

Aug. 25, 1964

D. P. WHITACRE

3,146,336

METHOD AND APPARATUS FOR HEAT TREATING METAL

Filed Nov. 15, 1962

2 Sheets-Sheet 1

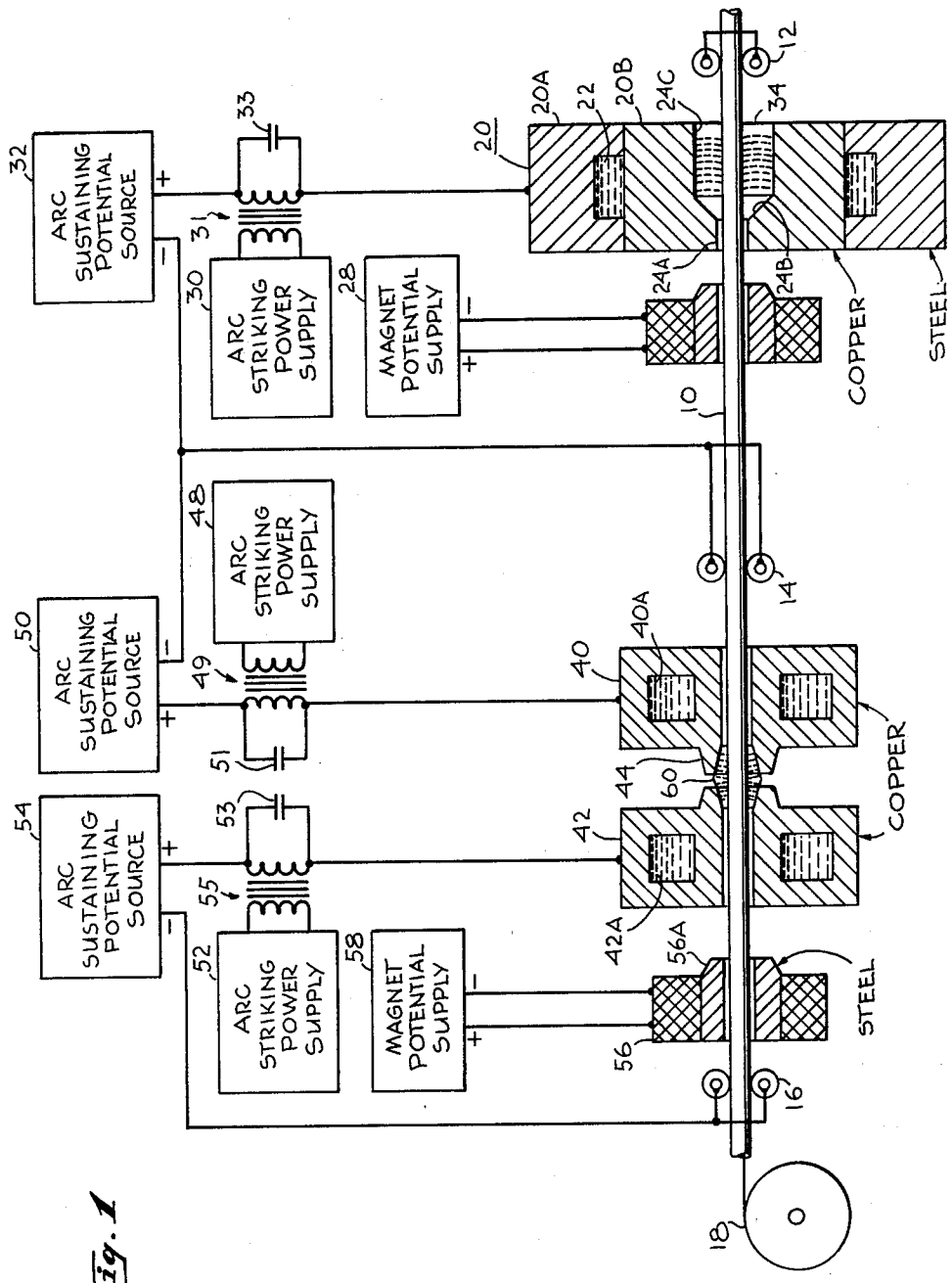


Fig. 1

INVENTOR
DONALD P. WHITACRE
BY *Lyons Lyons*
ATTORNEY

Aug. 25, 1964

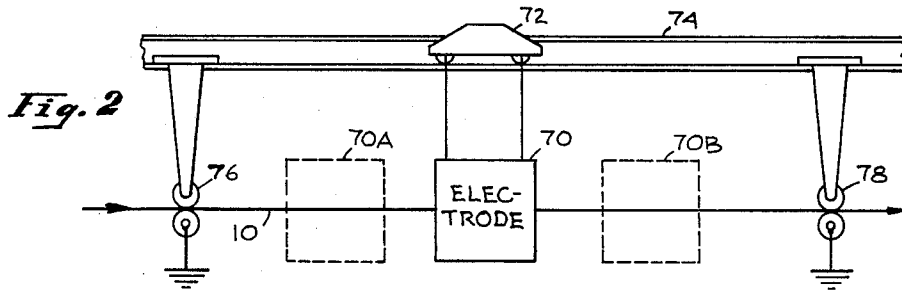
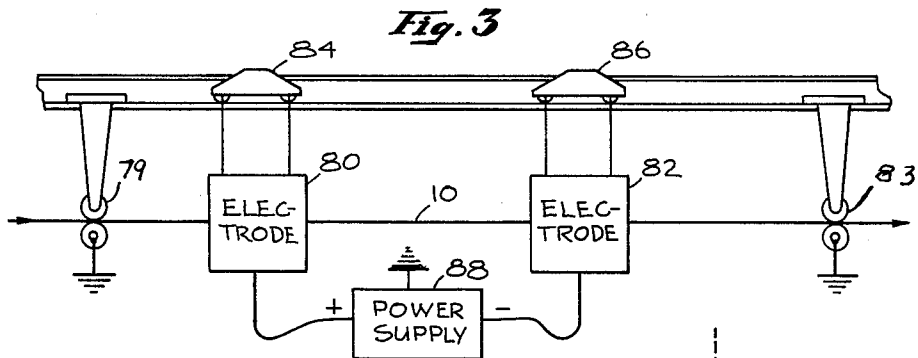
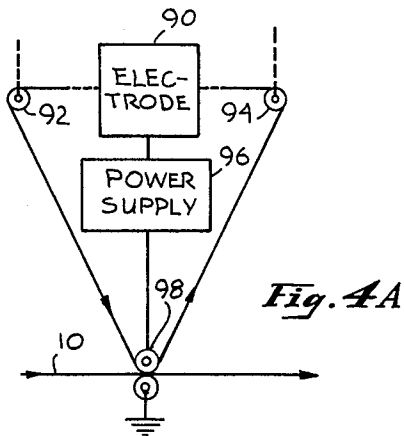
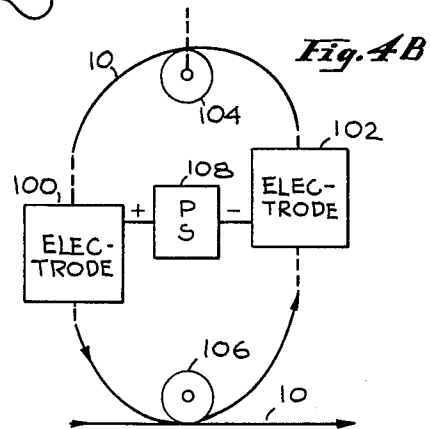
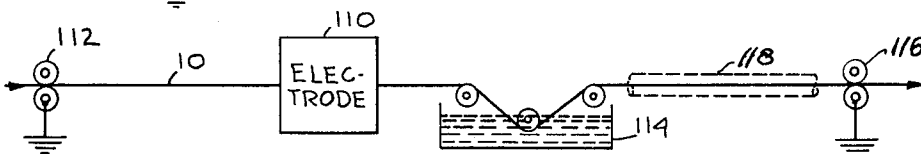
D. P. WHITACRE

3,146,336

METHOD AND APPARATUS FOR HEAT TREATING METAL

Filed Nov. 15, 1962

2 Sheets-Sheet 2



INVENTOR
DONALD P. WHITACRE
BY *Hyoun Hyoun*
ATTORNEY

1

3,146,336

METHOD AND APPARATUS FOR HEAT TREATING METAL

Donald P. Whitacre, Alhambra, Calif. (5649 Alhambra Ave., Los Angeles 32, Calif.), assignor, by mesne assignments, to Donald P. Whitacre and Joseph E. Harling

Filed Nov. 15, 1962, Ser. No. 237,909
23 Claims. (Cl. 219—121)

This invention relates to a method and apparatus for cleaning the surface of metal and, more particularly to improvements therein.

This application is a continuation in part of an application for a Method and Apparatus for Cleaning Metal, Serial No. 97,498, filed March 22, 1961, and assigned to a common assignee, now abandoned.

After metal such as steel wire or rod stock has been rolled or otherwise treated at a mill, there remains the problem of removing the scale which is on its surface. Considerable effort has been expended in trying to find the best way for most expeditiously and economically removing this scale. A favored arrangement at present appears to be to employ tanks full of acid through which the stock is drawn. It will be appreciated that concomitant with the acid tanks there must be established expensive ventilation equipment and other protective devices for human beings, as well as facilities for removing the acid from the surface of the stock. Thus, although such an arrangement is being used, it does not appear to be completely satisfactory.

An object of this invention is the provision of a new and improved method and means for removing scale from the surface of metal.

Another object of this invention is the provision of a method and means for removing scale from the surface of metal which does not require the use of acids.

Still another object of the present invention is the provision of an inexpensive and effective method and means for cleaning and/or heat-treating metal.

Yet another object of the present invention is the provision of an arrangement for removing scale from wire stock which operates more rapidly than previously known methods.

Still another object of this invention is the provision of a novel method and means for establishing and maintaining a rotating plasma arc while one of the electrodes is moved.

These and other objects of the invention are achieved in an arrangement wherein there is established a scavenging station through which the elongated conductive stock, such as rod or wire stock, is passed. At such scavenging station there is established one or more rotating plasma arcs which terminate at the surface of the conductive stock and act to remove the scale from the surface of the stock.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawings.

FIGURE 1 illustrates an embodiment of this invention.

2

FIGURE 2 illustrates an embodiment of this invention using adjustable roller electrodes as well as a single movable plasma electrode.

FIGURE 3 shows an embodiment of the invention using two electrodes.

FIGURE 4A and FIGURE 4B show embodiments of the invention in a vertical loop configuration.

FIGURE 5 illustrates an embodiment of the invention including a quenching step.

The phenomenon comprising an arc discharge through a gas is well known. It is known as a plasma arc when the gas becomes sufficiently ionized to become electrically conductive and conduct the arc currents flowing in the ionized gas. Arrangements for causing such arc discharge are well known and simply comprise applying a voltage across two electrodes, which are spaced from one another, to cause a discharge through a gas which is provided between the electrodes. According to the present invention, such an arc is established between an electrode and the conductive stock which serves as the other electrode and caused to rotate by the presence of a magnetic field. The arc provides an electronic and ionic bombardment of the surface of the conductive stock, which effectively blasts the scale away and thus scavenges the stock.

Besides exhibiting the property of being able to conduct electrical current, a plasma arc also provides an elevated temperature on the order of thousands of degrees Fahrenheit. Because the stock moves through the arc rapidly, only a very thin surface layer is exposed to the heating effect, but its rise is insufficient to cause oxidation. However, by slowing the speed of travel of the stock through the arc, advantage of the heating property of the arc may be taken in accordance with this invention for the purpose of heating the surface of the stock sufficiently to burn away any scale which is acquired in the process of the stock fabrication, such as by hot rolling. In this instance, the conductive stock must be kept in an inert atmosphere until it can cool down to a temperature at which its surface will not reoxidize. Alternatively, the heating effect may be employed for elevating the temperature of the stock sufficiently to enable heat treatment thereof.

Although arrangements for striking and maintaining a plasma arc in the presence of stationary electrodes is well known, problems arise where it is desired to strike and maintain the arc stationary while one of the electrodes, which here is the elongated conductive stock sought to be treated, is moved. The plasma arc exhibits what is known as a viscous or cathode effect—that is, as the electrode is moved, the arc tends to stay with the spot at which it is ignited and thus tends to elongate in the direction of motion and thereby becomes extinguished. Accordingly, it was necessary to find an arrangement for overcoming this viscous effect.

Another problem which presents itself is that the plasma arc is affected by a magnetic field. Thus, if an arc is struck between an electrode and an elongated wire serving as the other electrode, then a magnetic field will exist due to current flowing in the elongated wire which can move the arc and thereby lengthen it sufficiently to be extinguished, this phenomenon being known as the magnetic pressure effect. Other effects such as the entropy effect and the cyclotron effect also cause displacement of the arc by virtue of applied magnetic fields in-

teracting with the fields produced at the surfaces of the arc and the fields, due to the flow of current in the electrodes which, to a degree, can adversely affect the stability of the arc. Thus, it was necessary to find an arrangement which could maintain the plasma arc on the moving stock, despite the presence of these adverse effects.

Reference is now made to the drawing FIG. 1, wherein there may be seen an arrangement in accordance with this invention for applying a plasma arc to the surface of an elongated conductor such as wire stock. The resultant heat can scavenge the surface of the wire stock to effectuate cleansing or may be used for heat treatment if desired. The wire stock 10 is supported by conductive rollers 12, 14, 16, and as viewed on the drawing, is moved through these rollers by being wound up on a drum 18, which is driven by a motor, not shown. The arrangement for moving the stock may be any of those well known in the art. The rollers may be driven and thus move the stock.

In being pulled through the rollers, the conductive metal stock also is pulled through what may be termed as a scavenging location. Two are shown in the drawing. However, it will be understood that as few or as many of these may be employed as are required for performing the desired operation.

Considering the first location at which a rotating plasma arc is established, the mechanism for creating this arc includes a cylindrical electrode 20, shown in section. This electrode actually comprises a metal holder 20A, preferably of steel, having a cylindrical opening in which there is inserted a copper cylinder 20B. Provision is made for cooling the copper cylinder, which is the actual operating electrode, by having an aperture 22 in the steel cylinder which abuts the copper cylinder and through which cooling liquid is caused to flow. The copper cylinder has a central aperture through which the stock to be treated may pass. This central aperture may be described as having three portions: a small-diameter portion 24A, a transition portion 24B, and a large-diameter portion 24C. The small-diameter portion extends inward from the downstream side of the electrode 20B; the large-diameter portion extends inward from the upstream side of the electrode 20B; and the transition portion 24B extends between these two portions. It should be noted further that the large-diameter portion extends for a longer distance than does the small diameter portion.

Positioned adjacent the upstream side of the electrode 20 is a magnet 26, shown in section, which includes a ring-like pole piece 26A and an exciting winding 26B and which produces a generally axial magnetic field in the vicinity of the electrode 20. A magnet potential supply 28 provides current for driving the exciting winding 26B. The pole-piece 26A, which is here shown in section, has a pole tip for directing flux at the opening between the electrode 20B and the wire stock 10 being treated. The steel holder is provided to assist in shaping the magnetic field from the magnet 26, so that the most concentrated flux region exists across the small-diameter portion 24A of the electrode, and a less concentrated flux region exists across the large-diameter portion 24C of the electrode. The reason for establishing this flux field in this manner is to partially counteract the viscous effect on the arm by establishing a field of greater energy density in the direction of movement of the arc than exists in the region where the arc is to be maintained. The arc will, of course, tend to move to the region of minimum energy density.

For initiating a plasma arc, there is provided an arc striking-power supply 30, which can comprise any source of high potential, which, when applied between the electrode 20 and the conductive rollers 14 to which the source of potential is connected, will cause a spark to be initiated between the electrode 20 and the conductive stock 10. As soon as this spark has been struck, a power

arc develops which is maintained by a direct-current power supply, here designated as the arc-sustaining-potential source 32, which is also connected between the electrode 20 and the rollers 14. The arc-striking-power supply is automatically turned off when the arc is ignited by any suitable means well known in the art, such as apparatus for sensing when a current flow is initiated by virtue of the arc being created.

Either a high-potential D.C. supply may be employed for striking the arc or a high-potential A.C. supply. In an embodiment of the invention which was built, the arc-striking-potential source was A.C. and was coupled in series with the arc-sustaining-potential supply by the secondary winding of an output transformer 31 having a capacitor 33 connected thereacross. The arc-sustaining-potential supply may be any supply for providing sufficient current to maintain the arc. A welding supply was employed in an embodiment of the invention which was built which provided 400 amperes current across the 45-volt drop existing in the circuit when the arc was struck.

In an embodiment of the invention which was built, the atmospheric air provided the gas which is necessary for a plasma arc. This should not be construed as a limitation upon the invention, since, if desired, any of the other well-known gases, such as argon or helium, may be employed.

It was previously stated that because of the cathode effect or viscous effect, an arc which terminates on a moving electrode will be drawn in the direction of motion of the electrode until it is extinguished. The arrangement shown in the drawing overcomes this effect, first, because of the shape of the magnetic field provided by the magnet 26 which tends to direct the plasma arc in a direction opposed to the direction of motion of the elongated conducting stock, and, second, because of the shape of the central aperture of the electrode 20. As a result, of this shape, an automatic gas-pumping action occurs, and the arc is pushed as a result of this gas-pumping action in a direction to counteract the viscous effect. Since the orifice presented in the portion 24A of the central opening is smaller than the orifice presented in the portion 24C of the central opening, a type of ram-jet effect is created, wherein the gas or air is inspirated through the small-diameter opening, is heated due to the presence of the plasma arc, and then an incandescent gas is exhausted through the large-diameter portion 24C of the central opening. This helps to stabilize the left side of the plasma arc by presenting a cold, nonionized barrier. This also serves to continually purge the plasma arc of generated impurities, thereby further enhancing stabilization. The plasma arc represented by the lines 34, once struck, tends to maintain itself between the electrode at the wide-diameter portion 24C and the stock 10.

At the second heat-applying location, an arrangement for applying a plasma arc to the stock includes two ring electrodes 40, 42, which are here shown in section. In an embodiment of the invention which was built, these ring electrodes were made of copper and each had an aperture therein, respectively 40A, 42A, for the purpose of permitting the circulation of a coolant, such as water. The ring electrodes 40, 42, each have at the surface opposing the other electrode and near the central aperture portion a protuberance, respectively 44, 46. These protuberances 44, 46, oppose one another, and the opposing surfaces are flattened. The pair of ring electrodes 40, 42, are spaced quite close to one another in the region of these protuberances.

There is provided for the electrode 40 an arc-striking-potential supply 48 which has an output transformer 49. The secondary winding is resonated by a capacitor 51. The secondary winding is connected through an arc-sustaining-potential source 50 between the electrode 40 and the conductive rollers 14. There is provided an arc-striking-power supply 52, which has an output transformer 55. The secondary winding is resonated by a capacitor

53. The secondary winding is connected between the electrode 42 and the roller 16 through an arc-sustaining-potential supply source 54. In addition, there is provided at the second scavenging location a magnet 56 with its magnet-potential supply 58 and with its ring-like pole piece 56A, having the tips adjacent the electrode 42 shaped to form an axial magnetic field within the electrode apertures and to concentrate the flux at the space between the workpiece or conductive stock 10 and the electrode 42.

The funnel-shaped flux pattern produced by the magnet 56 serves to oppose any tendency of the plasma arc, which is struck by employing the respective arc-striking-power supplies 52 and 48 and which is maintained by the respective arc-sustaining-potential supplies 50 and 54, from moving in the direction of motion of the stock 10. The gas employed in the embodiment of the invention which was built was atmospheric air; however, as previously explained, any of the other well-known gases, such as argon, nitrogen, or hydrogen, may be employed instead. Because of the shape of the electrodes and their positioning, a further stabilizing effect on the plasma arc, here represented by the line 60, is provided. The arc is maintained in the region shown between the electrodes 40, 42 and the stock 10. The gas is drawn or inspired through the central aperture of the electrode 40 from the upstream side, and through the central aperture of the electrode 42 from the downstream side. Thus, there is an opposite and balancing pressure on the arc 60. The gas is heated in the arc and then exhausted in the space between the electrodes, thereby purging the plasma of any impurities.

It is preferred that the arc-sustaining-potential supplies 50 and 54 provide an equal potential to the electrodes 40, 42. In an embodiment of the invention which was built, wire rod was treated while being moved at a rate on the order of 200 feet per minute. The arc-sustaining-potential supplies 50 and 54 each provided 250 amperes across a 40-volt drop. It should be noted that the stock need not be round, but can have any other stock shape and can also, for example, comprise pipe stock. Furthermore, if desired, other materials may be fed into the arc to be plated or deposited on the rod. It should also be noted that because of the equal and opposite current flow between the conductive roller 14 through the stock 10 and through the arc and the conductive roller 16 through the stock 10 and through the arc the magnetic pressure effect due to current flowing through the workpiece is cancelled.

The plasma arc created in the ring electrodes is a continuously rotating one, rotation being due to the inner action of the axial magnetic field and the magnetic field created by the flow of current through the arc, which exerts a force on the arc in a direction so as to cause it to rotate around the stock at the center, thereby treating the entire outer surface of the stock as it is being pulled through the ring electrode. It is preferable to make the stock negative and the electrode positive, as shown in the drawing. Although the arrangement can operate with the polarities reversed, it is believed that a superior operation occurs with the arrangement as shown. Further, the arrangement may be operated using an alternating-current arc-sustaining-potential supply, if desired. As previously pointed out, the rise in temperature of the conductive stock, due to the arc and the current flow therethrough, may be effectively controlled by the rate at which the stock is pulled through the arc. Furthermore, the current flow through the stock, in a path which may be traced from the power supply through the electrode which applies plasma through the plasma arc, through the stock, and through a roller electrode back to the power supply, provides another control over the heating and/or heat treatment of the stock. This may be achieved by varying the spacing between a roller electrode and the plasma-applying electrode. This has the

effect of determining how long current will flow through the stock at a given rate of speed. Obviously, the longer the amount of time which the current flows through the stock, which is established by the spacing between the roller electrode and the plasma-applying electrode, the greater the heating effect due to the current flow through the stock. Thus, this invention provides a method and means of heating the stock for heat treatment, if desired, as well as for scavenging.

In the electrode and pickoff roller arrangement shown in FIGURE 1, current flows in the wire 10 between the plasma arc at 60 and pickoff roller 16, also between plasma arc 60 and roller 14, and also between the arc of the electrode 20 and the roller 14. By varying the distance between the rollers 16 and the electrodes, the length of current path and thereby the time (since the wire is always moving through the electrodes) during which the wire stock is heated by the current, is varied.

The distance between roller 16 and electrodes 40, 42, can determine the preheat time for the wire stock, the distance between electrode 40 and rollers 14 as well as the distance between rollers 14 and electrode 20 can determine the heating time for the stock.

Reference is now made to FIGURE 2 which shows an arrangement for using the invention for heat treating stock in addition to cleaning or stripping it. In order to simplify the showing the power supply is omitted from FIGURE 2. The electrode 70 which provides the plasma arc as described previously, may have its position altered from the position represented by the dotted rectangle 70A to the position represented by the dotted rectangle 70B. The electrode is supported by an overhead trolley 72, which rolls on a suitable track structure 74. The pickoff roller electrodes 76, 78, through which a connection is made through the stock back to the source of operating potential, are also attached to the overhead support 74, on which the trolley 72 rolls. Of course, the support for the rollers and the plasma generating electrode 70, are all by suitable insulating structures. The rollers may also be made movable, by sliding their support attachment along the overhead support.

In accordance with the foregoing description, the plasma electrode 70 will establish an arc to the stock 10. Current flows in that arc through the stock 10 to both pickoff electrodes 76 and 78. Therefore, with the direction of strip represented by the arrows in FIGURE 2 heat due to I²R loss is applied to the stock before it reaches the cleaning plasma arc 70 as well as afterwards. The length of time at which the stock is pre-heat treated and the length of time in which it is heat treated after leaving the arc, is determined by the relative position of the electrode 70 to the pickup roller 76, as well as to the pickup roller 78. Placing the electrode at 70A puts more current and thus more heat into the entering or cold section of the stock. At the other side of the electrode, the remaining stock section is a "temperature hold" section with a lower current because of higher path resistance, because of longer wire length. This section however, permits a "time at temperature" metallurgical transformation to take place. With the electrode 70, a rising temperature will occur over the path length between electrode 70 and roller 78. With the electrode at 70B, the greatest heating effect occurs between 70B and 78.

FIGURE 3 shows an arrangement for effectuating the heat treatment between the two spaced electrodes 80, 82. In the arrangement shown in FIGURE 3, the positions of the electrodes 80, 82, are movable since both are supported by overhead trolleys 84, 86, which are movable. The source of operating potential 88, may be a center tapped power supply which is connected to the two plasma electrodes 80, 82. Accordingly, the principal current path through the stock 10 is defined by the distance between the two plasma electrodes 80, 82. There is a preheat treatment given over the path length between roller 79 and electrode 80. The main current path exists between the two electrodes 80, 82, and heating occurs over this dis-

7

tance. By moving roller electrode 83, closer to or further from electrode 82, the temperature reached by the wire may be maintained, increased or gradually lowered, since the relative spacing of these electrodes varies the resistance in the shunt current path (in shunt with the current path between 79 and 82) and therefore varies the amount of current flowing, accordingly.

FIGURE 4A and FIGURE 4B illustrate arrangements for effectuating heat treatment while cleaning the stock in those locations where the stock is given a circular path. This path is usually a vertical one and is done to save floor space. The movement of the stock is indicated by the arrows present thereon. This arrangement is usually known in the trade as a Vertical Hot Loop operation. The idlers, or pulleys, 92, 94, are not involved in the electrical circuitry. They are adjustable in order to make the loop formed by the stock larger or smaller. The power supply 96, applies current to the electrode 90 and to the electrical pickoff roller 98. Therefore, the current path through the stock 10 is determined by the distance between the electrode 90 and the rollers 98, which in turn is determined by the size of the loop which the idlers 90, 92, created by their position relative to the position of the rollers 98.

FIGURE 4B illustrates the use of the vertical loop when two electrodes 100, 102 are employed. In this case, neither of the rollers 104, 106, are involved in the electrical circuitry. The power supply 108 applies potential with relative opposite polarity to the electrodes 100, 102, whereby a plasma arc may be struck to the wire stock 10. The electrode 104 is adjustable to increase or decrease the size of loop whereby the amount of wire which extends around the electrode 104 and is in the current path between the electrodes 100, 102, may be varied.

FIGURE 5 shows an arrangement for pre-heating the stock 10, then exposing it to the plasma arc, and then quenching it. The electrode 110, establishes two current paths, one current path extends through the stock 10 to the roller 112, the other path extends from electrode 110 to roller 116. Accordingly, due to the current flow through the wire stock 10, the wire is heated in the path up to the electrode 110. As the strip passes through the electrode 110 it is also heated and cleansed by the plasma arc. The stock is then quenched in a suitable cooling arrangement as by the tank 114. The quench there may be full, partial, or interrupted, depending upon the wishes of the user of the system. The stock 10, then passes on to be either held at a required temperature for a second heat treatment or may be allowed to cool further, as determined by the relative spacing of rollers 112, 116 and the plasma electrode 110.

Should the heat treatment of the wire stock cause it to sag or become weak so that the usual pulling of the wire through the rollers and electrodes may damage the wire, then it may be necessary to drive the roller to carry the wire through the electrodes. Also, if desired, the wire stock may be made to pass through a pipe, as represented by the dotted lines 118, between pick-off rollers and electrodes through which a suitable reducing gas may be passed, if it is desired to maintain a proper reducing atmosphere during the heat treatment.

There has accordingly been described and shown herein a novel, useful and unique arrangement for effectuating heat treatment of metal stock using an electrode arrangement which applies a plasma arc to the stock.

I claim:

1. In apparatus for cleansing the surface of elongated conductive stock wherein an electrode through which said stock moves is provided for establishing a plasma arc therebetween by application of potential to said electrode and to a current pick off electrode positioned at said conductive stock spaced from the position of said electrode, the improvement in said apparatus for controlling the heat treatment of said stock comprising means for adjusting

8

the relative spacing of said electrode and said pickoff electrode to one another to adjust the electrical current flow path length through said stock to thereby control the heat treatment of said stock.

2. In apparatus for cleansing the surface of elongated conductive stock wherein an electrode through which said stock moves is provided for establishing a plasma arc therebetween by application of potential to said electrode and to a current pick off electrode positioned at said conductive stock spaced from the position of said electrode, the improvement in said apparatus for controlling the heat treatment of said stock comprising means for movably supporting said electrode for motion along said conductive stock, and means for movably supporting said pickoff electrode for motion along said conductive stock whereby a desired heat treatment of said stock is effectuated by moving said electrode and said pickoff electrode to establish a current path through said stock which effectuates the desired heat treatment.

3. In apparatus for cleansing the surface of elongated conductive stock wherein an electrode through which said stock may pass is provided for establishing a plasma arc therebetween by application of potential across said electrode and two current pickoff electrodes positioned at said stock and one on each side of said electrode, the improvement in said apparatus for controlling the heat treatment of said stock comprising means for supporting said electrode to be movable along said conductive stock for effectuating a predetermined heat treatment of said stock by the position to which said electrode is moved relative to said pickoff electrodes.

4. In apparatus as recited in claim 3 wherein each said pickoff electrode includes means for movably supporting said pickoff electrode for adjusting its position relative to said electrode.

5. Apparatus for heat treating elongated conductive stock comprising an electrode through which said elongated conductive stock may be passed, a conductive roller in contact with said elongated stock spaced from said electrode, means for applying potential between said electrode and said conductive roller to establish a plasma arc between said electrode and said elongated stock, means for moving said elongated stock through said electrode while maintaining said plasma arc, and means for adjusting the spacing between said conductive roller and said electrode to adjust current path length to effectuate a desired amount of heat treatment to the elongated stock therebetween.

6. Apparatus for heating treating elongated conductive stock comprising a plurality of roller means positioned for guiding said conductive stock in a loop, at least one of said roller means being conductive, an electrode through which said conductive stock may pass positioned at said conductive stock which is within said loop, means for applying potential between said electrode and said conductive roller means to establish a plasma arc between said electrode and said elongated stock, means for moving said elongated stock through said electrode in said loop while maintaining said plasma arc, and means for moving said roller means for varying the loop size and thereby the length of stock extending between said electrode and conductive roller means to thereby determine the heat treatment received by said conductive stock.

7. Apparatus for cleansing and heat treating wire stock comprising a first and second electrode through which said wire stock may pass, means for movably supporting said electrodes for adjusting the relative spacing therebetween along said wire stock, a first pickoff roller positioned along said wire stock adjacent said first electrode, a second pick-off roller positioned along said wire stock adjacent said second electrode, means for supporting said first pickoff roller to enable adjusting the spacing thereof from said first electrode, means for supporting said second pickoff roller to enable adjusting the spacing thereof from said second electrode, means for moving said wire stock through said rollers and electrodes, and means for apply-

ing potential to said electrodes and said pickoff rollers to establish plasma arcs between said electrodes and said wire stock for cleansing the surface thereof and to cause current to flow through said wire stock between the plasma arc positions and said electrodes for affording heat treatment of said wire stock.

8. Apparatus for scavenging the surface of elongated conductive stock comprising means establishing a scavenging location, means for passing said elongated conductive stock through said scavenging location, and means for establishing a rotating plasma arc terminating on the surfaces of said elongated conductive stock as it is passed through said scavenging location.

9. Apparatus for treating the surface of elongated conductive stock with a plasma arc comprising an electrode through which said elongated conductive stock may be passed, means for establishing a plasma arc between said electrode and said elongated conductive stock, and means for moving said elongated conductive stock through said electrode while maintaining said plasma arc for obtaining treatment of the surface thereof.

10. Apparatus for blasting the surface of elongated conductive stock with high-energy ions comprising an electrode having an aperture therethrough, means for moving said elongated conductive stock through said electrode aperture, and means for establishing a rotating plasma arc between said electrode and said elongated conductive stock for blasting the surface thereof.

11. Apparatus as recited in claim 10 wherein the aperture of said electrode is shaped to counteract the viscous effect on said rotating plasma arc caused by motion of said elongated conductive stock through said aperture.

12. Apparatus as recited in claim 10 wherein said electrode comprises a conductive cylinder, said aperture has a first diameter continuing from one end inward for a portion of said cylinder, a second diameter larger than said first diameter continuing inward from the other end of said cylinder for a portion of said cylinder larger than said first diameter portion, and a transition region between said first and second diameter portions.

13. Apparatus for scavenging elongated conductive stock comprising a plurality of electrodes spaced from one another, said electrodes each having apertures through which said elongated conductive stock may pass, means for passing said elongated conductive stock successively through said plurality of spaced electrodes, means for establishing a rotating plasma arc between each of said electrodes and said elongated conductive stock as it is passed through said spaced electrodes for blasting the surface thereof, and means positioned adjacent each plasma arc for opposing any viscous effects due to motion of said conductive stock.

14. Apparatus for scavenging as recited in claim 13 wherein said means for passing said elongated conductive stock successively through said plurality of spaced electrodes includes a plurality of conductive rollers for movably supporting said stock, and said means for establishing a rotating plasma arc between each of said electrodes and said elongated conductive stock includes a separate source of operating potential connected between an electrode and a roller and means for establishing a magnetic field along said conductive stock.

15. Apparatus for scavenging as recited in claim 12 wherein two of said plurality of spaced electrodes are placed sufficiently close to one another for achieving gas inspiration from opposite directions with an exhaust gas flow therebetween and to achieve cancellation of the magnetic pressure effect caused by the currents flowing in the conductive stock.

16. Apparatus for scavenging as recited in claim 13 wherein said means positioned adjacent each plasma arc for opposing any viscous effects due to motion of said conductive stock includes a ring magnet having a central aperture through which said conductive stock passes, said ring magnet being positioned adjacent an electrode and

having its pole piece shaped for forming a region of greater flux concentration in the region adjacent said arc in the direction of stock movement than in the region of an electrode in which an arc is established.

17. Apparatus for treating elongated conductive stock with high-energy ions comprising a pair of cylindrical electrodes each having a central aperture through which said stock may be passed, said cylindrical electrodes being positioned adjacent one another with their central apertures aligned, each said electrode having on the side facing the other electrode and near the central aperture a raised flattened protuberance, said protuberances opposing each other, a conductive means positioned on either side of said pair of circular electrodes for supporting said elongated stock for passage through said pair of electrodes, a means connected between an electrode and a conductive means for establishing a plasma arc between each of said electrodes and said elongated conductive stock, and means positioned adjacent the one of said pair of electrodes on the downstream side of said pair of electrodes for providing a magnetic field to oppose any viscous effect on said plasma arc.

18. Apparatus for treating elongated conductive stock with a plasma arc comprising a plurality of cylindrical electrodes each having a center cavity through which said stock may be passed, one of said cylindrical electrodes having a center cavity with two dimensions one of which is smaller than the other, there being a gradual transitional region between said two cavity dimensions, the portion of said cavity having the smaller cavity being on the trailing-edge side of said electrode relative to motion of said conductive stock therethrough, a pair of said plurality of cylindrical electrodes being positioned adjacent one another with their central apertures aligned, each of said pair of electrodes having on the side facing the other electrode and near the central aperture a raised flattened protuberance, said protuberances opposing each other, first conductive roller means for supporting said conductive stock positioned between said one electrode and said pair of electrodes, second conductive roller means for supporting said conductive stock positioned on the side of said pair of electrodes furthest away from said first conductive roller means, first means for establishing a plasma arc between said conductive stock and said one electrode connected between said one electrode and said first conductive roller means, second means for establishing a plasma arc between said conductive stock and one of said pair of electrodes connected between said one of said pair of electrodes and said first conductive roller means, and third means for establishing a plasma arc between said conductive stock and the other of said pairs of electrodes connected between said other of said pair of electrodes and said second conductive roller means.

19. Apparatus as recited in claim 18 wherein there is provided for each said one electrode and for said pair of electrodes and positioned on the downstream side thereof a magnetic means for opposing any viscous effects due to motion of said conductive stock, each of said magnetic means having a ring magnet with a central aperture through which said stock may pass, the pole piece of said ring magnet being shaped for forming a region of greater flux concentration in the region adjacent said arc in the direction of stock movement than in the region of the electrode in which an arc is established.

20. An electrode structure for establishing a plasma arc comprising a pair of cylindrical conductive cylinders positioned adjacent one another and having aligned central apertures each said cylinder having on the side facing the other cylinder and near the central aperture a raised flattened protuberance, said protuberances opposing each other.

21. The method of scavenging the surface of wire stock comprising establishing a rotating plasma arc terminating on the surface of said stock, moving said stock, and main-

11

taining said rotating plasma arc at the location at which it is established despite motion of said stock.

22. The apparatus of claim 10 wherein said means for establishing a rotating plasma arc between said electrode and said elongated conductive stock includes means for establishing a potential difference between said electrode and said conductive stock and means for establishing a magnetic field along said conductive stock.

23. The method of scavenging the surface of wire stock comprising establishing a plasma arc terminating on the

12

surface of said stock, rotating said plasma arc around said stock, moving said stock, and maintaining said rotating plasma arc at the location at which it is established despite motion of said stock.

References Cited in the file of this patent

UNITED STATES PATENTS

484,637	Hunter	Oct. 18, 1892
2,465,093	Hanson et al.	Mar. 22, 1949
2,874,265	Reed et al.	Feb. 17, 1959