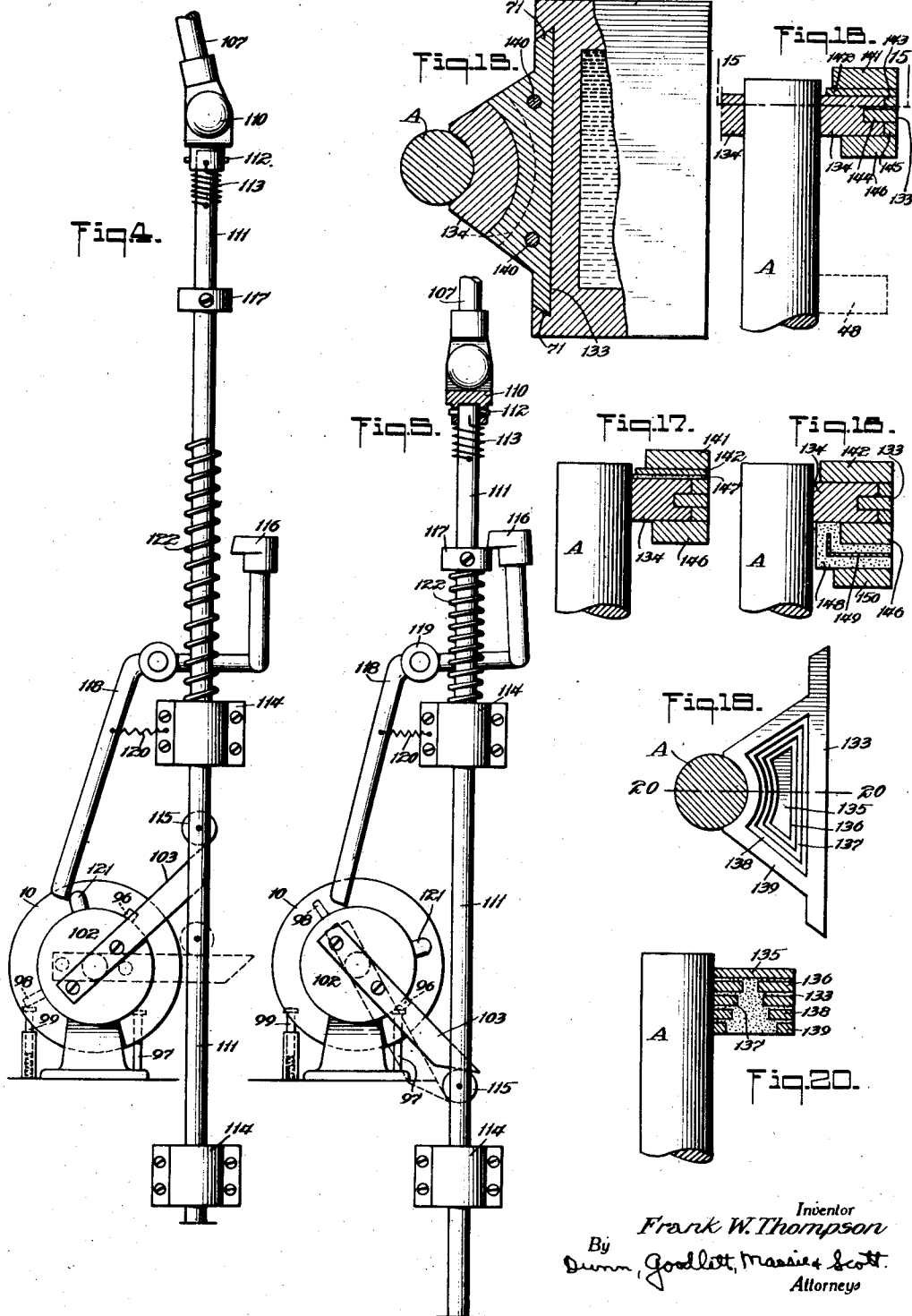
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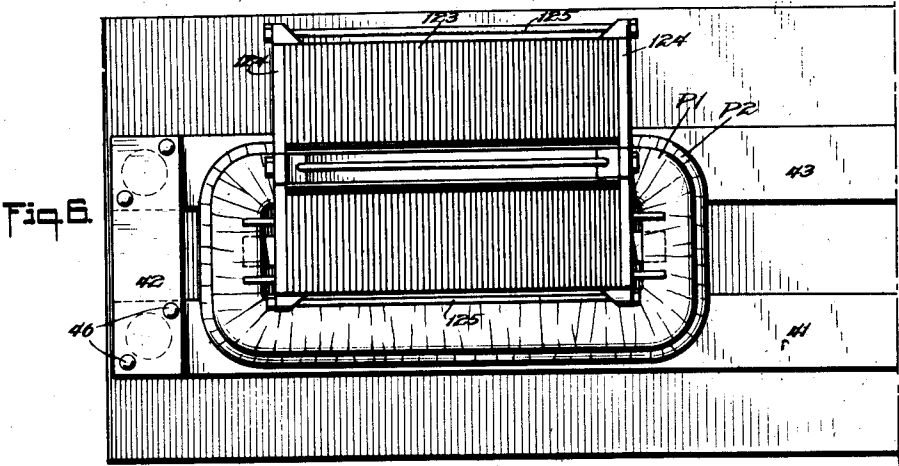
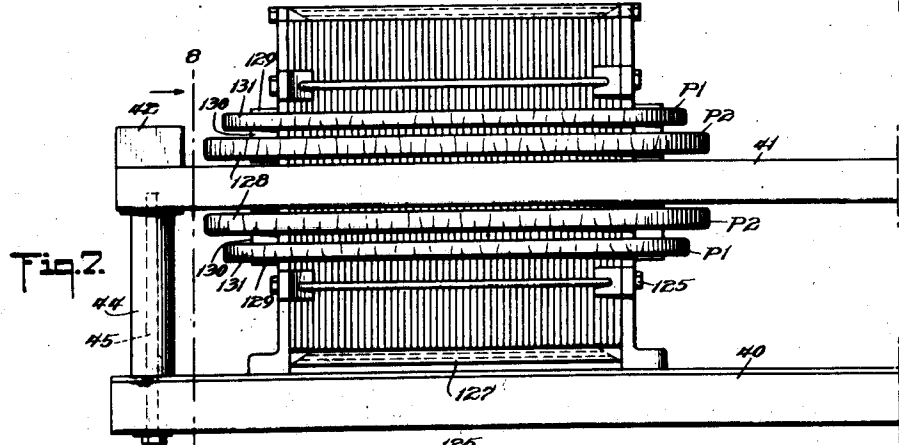
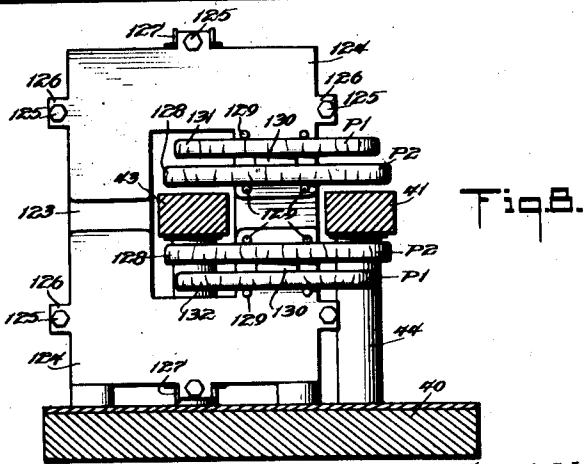
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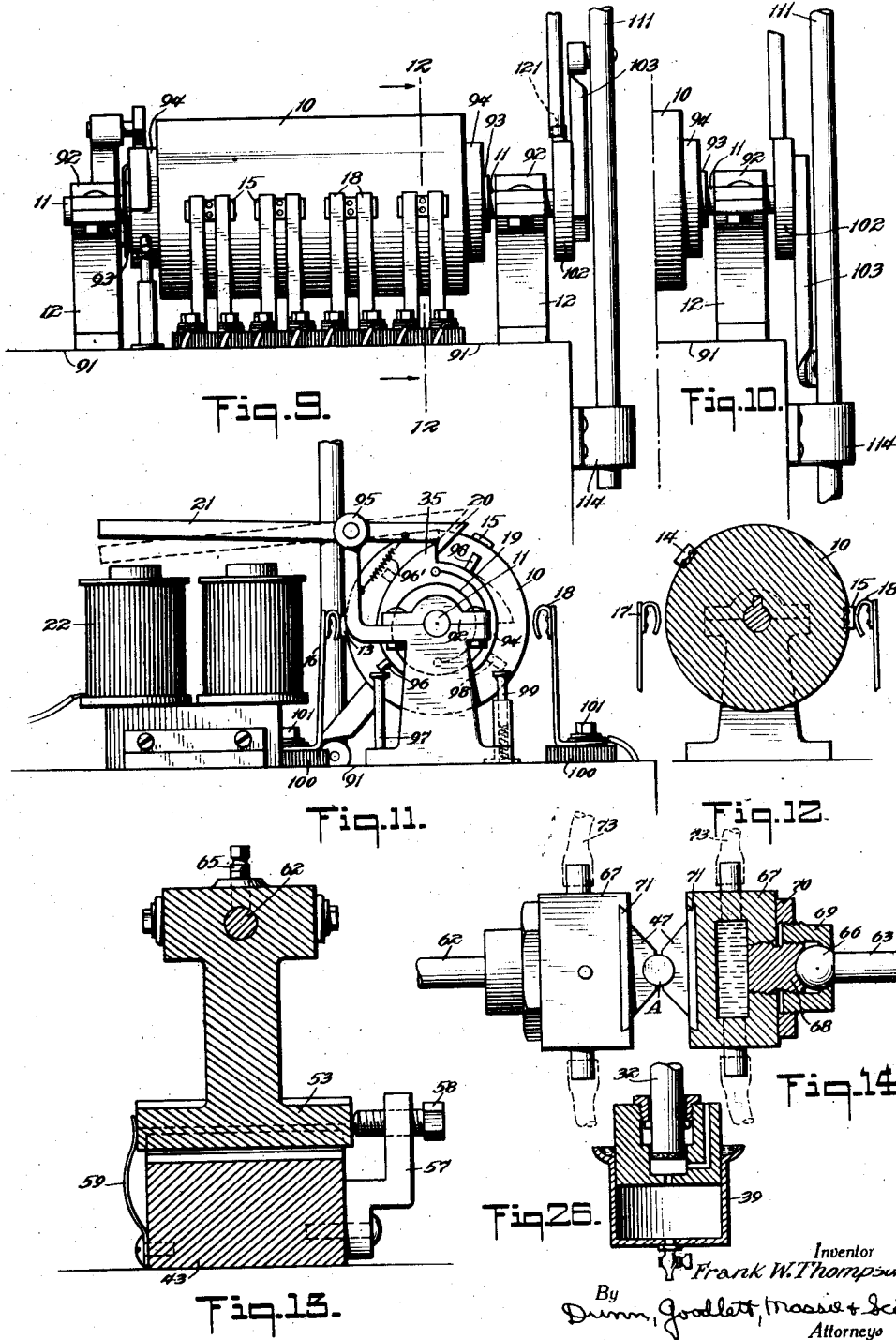
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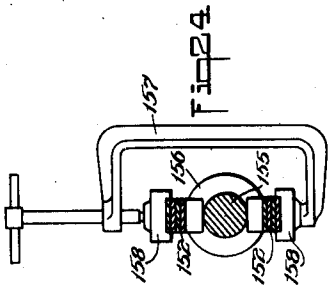
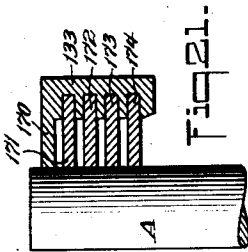
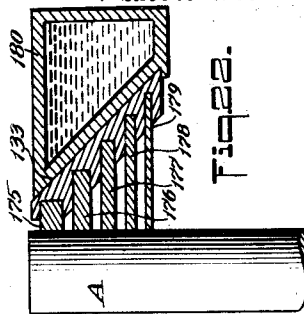
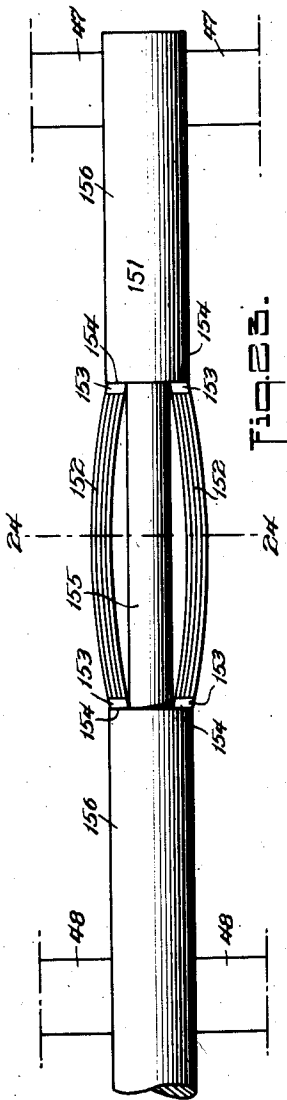
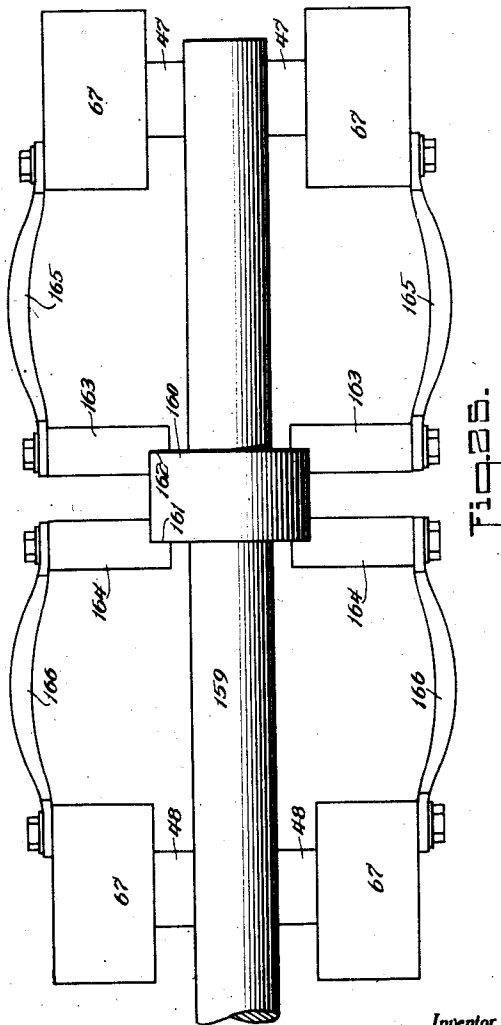
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UNITED STATES PATENT OFFICE.

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ELECTRIC HEATER.

Application filed April 12, 1922. Serial No. 551,864.

This invention relates to electric heating, and more particularly to a method for heating electro-conductive articles comprising the passage of electricity therethrough, and to an apparatus for carrying out the new method.

In certain manufacturing operations, it is desirable to heat metal blanks of various shapes, and whether of uniform cross sectional area or of irregular cross-section, to a uniform temperature, or to heat specified portions of the blanks to certain temperatures, while other portions are heated to different temperatures or are not heated at all, as the case may be.

An important object of this invention is to provide a method and means for heating electro-conductive blanks of varying or uniform cross-section throughout any specified portions to any number of different temperatures, by the passage of electricity through the blanks.

In heating short metal bars such as rivets, it has been the practice, in order to obtain uniform flow of current through the bar and good electrical contact between the bar and the electrodes, to compress the bar between two electrodes of opposite polarity, each end of the bar abutting against an electrode. Although this method of holding a bar to be heated is reasonably satisfactory for short thick bars having prepared ends, it is of comparatively little use with many articles of less strength or having rough or irregular ends, since the pressure of the electrodes necessary to establish good electrical contact, even with prepared ends, may be so great as to deform such articles and mushroom the ends abutting the electrodes when a high temperature is reached; while it would be difficult, if not impossible, to establish good electrical contact with the irregular and unprepared ends found on many articles to be heated.

It is another object of this invention to provide means for holding any article to be heated without materially deforming the same at any temperature below its melting point to which it may be heated.

A further object is to provide holding means which will control the distribution of heat throughout any desired portion of the article. For example, difficulties have been encountered in heating that portion of an article which contacts with the electrodes, and it is a particular object of the invention

to provide electrodes whereby the contacting portions of the article may be heated to an approximately uniform temperature or given any desired temperature gradient, or whereby the heating of such portions may be controlled at will.

In numerous industrial processes, for example in forging, it is necessary to heat a series of articles uniformly to a definite predetermined temperature, repeating the process over and over with a large number of substantially identical articles. Moreover the operator is not always ready to perform the next step upon the article at the instant when it attains the required temperature, and good results would not be accomplished if the heat were merely shut off, since cooling would begin at once and the article would not be at the proper temperature when the operator was ready to perform the next step. Again in heat treating certain articles, it is desirable to heat them at one rate to a given temperature and thereafter either to maintain such temperature constant, or to increase or decrease the temperature at a different rate until a final desired value is reached, which temperature may be maintained constant.

A further object of the invention is to provide means for automatically heating an electro-conductive article, to a predetermined temperature at one rate, then further heating or cooling the article at a different rate until a final predetermined temperature is reached, and thereafter maintaining such temperature substantially constant for any desired period, or for maintaining constant the predetermined temperature to which the article was heated at first.

It is still another object of the invention to provide a method of controlling electric circuits in response to a change in the resistance of an article being heated resulting from a change of the temperature of the article.

In accomplishing these objects there may be provided two or more sources of electric power of different potential, means for applying either source to an article to be heated, and means responsive to a predetermined increase of resistance of the article for cutting off a source of higher potential and applying a source of lower potential. It has been found in practice that this method of heating an article may be most economically carried out by the provision of an alternating current transformer having two primary windings,

one comprising a relatively large number of turns, the other a smaller number of turns, and a secondary winding consisting of a single open turn to be closed by the article to be heated.

In order to apply the current to the article to be heated without undue losses at the point of contact, or overheating of the electrode, and to avoid deforming the article to be heated, each electrode may advantageously comprise a clamp having two or more relatively movable jaws, which may be forced together to grip a strong portion of the article sufficiently tightly to give good electrical contact without tending to mushroom the portion gripped. Since the article is supported by two such clamps, it is not thereby subjected to any force which might tend to deform it, as would be the case if it were compressed between electrodes at opposite ends. The use of clamps gripping the sides of the article requires specially shaped electrodes of special composition, since otherwise the difference of resistance of the current path through the article being heated between different portions of the electrodes of opposite polarity would cause an uneven distribution of the current and of the heat. The details of a number of satisfactory electrodes will be given in the following description.

One embodiment of the invention as applied to the heating of metal bars for forging, has been illustrated in the accompanying drawings and will be described in detail, but it is to be understood that the invention is applicable to the heating of other articles, that the new method can be carried out by other means than those specifically described, and that the description is merely by way of example and not to limit the invention as defined in the appended claims.

In the drawings:

Fig. 1 is a circuit diagram of one electric heater for carrying out the invention;

Fig. 2 is a plan view with certain parts broken away of such an electric heater;

Fig. 3 is a front sectional elevation taken on the line 3—3 of Fig. 2 as seen in the direction of the arrows, showing certain parts of the heater and of the operating mechanism for a circuit changer;

Fig. 4 is an elevation showing on a larger scale the circuit changer operating mechanism seen in Fig. 3, together with the right hand end of a circuit changer operated thereby; part of the operating mechanism appearing in normal position in solid lines and in an intermediate position in dotted lines;

Fig. 5 is a view of the elements shown in Fig. 4 in operated position in solid lines, and in another intermediate position in dotted lines;

Fig. 6 is a plan view of a transformer forming part of the heater;

Fig. 7 is a front elevation of the transformer shown in Fig. 6;

Fig. 8 is a section taken on the line 8—8 of Fig. 7 as seen in the direction of the arrows;

Fig. 9 is an elevation showing the front of the circuit changer in normal position as viewed from the left of Fig. 4;

Fig. 10 is an elevation showing in operated position certain of the parts shown in Fig. 9;

Fig. 11 is an elevation showing in operated position the left hand end of the circuit changer together with a controlling magnet;

Fig. 12 is a section taken on the line 12—12 of Fig. 9 as seen in the direction of the arrows;

Fig. 13 is a section taken on the line 13—13 of Fig. 2 showing a detail of the heater;

Fig. 14 is a view on a larger scale and partly in section of the electrode mounting shown in Fig. 3;

Fig. 15 is a section taken on the line 15—15 of Fig. 16, showing on a still larger scale the electrode shown in Fig. 14;

Fig. 16 is a sectional plan view of a bar to be heated abutting an electrode;

Figs. 17, 18, 21 and 22 are views similar to Fig. 16 showing various modifications of the electrode;

Fig. 19 is a view similar to Fig. 15 showing another modification;

Fig. 20 is a section taken on the line 20—20 of Fig. 19;

Fig. 23 is a plan view of certain portions of a heater and an article to be heated having a reduced central portion;

Fig. 24 is a central transverse section taken on the line 24—24 of Fig. 23;

Fig. 25 is a plan view of certain portions of a heater and an article to be heated having an enlarged central portion, and

Fig. 26 is a transverse section of a dash-pot to cooperate with a solenoid.

The purpose of the various structures to be described will be more readily understood after a brief consideration of the circuit diagram in Fig. 1. In the diagram, 1 and 2 indicate conductors connected to a suitable source of alternating current which may be connected to conductors 3 and 4 by the closure of a switch 5. At the right of the diagram is shown a step-down transformer having two primary windings, P^1 consisting of a relatively large number of turns of fine wire, P^2 consisting of a relatively small number of turns of a larger wire and a secondary winding S consisting of a single open turn which preferably comprises a heavy bar of negligible resistance as compared with that of the primary windings. To vary the number of turns of primary winding P^1 , which may at any time be included in the circuit, the winding is tapped at suitable intervals and the successive taps connected to successive fixed contacts of a rotary switch 6. Similarly,

the number of turns in primary winding P^2 may be varied in accordance with the position of a switch 7.

In order to control the connection of the transformer to the source of power, there are provided a circuit changer 8 and a solenoid switch 9. The circuit changer in the present embodiment comprises a cylindrical drum 10 of wood or other suitable insulating material, carried by a shaft 11 rotatably supported on standards 12. Drum 10 carries a contact 13, a contact 14 and a row of contacts 15, each comprising a strip of copper secured to the drum, the strips 13, 14 and 15 being arranged to interconnect pairs of contact springs 16, 17 and 18, respectively. The contacts are shown in solid lines in their normal or first operative position, in which spring pairs 18 are interconnected by strips 15, while spring pairs 16 and 17 are open. When drum 10 is rotated in the direction of the arrow by operating mechanism to be described, the contacts move to the positions indicated in dotted lines, first opening springs 18, next closing springs 17 and a fraction of a second later closing springs 16. To hold the drum 10 in this second operative position against the force of a spiral spring 19 constantly urging it into the normal or first operative position, there is provided a pawl 20 carried by armature lever 21 of a release magnet 22.

To heat an article of uniform cross-section such as metal bar A, the electrical and thermal characteristics of which have been determined, the switch 6 is set to include that number of turns of primary transformer winding P^1 which will cause just sufficient current to flow through the secondary circuit S to compensate for all heat losses to which bar A is subject when it reaches its final predetermined temperature, so that such temperature will be maintained constant when the bar has been heated and current is flowing through winding P^1 . The switch 5 is then closed and the bar is positioned so as to complete the secondary circuit S. With the circuit changer 8 in the normal or first operative position, current flows through winding P^1 over a circuit which may be traced from conductor 1, right-hand side of switch 5, conductor 3, conductor 23 through the upper turns of winding P^1 , conductor 24, springs 18 closed by left-hand strip 15, conductor 25, remaining turns of the upper half of winding P^1 , conductor 26, second pair of springs 18 and contact 15, conductor 27, upper portion of lower half of winding P^1 , conductor 28, third pair of springs 18 and contact 15, conductor 29, remaining portion of lower half of winding P^1 , switch 6, conductor 30, right-hand springs 18 and contact 15, conductor 4, left-hand side of switch 5 to conductor 2.

The current flowing in this circuit, owing to the large number of turns in winding P^1 , induces a relatively low potential in the second-

ary winding, so that a current so weak as to heat bar A but slowly flows through the secondary circuit S and bar A in series. When, as is usually the case, it is desired to raise the temperature of the bar rapidly, the winding P^1 is disconnected, and winding P^2 which has fewer turns and hence induces a higher secondary voltage is connected. To effect the substitution of the transformer windings the circuit changer 8 is operated in a manner to be described to rotate drum 10 in the direction of the arrow, opening contact springs 18 to interrupt the circuit just traced, then closing springs 17 and a moment thereafter closing springs 16. When springs 17 ride into engagement with contact 14, a circuit is completed for winding P^2 which may be traced as follows: Conductor 1, right-hand side of switch 5, conductor 3, spring 17 and contact 14, conductor 31, winding P^2 (upper and lower halves in series), switch 7, winding of solenoid 9, conductor 4, left-hand side of switch 5 to conductor 2.

The heavy flow of current in this circuit immediately energizes solenoid 9 to attract plunger 32, lifting contacts 33 carried thereby out of engagement with stationary contacts 34 upon which they normally rest. Drum 10 is locked in operated position by the engagement of pawl 20 with a tooth 35 on shaft 11, and remains in this position until release magnet 22 is operated over a circuit prepared by the closing of springs 16 by contact 13, but interrupted by the opening of solenoid contacts 34. The release magnet circuit may be traced from left-hand stationary solenoid contact 34, through springs 16 and contact 13, winding of magnet 22, conductors 3 and 23, through a few turns of primary winding P^1 now out of the main electric circuit but acting as a low voltage secondary winding of the transformer, and thence over conductor 36 to the right-hand stationary contact 34 of solenoid 9.

This circuit will be completed whenever the current flowing through primary winding P^2 and solenoid 9 is too weak to offset the action of a compression spring 37 which tends to hold contacts 33 and 34 closed. The current flowing through primary winding P^2 over the circuit just traced sets up a very high current in the secondary winding S which passes through the cold metal bar A and starts to heat the same. The rapidity with which the bar A is heated depends on the voltage impressed on the secondary circuit which is in turn controlled by the position of switch 7, so that the temperature of the bar may be increased at any desired rate by proper design of the transformer and the inclusion of the proper number of turns of winding P^2 . As bar A becomes hot its resistance increases appreciably, thereby increasing the resistance of the secondary circuit of the transformer and hence decreasing the

current flow in the primary circuit. If the predetermined temperature to which bar A is to be heated lies below or only a little above the critical point of the material of which the bar is composed, it is merely necessary to adjust the tension of solenoid spring 37 and the vertical position of stationary contacts 34, so that when bar A has reached the predetermined temperature the effect of the current flowing in the primary circuit and through solenoid 9 will be just overcome by spring 37, which thereupon forces plunger 32 downward until movable contacts 33 encounter stationary contacts 34. Contacts 33, being carried by a metal bridge 38, close the circuit previously traced to operate release-magnet 22, thereby withdrawing pawl 20 from engagement with tooth 35. Spring 19 immediately returns drum 10 to its normal position, indicated in solid lines in Fig. 1, thereby interrupting the circuit through transformer winding P^2 and completing the circuit previously traced through winding P^1 . The number of turns included in winding P^1 has been arranged by proper positioning of switch 6 to induce the proper voltage in the secondary circuit to cause just sufficient current to flow through bar A to produce heat equivalent to the losses from the bar by radiation, convection and conduction, and thereby to maintain the temperature of bar A constant at a predetermined value which may be below, equal to or above the temperature at which the solenoid operated to cut out winding P^2 . The bar is then slowly cooled, maintained with unchanged temperature or heated, as the case may be, until the final temperature resulting from the particular position of switch 6 is reached. When the operator is ready to use the hot bar, he removes it and substitutes a cold one. The circuit changer 8 is again operated, the new bar is brought to exactly the predetermined temperature, the circuit through winding P^2 is then automatically interrupted and the bar retained at or brought to its final temperature, and so on for as many bars as are to be heated. Thus a single adjustment of switches 6 and 7 insures uniform heat treatment of any number of identical articles which may be heated one after the other.

It frequently occurs that the predetermined temperature to which it is desired to heat a bar will be materially higher than the critical point for the metal composing the bar to be heated. When this is the case, it would not ordinarily be possible to operate the heater in precisely the manner described, since when the critical point of the bar is reached the resistance does not increase in proportion to increase in temperature, and very nearly the minimum value of the current flowing through winding P^2 would be attained before the bar reached the predetermined temperature. It is therefore desirable

to introduce a time interval between the attaining of approximately the minimum value of the current through primary winding P^2 and the closure of solenoid contacts 33, 34, during which time interval the bar is heated beyond its critical point to the predetermined temperature by the current flowing in the secondary winding S, which is induced by the current still flowing in primary winding P^2 . To introduce the necessary time interval, there may be provided a dash pot 39 which may be regulated in conjunction with compression spring 37 to delay the closure of contacts 33, 34 for any desired interval after the bar has reached its critical temperature and the current in P^2 has reached its approximate minimum value. Thus, when the bar has been heated to its critical point, plunger 32 begins to move out of the solenoid winding 9, but this movement is opposed by dash pot 39 until when contacts 33, 34 finally close, bar A will have reached the predetermined temperature. As before, the closure of the solenoid contacts operates the release magnet to return the circuit changer to normal position, opening the heating circuit through transformer winding P^2 and closing the constant temperature circuit previously traced through winding P^1 . When the rate at which the bar is heated is very great, it is frequently unnecessary to employ a dash pot to provide an interval between the attaining of the approximate minimum value of the current through winding P^2 and the disconnection of said winding, since the time inherently required for operation of the solenoid, release magnet and circuit changer may be sufficient to allow heating of the bar A well beyond its critical point.

Considering now the structure of the heater as shown in Figs. 2 and 3, there is provided a table 40 of wood or other suitable insulating material at a convenient height from the ground upon which is set the heater, which comprises the transformer having primary windings P^1 and P^2 and the open secondary circuit S, which consists of a heavy copper bar magnetically linked with the primary windings of the transformer. Secondary turn S is most conveniently built up from three straight bars 41, 42 and 43, the bars 41 and 43 being supported at either end on sleeves 44 resting on table 40 and secured thereto by bolts 45, while bar 42 rests on the left hand ends of bars 41 and 43 and is held in close electrical contact therewith by any suitable means such as cap screws 46 (see Figs. 6 and 7). If an article to be heated were merely laid across the right hand ends of bars 41 and 43, while some current would flow through the secondary circuit, the contact between the article to be heated and the copper bars would be very poor, moreover the heat losses by conduction through the parts of the article in contact with the bars of the

secondary circuit would be so great as to almost wholly prevent heating of such portions of the article. Again if, as is usually the case, the article to be heated was composed of a material of higher resistivity than that of the secondary circuit, the resistance of the portions of the article in contact with the secondary bars would be so much higher than that of the bars themselves, that most of the current would enter the article at the interior edges of the bars and the small current flowing through those portions of the article contacting with the bars would be insufficient to heat the article materially. In order therefore to establish good electrical contact, to control the path taken by the current in entering the article to be heated, and to control the heat losses by conduction there are provided special electrodes 47 and 48 and special mountings therefor. In order that the electrodes may be relatively movable to accommodate articles of various lengths, the base for electrode 48 comprises a copper slab 49 which lies flat upon the right end of bar 41 of the secondary winding and is secured thereto by screws 50 passing through slots 51 and provided with friction washers 52 to engage the margins of said slots. By loosening screws 50 it is therefore possible to adjust the position of slab 49 throughout a wide range, and to clamp it against accidental displacement when properly positioned.

Owing to the expansion which will take place in any article to be heated as its temperature rises, provision must be made for such linear expansion and the base for electrode 47 is therefore allowed a limited movement relative to its bar 43. The base for electrode 47 consists of a copper slab 53 somewhat narrower than slab 49 to support which slab there are provided two copper bearing bars 54, parallel to each other and to slots 51, which bars are secured in any desired manner to the upper surface of bar 43. Slab 53 is provided with grooves, as shown, to cooperate with the bearing bars 54 and is thus in good electrical contact with the secondary bar 43 while capable of movement transverse thereto. To give still better electrical contact, slab 53 may be connected to bar 43 by suitable flexible conductors, not shown. To further control the movement of base 53 there are provided at the opposite ends thereof copper angle pieces 55 rigidly secured to bar 43 and having grooves to cooperate with similar grooves in the ends of base 53 in carrying balls 56 which limit the movement of base 53 on its bearing bars and ball bearings described. Two brackets 57 (see Fig. 13) are rigidly secured to the inner vertical face of the bar 43 and carry set screws 58 which limit the travel of base 53 towards base 49. To normally hold base 53 in contact with the set screws, two springs 59 are secured on the outer vertical face of bar 43 with their free ends

bearing against the outer face of base 53. Thus when the article being heated expands longitudinally, owing to its increasing temperature, it need not slip in its electrode 47 but base 53 will move against the tension of springs 59. The same result may be accomplished by making bar 43 of yielding construction, as by building it up from flexible sheets of copper.

Since the standards carried by bases 49 and 53 are identical, the description of those carried by base 53 will also serve as a description of those on base 49. Cast integrally with or rigidly secured to base 53 are two copper standards 60 and 61, through the heads of which are drilled holes at right angles to the direction of movement of base 53 and in alignment with one another. A rod 62 is slidably mounted in the hole through standard 60 while a rod 63 is similarly mounted in standard 61. To carry the thrust on rod 62, a screw 64 passes through the end of standard 60 in alignment with rod 62 and bears against the end thereof. A set screw 65 may further be provided in the top of the standard (see Fig. 11).

The mountings for the two parts of electrode 47 being identical it will be necessary to describe only the right hand mounting (clearly shown in Fig. 14). Rod 63 terminates in a ball 66 on which a water jacket electrode base 67 is carried by a knuckle joint consisting of tapered plug 68 which closes the hole through which the core used in casting water jacket 67 was withdrawn and which plug is shaped to bear against ball 66. Plug 68 is held against the ball, with just sufficient pressure to ordinarily prevent relative movement, by a nut 69 which is held in position by a lock nut 70. The two parts of electrode 47 are each dovetailed into a groove 71 provided in one face of water jacket 67. Since the knuckle joint described might not afford entirely satisfactory electrical connection between standards 60 and 61 and their respective water jackets, the standards are conductively united to the water jackets by copper braid 72 suitably secured to the standards and jackets, respectively, and having sufficient stiffness to return the water jackets to their normal opposed position when they have been moved on their knuckle joints, owing to some irregularity in shape of the article to be heated. Other means than braids 72 may be employed to straighten out the water jackets, or such means may be dispensed with entirely, since the compression of the electrodes against each bar will of itself move the jackets until the surface of the bar is in intimate contact with the electrode faces. To supply a flow of cooling fluid through jackets 67 to cool the electrodes, rubber or other non-conducting flexible tubing 73 is connected to a suitable supply of cooling fluid, not shown, and circulation of the water or other cooling fluid such

as oil is brought about in any desired manner.

The relative movement of the two halves of electrodes 47 and 48 is controlled in accordance with the position of rods 63 carrying the right hand halves of the electrodes. Each rod 63 terminates at its outer end in a rigidly secured collar 74, which may be integral with or otherwise fixed to a disc 75. A compression spring 76, bearing against the right hand face of standard 61 and the left of collar 74, constantly urges rod 63 to the right. A disc 77 is separated from disc 75 by three compression springs 78, the combined strength of which is considerably greater than that of spring 76, which they oppose. The faces of discs 75 and 77 are maintained parallel by an alignment pin 79 secured at the center of disc 77 and traveling in a cooperating hole in disc 75. Similar pins, not shown, may also be threaded through each of the three springs 78. Rigidly secured at the right hand ends of bases 49 and 53 are two standards 80 and 81, each terminating in a pair of ears perforated to form bushings for pins on which are rigidly mounted cams 82 and 83. The pin for cam 83 is coextensive with its bushings while the pin carrying cam 82 comprises a shaft 84 extending inwardly far enough to clear base 53. As seen in Fig. 3, in which it is shown in operated position, cam 82 is circular throughout its lower half up to the point of contact with disc 77 from which point the radius of curvature of the cam surface gradually increases until the surface becomes flat at 85. Cam 83 is of the same shape as cam 82 and the cams are operated by levers 86 and 87, the inner ends of which fit snugly into recesses provided in the cams to receive them. Rigidly secured at the outer end of lever 86 is a ring 88 through which is mounted a handle 89 of suitable insulating material extending to a semi-circular ring 90 open at its top and secured to the outer end of lever 87. Thus when cams 82 and 83 are in their normal position with levers 86 and 87 rising vertically and discs 77 resting against flat portions 85 of the cams, springs 76 will force collars 74 and rods 63 to their extreme right-hand position, so that the opposite jaws of electrodes 47 and 48 will be wide open to receive the article to be heated, in this case the bar A. After a bar has been inserted between the opposite faces of the electrodes, handle 89 is pushed down from its vertical position to the horizontal position shown in Fig. 3, during which motion cams 82 and 83 first compress springs 76, moving rods 63 to the left until the bar A is tightly gripped between the jaws of the electrodes and thereafter springs 78 are compressed until the full radius of the cams comes in contact with discs 77. Later when handle 89 is lifted it raises lever 86 and unclamps the jaws of electrode 47, but there being no top to ring 90, handle

89 in being raised allows lever 87 to remain in its operated position and electrode 48 continues to grip the bar A firmly until lever 87 is itself lifted. The releasing of cam 82 allows springs 76 and 78, which had been compressed by the operation of said cam, to expand and the friction between the cam face and disc 77 is so little that once the cam has started its return movement the expansion of these springs will cause it to resume its normal position. The removal of the right-hand jaw of electrode 47 from contact with bar A affects in nowise however the contact of said bar with the face of the left-hand jaw of the electrode since the bar is still firmly grasped by electrode 48. Upon the removal of pressure from the jaws of electrode 47 springs 59 return base 53 to its normal position abutting set screws 58.

Referring now to the structure of circuit changer 8 and its operating mechanism, illustrated in detail in Figs. 4, 5, 9, 10, 11 and 12, there is provided a suitable base 91 whose surface is located at a convenient height between table 40 and the floor. Mounted in the right-hand front corner of base 91 is a standard 12. A similar standard 12 is mounted at the same distance from the right-hand edge of the base but farther back thereon, as clearly shown in Fig. 9. The upper surface of each standard 12 is shaped to provide a bearing surface for a shaft 11 which carries the wooden drum 10 of circuit changer 8. Shaft 11 is retained on its bearings by fastenings 92 suitably secured to standards 12 as by the bolts and nuts shown. Drum 10 is rigidly secured for rotation with shaft 11 by collars 93 and 94, located at each end. Left-hand collar 94 has a cam surface to provide a tooth 35 to cooperate with a pawl 20. Behind drum 10 (to the left in Fig. 11) and at the left end of said drum is mounted a magnet 22 having an armature lever 21 pivotally mounted on an upward extension 95 of left-hand standard 12, armature lever 21 carrying at its front end the pawl 20 which cooperates with tooth 35 and being normally held in retracted position by a tension spring 96'. Thus when drum 10 is operated it moves in an anti-clockwise direction from the position shown in dotted lines in Fig. 11 to that shown in full lines, and is held in such operated position by pawl 20. The rotation of drum 10 in this direction is limited by the abutment of a pin 96 fixed to collar 94 against a stop 97 set in base 91. Upon the energization of magnet 22 and the consequent attraction of its armature lever 21, pawl 20 is disengaged from tooth 35 to permit a spiral spring 19 to rotate drum 10 (in a clock-wise direction as seen in Fig. 11) until a pin 98 comes in contact with a spring cushioned stop 99 secured to base 91.

Drum 10 carries the copper contact strips 13, 14 and 15, previously described in connection with Fig. 1, while their cooperating

contact springs 16, 17 and 18 are secured at their bases to blocks 100 of suitable insulating material by binding posts 101. When contact strips 13, 14 and 15 are of copper, it may be described to provide carbon strips (not shown) similarly positioned on drum 10 and arranged to be engaged by contact springs connected in parallel with the regular service springs 16, 17 and 18, or to provide some other conventional arrangement to prevent arcing upon the breaking of the metal contacts. To cooperate with other drum operating mechanism to be described, a disc 102 is rigidly secured to the right-end of shaft 11 and secured to the outer surface thereof is a lever 103.

As described in connection with the circuits in Fig. 1, it is desirable that the clamping of bar A between electrodes 47 and 48 should be simultaneous with the operation of the circuit changer 8 from its normal position, in which brushes 18 are connected by contacts 15, to its operated position in which said brushes are disconnected and brushes 16 and 17 are connected. The downward movement of handle 89 in clamping bar A causes shaft 84 of cam 82 to rotate. The rotation of shaft 84 is employed through suitable linkage to operate circuit changer 8. As shown, a lever 104 is mounted at the front end of shaft 84 and is caused to rotate therewith by means such as a set screw 105. As seen in Figs. 2 and 3, the outer end of lever 104 terminates in two ears 106 between which there fits the upper perforated end of a link 107 which may be held in place by a pin 108 passing through ears 106 and link 107. To insulate the secondary circuit S, which is in electrical contact with lever 104 and thus with the upper end of link 107, an insulating block 109 is inserted between the upper and lower portions of link 107. A universal joint 110 connects the lower end of link 107 to the upper end of a rod 111 which is made rotatable relative to joint 110 by the pin and slot connection shown at 112, a spiral spring 113 being provided to maintain the normal relative position between rod 111 and joint 110. Rod 111 is slidably mounted for vertical movement in supports 114 secured to convenient parts of table 40 and base 91 and carries a roller 115 which normally rests upon the outer end of circuit changer operating lever 103, as seen in Fig. 4.

When handle 89 is depressed to clamp the bar A between the electrodes, lever 104 forces link 107 downwardly thereby pushing down rod 111 with its roller 115 which moves lever 103 down through the position shown in dotted lines in Fig. 4 until it reaches the position shown in dotted lines in Fig. 5. When pin 96 abuts against the positive stop 97, lever 103 will not yield further and, as rod 111 has not yet reached the lowermost extent of its travel, the reaction of lever 103 on roller 115 causes rotation of rod 111 against the action

of spring 113 until roller 115 rides over the end of lever 103 as shown in Fig. 10, whereupon spring 113 rotates the rod and roller back to its normal position with respect to joint 110, as shown in solid lines in Fig. 5. Roller 115 is now below lever 103, so that upon the operation of release magnet 22 the roller will not interfere with the return to normal of drum 10. Rod 111 is retained in its lowermost position by a catch 116 which engages a collar 117 rigidly secured to the rod as by the set screw shown. Catch 116 is mounted on the upper end of a lever 118 pivotally mounted at 119 and normally held in the position shown in Fig. 5 by a spring 120. Upon the operation of release magnet 22 (see Fig. 11) spiral spring 19 causes the return to normal of drum 10 (in an anti-clockwise direction as seen in Figs. 4 and 5). In returning to normal a stud 121, projecting from disc 102, strikes the lower end of lever 118 thereby moving catch 116 to release collar 117 and rod 111. The rod is started on its upward travel by a spring 122 which was compressed upon the downward movement of rod 111. Once rod 111 has started its upward movement the cam 82 has begun to turn against disc 77 whereupon springs 76 and 78 complete the return to normal position of cam 82 and the operating mechanism for circuit changer 8, including rod 111. Just before rod 111 reaches its normal position, pin 98 comes in contact with cushion stop 99 and compresses said stop sufficiently to allow roller 115 to ride from below lever 103 around the outer end thereof to its normal position in contact with the upper face of said lever.

In connection with the structure of the circuit changer 8 and its relation to the electric heater described, it is to be noted that when the bar A is first inserted in position to be heated, circuit changer 8 is in normal position and the currents flowing through winding P¹ with its relatively large number of turns induces a relatively low potential in the secondary circuit S, so that there is no appreciable tendency to arcing as bar A is placed in contact with the left-hand stationary jaws of electrodes 47 and 48. In depressing handle 89 the drum 10 of the circuit changer has rotated far enough to move contacts 15 out of engagement with springs 18, thereby breaking the circuit for winding P¹, but not far enough to move contact 14 into engagement with spring 17 at the time when cams 80 and 82 bring the right-hand movable jaws of electrodes 47 and 48 into contact with bar A. Thus there is no current flowing in either primary winding of the transformer at the time bar A is clamped between the jaws of the electrodes and hence no tendency for arcs to occur at this time. It is only after handle 89 has been fully depressed and the bar is tightly clamped that contact 14 on the circuit changer drum 10 completes the

circuit for primary winding P^2 which thereby induces a heavy flow of current through the secondary circuit including the bar to be heated. Conversely, when the current flowing through winding P^2 has decreased sufficiently to allow solenoid 9 to complete the circuit for release magnet 22, contact 14 on drum 10 will have moved out of engagement with spring 17 before cam 82 has been turned sufficiently to break the contact between the right-hand movable jaw of electrode 47 and the bar A and, as there is no current flowing in either primary winding at the moment when the right-hand jaw of electrode 47 is removed from bar A, there is no tendency to arc at this time. When it is desired to take bar A out of the heater only the weak current induced by winding P^1 will be flowing through the secondary and lever 87 may be lifted to open the jaws of electrode 48 without causing any appreciable arcing. If, however, it is desired to avoid any arcing whatsoever at bar A, switch 5 may be opened before lever 87 is raised to release the bar.

In connection with the provision of a plurality of contacts 15 and cooperating springs 18 on the circuit changer drum, it is to be noted that these contacts and their cooperating springs constitute a break-up switch for primary transformer winding P^1 so that upon the operation of the circuit changer to close the circuit for winding P^2 , winding P^1 is broken-up into as many electrically separate parts as there are provided contacts 15. The purpose of thus breaking up winding P^1 is to avoid the existence of the high potential difference which would exist between the terminals of winding P^1 , acting as a step up secondary winding owing to its large number of turns, while current was flowing through winding P^2 . Thus by providing the required number of contacts 15 and pairs of springs 18 winding P^1 may be separated into elements each comprising so few turns that the difference of potential between terminals of each element will not be dangerously high while current is flowing through transformer winding P^2 .

Referring now to the structure of the transformer as seen in Figs. 2, 3, 6, 7 and 8 no particular structure is required, but a suitable transformer may be conveniently made up by assembling a laminated iron core 123 between four U-shaped cast iron heads 124, there being provided an upper and a lower head at each end of the core. Six tie-bolts 125 pass through lugs 126 to hold the core in assembly, while an upper and a lower channel iron 127 hold the core against vertical movement. To reduce magnetic leakage, the primary and secondary windings preferably pass around the same leg of the core, secondary bars 41 and 43 being supported by sleeves 44, as has been described, while primary winding P^2 is made up of two pancakes

128 held adjacent to the secondary bars by pins 129 and wedging blocks 130. The two upper elements of winding P^1 may be conveniently wound together in a pancake 131 while the two lower elements are wound in a pancake 132, which pancakes are likewise held in position adjacent to those comprising winding P^2 by pins 129 and blocks 130. It is to be understood, however, that the invention is not to be restricted to this particular transformer since many different structures might be used. For example, bars 41 and 43 might extend further to the left than as seen in Figs. 6 and 7, and connecting bar 42 might be removed and electrode mechanism similar to that shown at the right-hand of Fig. 2 might be supported on such extensions of bars 41 and 43. With this arrangement two bars A could be included in the secondary circuit simultaneously and the rapidity of production of heated bars by the electric heater thereby doubled. Moreover, more than the one set of secondary bars shown might be magnetically linked with the primary windings by encircling either leg of the transformer core or more than two articles to be heated might be connected in series with a single set of secondary bars if it were desired to heat simultaneously more than two bars A. In fact the number of identical articles which may be heated simultaneously is only limited by mechanical considerations in designing the transformer.

As has been pointed out there are many classes of work to be heated with which it would not be satisfactory to employ end-touch electrodes, that is electrodes which hold the article by contact with its opposite ends. For example such electrodes could not be used where it was desired to heat only certain portions of an article, or where the article had irregular ends which would not make good electrical contact with the electrode, or where the pressure necessary to give good electrical contact would be sufficient to bend the article when hot. In these and other instances it is desirable to provide side-touch electrodes which contact with the article to be heated in the manner illustrated by electrodes 47 and 48 and bar A in Figs. 2 and 3. In order that the electrodes may support the work as well as conduct electricity to it, each electrode preferably comprises a clamp having at least two relatively movable jaws, as seen at 47, Figs. 3 and 12. To insure good electrical contact between the jaws of the electrode and the article to be heated, the surface of each jaw is most desirably shaped to fit closely against said article. In the present case the work to be heated has been illustrated as a cylindrical bar A so that the contacting faces of the electrodes are of cylindrical configuration. If the work were hexagonal or some other shape, the electrode contact surface should be hexagonal or of what-

ever shape necessary to fit the portion of the work to be held between jaws of the electrodes.

In considering the design of side-touch electrodes it is to be noted that if the electrode 47 consisted solely of a single metal block 134 without the various other elements indicated in Fig. 15, the electrical resistance of the path between the surface 133 of the electrode, which contacts with the face of water-jacket 67, through the electrode and bar A to electrode 48 which contacts with a lower portion of the bar A, would not be uniform. The path of least electrical resistance would extend from water-jacket surface 133 along the lower edge of block 134 and thence through the shortest extent of bar A included between electrodes 47 and 48, while the path of greatest resistance would extend from surface 133 along the upper edge of block 134 and through the portion of the bar A which is in contact with the surface of blocks 134. The increased resistance of this second path due to the inclusion of the portion of bar A which is between blocks 134 would be so great that in the assumed case, in which block 134 constituted the entire electrode, practically all the current would flow along the lower edge of the block 134 passing into bar A at the left-hand lower corner of the right-hand block as seen in Fig. 16, and only a negligible amount of current would pass through the remaining contact surface between the work and the electrode. The great current density at the lower edge of block 134 would tend to produce an unduly high temperature along the lower edge of the block and could easily bring about a welding condition at the meeting point with the work, while the very small flow of current through the end of the bar would be insufficient to raise its temperature appreciably. When, therefore, it is desired to heat work not only between the adjacent edges of electrodes of opposite polarity but also throughout the portions which contact with the electrode faces, special means must be provided to cause the current to flow through the portions of the work in contact with the electrode and special attention must be given to the thermal conductance and physical dimensions of the electrode, so that heat will not be dissipated through the water-jackets as fast as it is produced in the end of the bar being heated.

In order to heat the tip of an article such as bar A to a temperature uniform with that of the remainder of the bar which is not in contact with the electrode, it is obvious that either substantially all the current entering the bar must pass along that edge of the electrode which is adjacent the tip of the bar and further removed from the electrode of opposite polarity, or heat must be supplied by conduction from the electrode itself to the

tip of the bar, or both of these conditions must be brought about. If it were possible to make a side-touch electrode of negligible thickness to contact with the extremity of the bar being heated all the current would no doubt flow through the entire bar and uniform heating of the bar would result, but with any conducting material now known the current density in the electrode would be so great as to heat the electrode to a point where it would decompose by oxidation or else soften and mushroom out of shape or melt away so that replacement of the electrode would be necessary each time an article was heated if not more often. Since this would not be practical a compromise is struck by providing an electrode with sufficient surface in contact with the work to carry the heating current without destruction of the electrode, while the current density through the tip side of the electrode is made as high as possible and the current density through the side of the electrode adjacent the electrode of opposite polarity (the lower edge of block 134 in Fig. 16) is kept as low as possible. A large number of different structures for accomplishing this result have been found, all working however on the principle that the electrical resistance of the portion of the electrode near the tip of the bar is to be less than the resistance of the portion removed from the tip.

One electrode constructed on this principle is shown in Fig. 21, and consists of a base 170 of highly conductive material such as copper, having an extension which forms the top strip of the electrode, the base being slotted to receive strips 171, 172, 173, and 174 of identical dimensions, but each composed of metal or alloy of lower conductivity than the preceding one. For example strip 171 may be nickel, 172 nickel and manganese, 173 Monel metal, and 174 manganin. It is sometimes desirable to further vary the resistance of the different strips by varying their dimensions as shown in Fig. 22. The electrode there shown comprises a short thick strip 175, and progressively longer and thinner strips 176, 177, 178, and 179. When the electrode is used in heating certain articles these strips may be of the same material, while with other articles the resistivity of the various strips is also varied. The electrode as just described is composed of a plurality of structurally separate conducting elements assembled to form a built-up electrode and to ensure intimate contact of the mutual contacting surfaces of the said elements, the latter are coated with a suitable conducting material, preferably mercury amalgam.

Another electrode may be made up as seen in Figs. 19 and 20, a triangular plate 135 forming the edge of the electrode adjacent the tip of the bar, while the resistance of each succeeding sheet 136, 137, 138 and 139 is made

progressively greater by cutting out a small central portion from sheet 136; and an increasingly larger portion from each of the remaining sheets 137, 138 and 139, to progressively decrease the cross sectional area of the conducting path from base surface 133 to bar A. The increased resistance may also be brought about by using metals and alloys of different resistivity for the different sheets, with solid or cut-out centers as required. As shown in Fig. 20 an electrode of this type may be given greater strength without substantially varying its electrical characteristics by filling the interstices with a suitable refractory cement such as corundum or carborundum which also helps to cool the electrode, being a better heat conductor than air.

A still more durable electrode to accomplish the same purpose may be made up as shown in Figs. 15, 16, 17 and 18 from a number of elements comprising sheets or blocks of different metals held in physical contact with one another by suitable means such as pins 140 which are driven through holes drilled transversely through the assembled elements near the base of the electrode. The electrode shown in Figs. 15 and 16 is composed of a block 134 of difficultly oxidizable metal of relatively high electrical resistivity and low thermal conductivity, and strips 141, 142, 143, 144, 145 and 146 composed of metal of negligible electrical resistivity as compared with that of the block 134. For example, in an electrode to be used in heating a bar A of medium carbon steel, the block 134 may advantageously be composed of a silicon chromium resistance alloy of iron having a resistivity of about 115 microhms per cm^2 while the other elements of the electrode may be made of copper which has a resistivity of only about 1.7 microhms per cm^2 . As has been pointed out, if the electrode consisted merely of the iron alloy block 134 and copper base made up of strips 143, 144 and 145, a relatively dense current would flow along the lower edge of the block while only a weak current would flow through the upper edge, so that the Joulean or I^2R heat developed in the tip of the bar A, which is in contact with blocks 134, would be much smaller than that developed farther down the bar where the total current is flowing. In order, therefore, to cut down the resistance along the upper edge of block 134 between base surface 133 of the electrode and the bar to be heated, and thereby to cause a more dense current to flow through the upper portion of the block, a strip 142 of low resistance metal is placed in contact with the upper surface of the block, and extends from the plane of the surface 133 to a point just out of contact with the bar. In practice, the distance between the bar and the left hand edge of strip 143 would ordinarily not be less than

$\frac{1}{32}$ of an inch; while its exact distance is a matter of design in each case and is determined in accordance with the electrical resistance required at that point. In some cases it is easier to control the electrical characteristics of the electrode by adding the further strip 141 of low resistance metal, but it is not essential since a single strip 142 may be designed to bring about the desired dense flow of current through the upper portion of block 134. The block 134 being of low thermal-conductivity would not under operating conditions in which a series of bars were rapidly heated one after the other, have sufficient time to cool off between the removal of a hot bar and the insertion of a cold one, so that for cooling purposes it is desirable to provide a strip 146 of high thermal-conductivity in contact with the lower surface of block 134. Strip 146 also affects the flow of current through the block 134, and its left hand edge is considerably farther removed from the bar A than is that of strip 142, so that a less dense current will pass through the lower portion of the contact surface of block 134 than passes through the upper portion of said contact surface. To further aid in the conduction of heat from block 134, strip 144 of high thermal-conductivity preferably forms a fin fitting snugly into a central groove cut along the base of block 134, while for manufacturing reasons strips 143 and 145 of high thermal-conductivity are fitted between strips 142, 144 and 146 to give a smooth bearing surface 133 which will make good electrical contact with the face of the copper water-jacket 67. For ease in changing the electrodes all the strips are preferably dovetailed to fit against shoulders of the previously described groove in the face of the water-jacket, so that it is merely necessary to slide out one electrode and slide in another when a change is to be made. When an electrode is to be used in heating an article to a high temperature, it is desirable to insert a thin carbon strip 147 between strip 142 and the upper surface of block 134 where the current density is the greatest, and contacting with the article being heated, so that a reducing atmosphere will be produced by the carbon to counteract any tendency to oxidization at the contact surface between block 134 and the work A, as shown in Fig. 17. Additional carbon strips may be inserted between other sheets of the electrode, or transversely of the electrode elements and parallel to the bar A, thereby extending the reducing area.

To further aid in cooling the block 134, it is desirable under certain working conditions to enclose the strip 146 and the exposed lower surface of block 134 with a cement of refractory material, such as corundum or carborundum as seen at 148, having embedded therein a copper fin 149 and supported at its lower

edge by a retaining strip 150. The refractory cement is of such low electrical conductivity as not to materially influence the electrical characteristics of the electrode, and insulates therefrom the copper fin 149 and retaining strip 150 but the thermal conductivity of such cement is much higher than that of air so that the resultant cooling is considerably greater than with the structure shown in Figs. 16 and 17.

The particular conducting materials to be employed in constructing electrodes, and the dimensions of each element of the electrode are governed in all cases by the electrical and thermal characteristics of the work to be heated, and will differ also in accordance with the temperature difference which is to be maintained between the work and the water-jacket, and further will vary according to the temperature gradient which is to be produced in the work itself when the electrode is not designed to heat the tip of the work uniformly with the portion between electrodes of opposite polarity. For example, in producing a uniform temperature in a given time throughout a bar A, it is obvious that no matter what the relative dimensions or resistivities of block 134 and strips 141, 142 and 146 may be, the portion of the bar below the lower surface of block 134 carries all the current flowing in the work circuit, while the upper part of the portion of the bar gripped between the electrode blocks does not carry the whole current, since there is some current passing from block 134 into the bar at all points on the surface of the block. Hence, it follows that the I^2R heat developed in the tip of the bar will be less per unit volume than that developed between the electrodes 47 and 48. In order to raise the temperature of the tip uniformly with that of the remainder of the bar heat must therefore be supplied to the tip by conduction from the electrodes. If the I^2R heat developed within the electrode were proportionately greater than the heat conducted by the electrode from the bar to the water-jacket, a condition of thermal equilibrium would exist at the contact surface of block 134 and the temperature of the bar would not be influenced by its contact with the electrode. Since it is necessary in the instant case to supply heat to the tip by conduction, it follows that the I^2R heat developed in the electrode must be determinately but proportionately greater than the heat which would pass from the bar to the water-jacket by conduction through the electrode, the exact amount being governed by the particular conditions under which the electrode is to be used. The best results have been obtained by making the contact block 134 of a resistance alloy having a resistivity considerably greater than that of the work to be heated,

but having a far lower temperature coefficient of resistivity. All the other metal in the electrode should be of very low electrical and thermal resistivity. By employing an electrode made up of such metals it is possible to design the electrode so that when a cold bar is put in the heater and current begins to flow through the work circuit heat will be supplied by conduction from the electrode to the tip of the bar at a rate sufficient to equalize the lesser I^2R heat developed in the tip of the bar; while as the work and electrode are heated up by the continued flow of current, the resistance of the work increases faster than that of the electrode, until at the point when the desired predetermined temperature of the work has been reached thermal equilibrium will exist at the contact surface between block 134 and the work, at which time the I^2R loss in the electrode is considerably greater than the conductance loss between the bar and water-jacket.

It is to be noted that with the mechanical arrangements of the electric heater previously described, when the desired temperature has been reached by the work the electrical potential applied to the work circuit is decreased so as to weaken the current flowing through said circuit to a point where no further increase in temperature occurs in the work, but the current supplied just equalizes the heat losses by conduction, convection and radiation from the work. Such weaker current would not develop enough heat in the electrodes to maintain the thermal equilibrium existing at the contact surface between blocks 134 and the work, so that there would be a tendency to lower the temperature of the tip of the work. In order to prevent such a result the contact area between the electrode and the work is decreased by opening the jaws of the electrode whereby the tip remains in contact with the left-hand jaw of electrode 47, as seen in Figs. 2 and 3, and is out of contact with the right-hand jaw. By properly choosing the relative dimensions of the two jaws of the electrode, or by using more than two jaws and removing the proper number when the lowered potential is applied to the work circuit, it follows that thermal equilibrium may be maintained at the contact surface between blocks 134 which remain in contact with the work after the current flowing through the work circuit has been decreased.

Electrodes of the type previously described and shown in Figs. 15-22 may also be made to produce any desired temperature gradient within the portion of work engaged by the electrode jaws, a result which is often desirable in heat treating portions of certain articles where no sharp line of demarcation is desired between the treated and untreated

portions. Where a temperature gradient is to be produced over a considerable distance, an electrode of the type shown in Figs. 19, 20 or 21 may be used, the sheets being spaced much farther apart than as shown in Fig. 20, so as to include the entire portion of the work throughout which the gradient is to exist.

In heating electro-conductive articles of varying cross-section such as the bars 151 and 159 seen in Figs. 23, 24 and 25, a uniform temperature would obviously not be produced in the article if it were merely inserted in the heater between electrodes 47 and 48 in the manner indicated by bar A in Fig. 2. Since if the only points of contact with the source of current were said electrodes, the current passing through any section of the bar between electrodes 47 and 48 would be uniform and therefore the current density would be greater in the portion of the article having a smaller cross-sectional area than in the portion having a larger area, the smaller portion would therefore heat faster and in a given time reach a higher temperature than the larger portion. Special means must therefore be provided to produce uniform heating of an article having varying cross-section.

The particular means employed in producing uniform heat throughout articles of varying cross-section will differ in accordance with the particular conditions to be met in any given article, but the underlying principle is the same regardless of the configuration of the article in question, namely that current of approximately uniform density should flow through all parts of the article. In order to heat a bar having a reduced central portion such as bar 151, shown in Figs. 23 and 24, it is merely necessary to provide suitable means for carrying the excess current around the reduced portion. In the present case there are provided moderately flexible leaf springs 152 having end pieces 153 of difficultly oxidizable conducting material which abut against the shoulders 154 formed by the decrease in diameter of the reduced central portion 155. By properly proportioning the resistance of the shunt springs 152, it is obvious that the current density in the reduced portion 155 may be maintained substantially equal to that in the enlarged portions 156. Any convenient means may be employed to hold the shunt springs in position during the heating operation such for example as the clamp 157 having jaws faced with blocks 158 of non-conducting refractory material, as seen in Fig. 24. The clamp is most desirably located midway of the springs and tightened just sufficiently to insure good electrical contact between spring tips 153 and shoulders 154.

In the case of an article such as the bar 159 having a central portion 160 of larger diam-

eter than the end portions as indicated in Fig. 25, the current density is most economically kept uniform by providing auxiliary elements of the electrodes 47 and 48 of opposite polarity to contact with the opposite edges 161 and 162 of the enlarged central portion 160. The auxiliary electrode elements may comprise relatively movable jaws 163 and 164, the jaws 163 being conductively united with electrode 47 by spring brackets 165 secured to water-jacket bases 67, while jaws 164 are similarly connected to electrode 48 by brackets 166. From the foregoing description it is obvious that by constructing auxiliary jaws 163 and 164 and brackets 165 and 166 of materials of suitable resistivity, and by properly dimensioning such auxiliary conducting path, it will be possible to establish a number of parallel circuits between electrode 47 and electrode 48 and thereby to maintain approximately equal current density throughout the article 159 being heated. For example, as shown in Fig. 25, one path of heating current would extend from electrode 47 through bar 159 to electrode 48, while a parallel path would exist from electrode 47, base 67, bracket 165, jaw 163, shoulder 162 of the enlarged portion 160, shoulder 161, jaw 164, bracket 166, base 67 and electrode 48. Under certain operating conditions the auxiliary electrode jaws 163 and 164 would most desirably be cooled by some circulating fluid in which case it is obvious that suitable means, such as water-jackets, might easily be provided for this purpose.

While one electric heater embodying a number of types of electrodes and one method of operating such heater have been described with considerable detail, it is to be understood that the invention contemplates the provision of heaters of quite different structure and of different operating mechanism. For example, all the functions performed by the circuit changer and its operating mechanism might be performed by manually actuated switches, or the same or a different circuit changer might be operated by entirely different mechanism. In particular it is to be noted that solenoid 9 with its dash-pot 39 which is directly responsive to current flow in the primary circuit of the transformer may properly be considered as means for operating the circuit changer when a predetermined time has elapsed after the work circuit S has been closed by the inclusion of an article A to be heated, and potential has been applied to such circuit by the completion of the circuit through winding P² of the transformer. This follows from a consideration of the fact that a series of identical bars A will all reach a predetermined temperature and therefore cause a predetermined increase in the resistance of the work circuit and consequent decrease in

current flow in the primary circuit and through the solenoid in the same time interval. Such being the case, it will be apparent that for the particular means previously described (solenoid and dash-pot) to control the operation of the circuit changer there might be substituted time control means such as clock work or escapement devices to control the time during which the circuit through primary winding P^2 is maintained closed.

What I claim is:

1. An electrode for electric heaters comprising a block of conducting material of higher resistivity than that of an article to be heated and having a face shaped to contact with such article, and a strip of material of lower resistivity than that of the block, said strip overlying and contacting with one side of said block but cut away from the face whereby it is out of contact with the article to be heated.

2. In an electric heater, an electrode comprising a clamp having a plurality of jaws adapted to grip the sides of an electro-conductive article to be heated, one of the jaws being connectible to a source of electric current and comprising conducting material arranged when so connected to cause a current of high density to flow through one edge of the jaw into the article to be heated and current of density diminishing in proportion to the distance from said edge to flow through the remainder of the surface gripping the article to be heated.

3. In an electric heater, an electrode comprising the combination with a metal block of relatively high resistivity and a strip of reducing material such as carbon arranged to contact with an article to be heated, of a strip of metal of relatively low resistivity in contact with the reducing strip and out of contact with the article.

4. In an electric heater, in combination, an electrode comprising two relatively movable jaws adapted to receive an article to be heated, one of the jaws having a surface shaped to fit the article to be heated, and a universal joint to carry said jaw whereby clamping of the jaws will bring the shaped surface into intimate contact with the article to be heated.

5. In an electric heater, in combination, an electrode comprising two relatively movable jaws having face portions adapted to receive an article to be heated, a mounting comprising a universal joint for one of said jaws whereby movement thereof towards the other jaw will bring its face portion into intimate contact with the article to be heated, and means operable upon movement of said jaw out of such contact for returning said jaw to its normal position relative to its mounting.

6. In an electric heater, an electrode comprising two jaws adapted to grip an article

to be heated, a base for each jaw, a mounting for each base, a joint to permit limited universal movement between each base and its mounting, a longitudinally movable member to carry one of said joints, and means limiting the movement of the joint carrying member whereby the locus of the center of movement of the carried joint will be a straight line intersecting the center of movement of said other joint.

7. In an electric heater, an electrode comprising a block of conducting material of one resistivity to contact with an article to be heated, and a block of material of lower resistivity in contact with the first block and separated from the article.

8. In an electric heater, a composite electrode comprising a plurality of elements composed of material of different electrical and thermal conductivity, and an additional element providing a protecting face for the electrode adapted to contact with an article to be heated and said protecting face consisting of a thin strip of difficultly oxidizable electro-conductive material.

9. In an electric heater, an electrode comprising a plurality of electro-conductive jaws to grip an article to be heated, means for passing electric current through the jaws into the article to heat the same and means operable upon a predetermined change in the flow of current to change the number of jaws in contact with the article.

10. In an electric heater, an open work circuit having terminals, an electrode comprising a plurality of relatively movable jaws secured to terminals of one polarity and adapted to grip an article to be heated, means for impressing an electromotive force upon the work circuit, means responsive to a predetermined increase in temperature for discontinuing the application of electromotive force, and means responsive to the operation of said discontinuing means for removing certain of said jaws from contact with the article being heated.

11. In an electric heater, an electrode adapted to contact with the side of an article to be heated near the tip of the article and with a work circuit terminal, said electrode comprising a path of varying electrical resistance to conduct relatively dense current through the portion of the electrode adjacent the tip of the article and through the remainder of the electrode current of density diminishing as the distance from such portion increases, whereby the tip of the article may be heated to any desired degree relative to the remainder of the article.

12. In electric heating, the combination with a conductor whose resistance is a function of its temperature, the conductor being included in an electric circuit associated with means for maintaining a potential in the circuit to cause current to flow through the con-

ductor thereby heating it and changing the resistance; of devices responsive to the change of current brought about by a predetermined rise in temperature for changing the potential in the said circuit.

13. In an electric heating apparatus, a work circuit including an article to be heated, means for applying an electric potential to the circuit whereby a current flows therethrough to heat the article and change the resistance of the work circuit, and means responsive to a predetermined change of said resistance for changing the potential applied to the circuit.

14. In an electric heating apparatus, a work circuit including an article to be heated, means for applying an electric potential to the circuit whereby a current flows therethrough to heat the article and change the resistance of the work circuit, and means responsive to a predetermined change of said resistance for discontinuing the application of said potential.

15. In an electric heater, a work circuit including an article to be heated, means for applying an electric potential to the circuit whereby a current flows therethrough to heat the article and change the resistance of the work circuit, and means responsive to a predetermined change of said resistance for discontinuing the application of said potential and applying a different potential to the circuit.

16. In an electric heater, a work circuit adapted to include an electro-conductive article to be heated, means for applying an electromotive force to the work circuit to generate a current to heat the article, means operable upon the elapse of a predetermined time interval from the application of such electromotive force to discontinue the application of such electromotive force and apply an electromotive force of different value.

17. In an electric heater, in combination, a work circuit arranged to include an article to be heated, means for applying an electric potential to the circuit whereby a current flows therethrough to heat the article and thereby change the resistance of the work circuit, a circuit changer operable to change the potential applied to the work circuit, means for operating the circuit-changer, and means responsive to a predetermined change in the flow of current in the work circuit for actuating said operating means.

18. In an electric heater, in combination, a work circuit arranged to include an article to be heated, means for applying an electric potential to the circuit whereby a current flows therethrough to heat the article and thereby change the resistance of the work circuit, a circuit changer operable to change the potential applied to the work circuit, means for operating the circuit-changer, means responsive to a predetermined change in the

flow of current in the work circuit for actuating said operating means, and means for delaying for a predetermined time interval the actuating of said operating means.

19. In an electric heater, an alternating current transformer having two primary windings independently connectible to a source of alternating current and having a secondary winding comprising an open work circuit adapted to be closed by an article to be heated, a circuit-changer operable to connect either of the primary windings to the source of current, a magnet to operate the circuit changer, a solenoid switch responsive to current flow in one primary circuit to operate the magnet, and a dash-pot to retard the operation of the solenoid to introduce a time interval between the occurrence of the solenoid operating current condition in the primary circuit and the operation of the circuit changer.

20. In an electric heater, an alternating current transformer comprising a core, one primary winding comprising a relatively large number of turns about the core, another primary winding comprising a relatively small number of turns about the core, said primary windings being independently connectible to a source of power, a secondary winding, and means for breaking up one of said primary windings into a plurality of electrically separate elements.

21. In an electric heater, the combination with a transformer comprising two electrically separate primary windings and a secondary winding inductively coupled with the primary windings by a core, of a circuit changer operable when in one position to connect one primary winding to a source of power and to disconnect the other primary winding from said source, said circuit changer being operable when in another position to connect said other primary winding to the source of power and to break up the first primary winding into a plurality of electrically separate elements having terminals, whereby the difference of potential between the terminals of each element is made less than the difference of potential between those of the winding as a whole would be were it not broken up.

22. In an electric heater, an electrode having a surface adapted to contact with an article to be heated and said surface being provided by a plurality of elements constructed and arranged by selection to control the distribution of current admitted to said article.

23. In an electric heater, an electrode adapted to inter-connect an article to be heated with a source of electric current and the electrode comprising a plurality of graded elements providing paths of different electrical resistance between the source of current and the article.

24. In an electric heater, a work circuit, an

electrode adapted to conduct electric current between one terminal of the work circuit and an electro-conductive article to be heated, said electrode comprising a plurality of graded elements providing a graduated electrical resistance, and means for cooling said electrode so as to establish and maintain a thermal equilibrium between said article and said electrode.

25. In an electric heater, a work circuit, an electrode adapted to conduct electric current between one terminal of the work circuit and an electro-conductive article to be heated, said electrode comprising a plurality of graded elements providing a graduated electrical resistance, said electrodes being constructed and arranged to provide gripping jaws for the article to be heated and one of said jaws being retractible under pressure resulting from expansion of said article.

26. In an electric heater, an electrode carrying electric current to an article to be heated; said electrode comprising a base electrically connected to a source of electric current supply, a surface contacting with the article to be heated and a plurality of graded elements providing graduated resistance for electrically connecting said base with said contact surface.

27. In an electric heater, a work circuit having open terminals consisting of a pair of electrodes arranged to be bridged by an article to be heated, a source of electric energy connectible to the work circuit, and one of said electrodes comprising a plurality of graded contact elements providing a plurality of paths of different resistance to conduct electricity from one of the terminals to the article to be heated.

28. In an electric heater, an electrode connected in a work circuit and contacting with an article to be heated, and said electrode comprising a plurality of graded contact elements of different resistance to vary the current density at different points of contact between the electrode and the article and thereby control the rate, gradient or degree of temperature increase of that portion of the article immediately adjacent the electrode.

29. In a system as described means for heat treating a work-piece whereby said work-piece is first subjected to the action of electric current of one potential during a predetermined time established by the resistance of the work piece and associated means operated by said current for disconnecting said current and substituting another current of a different potential.

30. The method of heating a selective part of an electro-conductive article to a required temperature and maintaining that temperature constantly which consists in holding the article at one limit of the part to be heated between the jaws of an electrode having multiple contacting elements and placing an-

other electrode in contact with the other limit of the part of the article to be heated, then connecting the two electrodes to opposite poles of a source of electric current supply whereby current flowing through the article will heat the same to the desired temperature, subsequently by automatic means lowering the potential of the current applied to a degree sufficient to maintain the temperature of the article constantly at a predetermined degree, and finally moving one or more of said multiple contacting elements out of contact with the article so as to lessen the heat loss by conduction therethrough.

31. The method of heat treating a work piece employing a work circuit, means for conducting an electromotive force derived from the work circuit to establish a current to heat the work-piece and means operating automatically upon the elapse of a predetermined time interval from the application of such electromotive force to discontinue such electromotive force and disconnect the said first mentioned means so as to reduce the heat loss from the work-piece by heat conduction therethrough.

32. The method of heat treating a work-piece employing a work-circuit, means for conducting an electromotive force derived from the work circuit to establish a current to heat the work-piece, and means operating automatically upon the elapse of a predetermined time interval from the application of the electromotive force to discontinue said work circuit and sequently disconnecting the first mentioned means to effect release of the work-piece.

33. In a system of heat treating metal electrically, a source of electric current supply of different potentials, means comprising a circuit changer for automatically effecting the change of the current at a predetermined time, and said source of electric current supply including an alternating current transformer having two primary windings of relatively different ratios independently connectible to the main source of electric current supply, a secondary winding constituting a heating circuit and said windings being inductively coupled by the core of the transformer.

34. In a system of heat treating metal electrically, a source of electro current supply of different potentials, means comprising a circuit changer for automatically effecting the change of the current at a predetermined time and independently operating means for determinately retarding the operation of said circuit changer.

35. In a system as described for heat treating a work-piece of electro-conductive material, a source of electric current supply, means comprising a circuit changer for automatically controlling said current at a predetermined time established by the resistance of

the work-piece and independently operating means initially controlled by the resistance of the work piece for determinately retarding the operation of said circuit changer.

- 5 36. In a system as described, a source of electric current supply, means comprising a circuit changer for automatically controlling said current at a time determinable according to the resistivity of the work-piece.
- 10 37. In a system as described, a source of electric current supply, means comprising a circuit changer for automatically controlling said current, and means for effecting operation of said circuit changer at a time determinable according to the resistivity of the work-piece.
- 15 38. In a system of heat treating metal electrically, means for treating a work-piece having an irregular or varying cross section in the path of the current and said means comprising a plurality of electrodes of different resistance electrically connected to-

gether and said work-piece at different points.

- 25 39. In a system of heat treating metal electrically, means for treating a work-piece having an irregular or varying cross section and said means comprising a plurality of electrodes electrically connected together by a conductor or conductors of determined resistance.

- 30 40. In an electric heater, a primary circuit an electrode constituting a gripping jaw for holding the article to be heated; means for creating a secondary circuit from said primary circuit to pass electric current through said jaw for heating said article; electrical means operating at a predetermined time to change the flow of current in said secondary circuit and mechanical means interlocking with said electrical means operating in determined sequence to break said primary circuit and open said jaw.

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