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[54] **FLUID-COOLED ELECTRODES HAVING PERMANENT MAGNETS TO DRIVE THE ARC THEREFROM AND ARC HEATER APPARATUS EMPLOYING THE SAME**
18 Claims, 6 Drawing Figs.

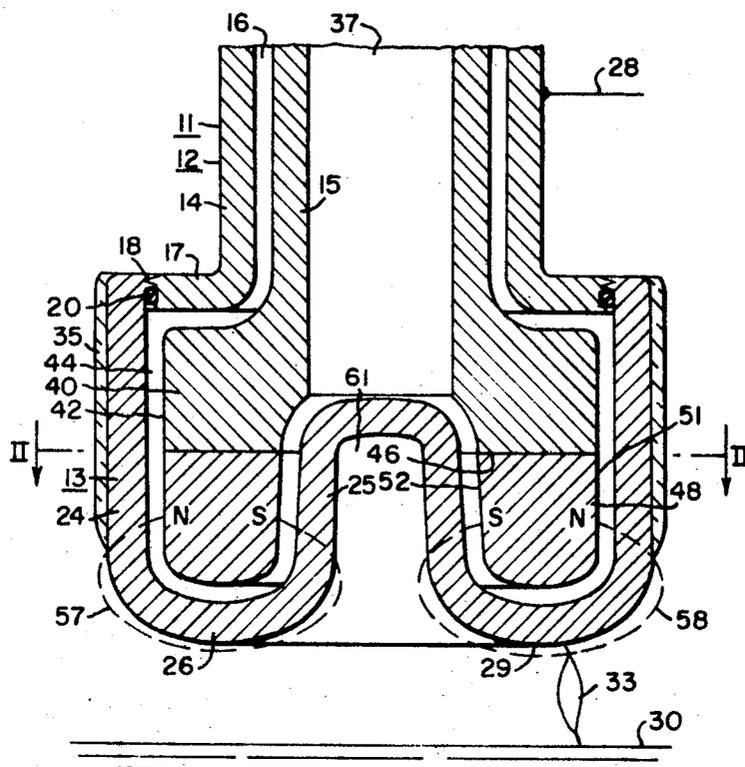
- [52] U.S. Cl. 13/18,
313/156
- [51] Int. Cl. H05b 7/08
- [50] Field of Search. 13/18;
313/153, 156, 157

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- | | | | |
|-----------|--------|--------------------|----------|
| 2,286,211 | 6/1942 | Dawson et al. | 13/18 UX |
| 3,369,067 | 2/1968 | DeCorso | 13/18 |

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ABSTRACT: An electrode has a tip forming an arcing surface, the tip being hollow, preferably generally annular in shape and preferably generally U-shaped in cross section. Disposed within the tip is according to one embodiment a permanent magnet having a contour similar to that of the tip, preferably having flat inside and outside walls, and which has the outside wall surface thereof forming either the north or south pole and

the inside surface thereof forming the other magnetic pole. Lines of force leaving the magnet from, for example, the inside annular surface thereof being of the same polarity oppose each other and bend around the arcing surface of the tip to the pole formed by the outside wall surface of the permanent magnet. The magnetic field lines extend generally radially from the axis of the tip and transverse to the arcing surface, the lines also being transverse to the current in the arc path, and the field exerts a force on the arc which causes it to move substantially continuously around the arcing surface. The tip includes a passageway for the flow of the cooling fluid between the permanent magnet and the arcing surface to conduct heat flux therefrom, a wall portion of the tip separating the fluid passageway from the arcing surface. In another embodiment two annular permanent magnets radially spaced from each other have their upper and lower axially spaced surfaces forming the magnetic poles; a line between the north and south pole of each magnet may lie in a direction substantially parallel to the axis of the electrode, that is the axial ends of the magnets are the poles. The two magnets have their north and south poles oppositely disposed with respect to each other. The gap between the upper poles of the two radially spaced annular magnets is closed by an annular ring of ferromagnetic material. The magnetic field between opposing poles at the lower end surfaces of the magnets extends transverse to the arcing surface around the entire face or periphery of the arcing surface, said transverse magnetic field exerting a force on the arc which causes it to rotate or move substantially continuously. A third embodiment employs a ceramic coating over a portion of the arcing surface to limit the width of the track on which an arc path may be formed to thereby utilize only the portion of the arcing surface of the tip which has substantially the total magnetic field parallel thereto and extending radially thereacross. An additional embodiment uses peripherally spaced discrete radially extending bars, the inner ends of all bars having the same or like polarity. An arc heater has two axially spaced electrodes, each of which is fluid cooled and includes at least one annular permanent magnet in the electrode tip and passageway therein for the flow of cooling fluid.



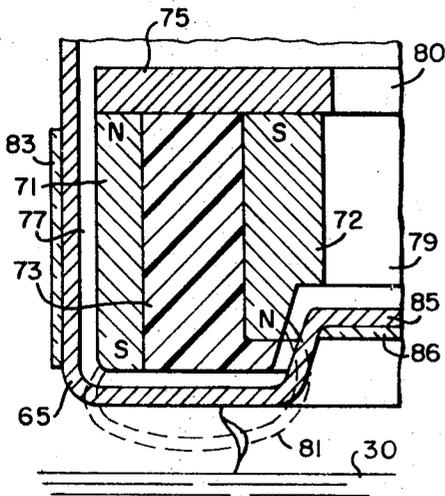


FIG. 3.

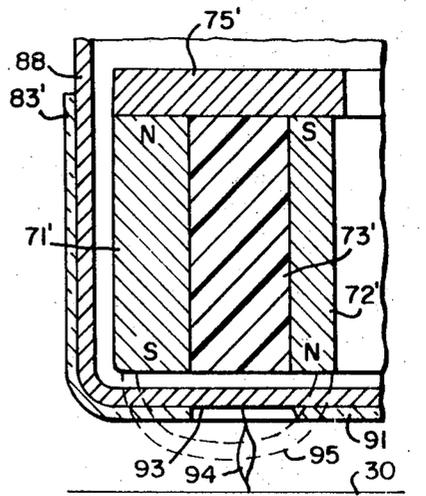


FIG. 4.

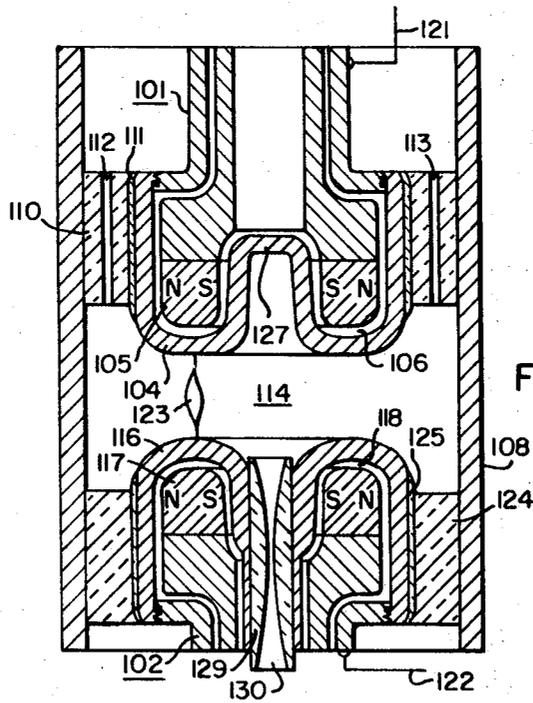


FIG. 5.

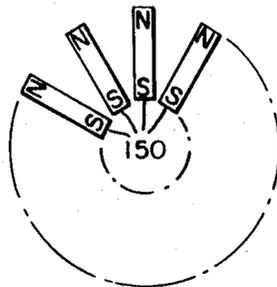


FIG. 6.

FLUID-COOLED ELECTRODES HAVING PERMANENT MAGNETS TO DRIVE THE ARC THEREFROM AND ARC HEATER APPARATUS EMPLOYING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to the copending application of Armin M. Bruning for "Nonconsumable Electrode for Electric Arc Heating and Melting and Methods," Ser. No. 866,274, filed Oct. 14, 1969 and assigned to the assignee of the instant invention, which is a continuation-in-part of application Ser. No. 407,332, filed Oct. 29, 1964, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to electrodes employing magnetic fields transverse to an arc path from the tip thereof for setting up a force on the arc to cause the arc to move substantially continuously around the arcing surface of the electrode.

2. Description of the Prior Art

It has been suggested heretofore that a single permanent magnet located near an arcing surface but not within the tip, with its north and south poles axially spaced, be used to move an arc; such a suggestion was made in application Ser. No. 407,332, filed Oct. 29, 1964.

A number of patents have issued on prior art electrodes in which a magnetic field coil is located in a tip generally annular in shape and generally U-shaped in cross section, with a fluid passageway U-shaped in cross section extending around the entire tip to conduct cooling fluid near the arcing surface and remove heat flux therefrom. Such prior art electrodes with field coils are exemplified by Pat. No. 3,369,068 to P. F. Kienast issued Feb. 13, 1968, and Pat. No. 3,398,229 to Decorso et al. issued Aug. 20, 1968.

Such prior art electrodes employing field coils for setting up magnetic fields to rotate the arc are complicated by the necessity of providing electrical insulation between the magnetic field coil and the electrode structure, and require that leads for energizing the field coil pass through at least a portion of the electrode structure and usually pass the entire long distance between the electrode tip and the upper or head portion of the electrode. Furthermore, magnetic field coils are relatively expensive compared to permanent magnets.

Additionally, magnetic field coils almost always have the north and south poles of the coil disposed with respect to each other in a direction parallel to the longitudinal axis of the electrode, with the result that many flux lines leave the electrode tip in a direction which is substantially perpendicular to the arcing surface rather than transverse to the arc path; the magnetic field over the arcing surface is nonuniform and there is a tendency for the arc to be driven toward the inside annular surface of the electrode tip as a result of the configuration of the magnetic field lines, or more precisely, the shape of the magnetic field, density, and strength of field components in certain directions.

SUMMARY OF THE INVENTION

Our electrode employing a permanent magnet is cheaper than prior art structures, needs no electrical insulation or electrical connections to a field coil, and furthermore in our electrode employing a permanent magnet with the north and south poles of the magnet being selectively the outside annular surface and the inside annular surface, or vice versa, we produce a magnetic field which extends transversely to (substantially radially across) a much larger portion of the arcing surface of the electrode tip. This is also true of other embodiments of our invention. An arc heater having electrodes embodying our invention is very simple and easy to construct compared to prior art arc heaters.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical section partially broken away through an electrode and electrode tip according to one embodiment of our invention;

FIG. 2 is a section through the lines II—II of FIG. 1;

FIG. 3 is an electrode tip partially broken away according to a second embodiment of our invention in which two radially spaced annular permanent magnets are employed;

FIG. 4 is an additional embodiment of our invention employing two radially spaced annular permanent magnets;

FIG. 5 is a cross-sectional view through an arc heater employing electrodes according to our invention in which annular or ring-shaped permanent magnets are mounted in the tips of the electrodes; and

FIG. 6 shows schematically segmented permanent magnet field producing means including peripherally spaced radially extending bars all having the same magnetic pole at the inner ends thereof.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1 the electrode generally designated 11 is seen to include a supporting column portion generally designated 12 and an electrode tip generally designated 13. The supporting column is shown as consisting of two coaxially mounted tubes 14 and 15, the tubes being radially spaced from each other to provide a cylindrical fluid flow passageway 16 therebetween. The outer tube 14 has a flaring transverse flange portion 17 at the lower end thereof with threads 18 to receive in threaded engagement the electrode tip generally designated 13. An O-ring 20 disposed within a suitable annular groove provides a fluidtight seal.

The electrode tip generally designated 13 includes an annular shell composed of material having high thermal and electrical conductivity with an outer wall portion 24 of larger diameter and an inner wall portion 25 of smaller diameter, and an annular bottom portion 26, shown as curved with the inner and outer edges being extensions of wall portions 25 and 24. Lead 28 symbolizes means for connecting the electrode to one terminal of a source of potential, the other terminal of opposite polarity being connected to a melt 30 which is at least partially conductive, cylinder 14 being conductive for bringing current to the tip to produce the arc 33 from the tip to the melt. An axial portion of the outside surface of outer wall 24 is coated with a ceramic coating 35 to provide thermal insulation.

The aforementioned tubular member 15 of the supporting column provides inside thereof a fluid passageway 37 and is seen to have at the lower end thereof a thickened flaring portion 40 of considerably enlarged outside diameter which has the outside wall 42 thereof spaced from the inside surface of outer wall 24 of the electrode tip to form a cylindrical passageway 44 which extends around the entire tip, which passageway 44 communicates at one end thereof with the aforementioned cylindrical passageway 16 between the tubular support members 14 and 15, and communicates at the other end thereof with passageway 37.

The lower end portion of enlarged diameter 40 is terminated at a predetermined axial position with respect to the electrode and tip and has secured to the lower surface 46 thereof by any convenient means, not shown for convenience of illustration, a permanent magnet generally designated 48. Member 15 including portion 40 may be made of iron and magnet 48 secured thereto by magnetic attraction. On the other hand, where considerations of magnetic field strength at the arcing surface make a low reluctance path within the tip which may be followed by some of the lines of force undesirable, the sleeve and collar portion may be made of nonmagnetic material and the magnet secured thereto by small peripherally spaced screws inset so as not to obstruct the flow of fluid. The permanent magnet 48 is ring-shaped with an outer annular wall surface 51 and an inner annular wall surface 52, these being preferably substantially flat, both these surfaces being spaced from the adjacent inside wall surfaces of the tip, the bottom of the magnet 48 also being spaced from the adjacent inner surface of the electrode tip so as not to obstruct the aforementioned fluid flow passageway 44 which extends around the permanent magnet on three sides thereof

and around the entire tip, passageway 44 as aforementioned communicating at the inside annular opening thereof with the passageway 37 in cylinder 15, forming a complete fluid flow passageway for conducting cooling fluid near the arcing surface 29 in a path U-shaped in cross section which extends annularly around the entire tip, the coolant entering one and thereafter being removed through the other fluid flow passageway in the supporting structure generally designated 12.

It will be understood that tube 15 is illustrated as supported from above and held in position by means, not shown for convenience of illustration, to thereby maintain the permanent magnet 48 in desired position within the tip and spaced therefrom, although other long known and conventional spacing means could be employed, such for example as spaced studs so positioned as not to substantially impede the flow of cooling fluid.

Permanent magnet 48 by way of illustration has the outside substantially flat annular surface 51 thereof forming the north pole of the magnetic structure and the inside substantially flat annular wall surface 52 thereof forming the south magnetic pole. Lines of force of similar polarity leaving or entering the inside wall surface 52 of the magnet are repelled from each other because of their like polarity, are bent around the arcing surface of the electrode, and enter the magnet again at the surface of opposite polarity 51, these lines of force being illustrated at 57 and 58. It will be understood that the north and south poles may be reversed if desired.

The permanent magnet may be composed of ferrite material or ceramic material and by suitable choice of material and dimensions may supply a magnetic field having a strength or flux density, when the field emerges from the magnetic pole surfaces, of several thousand gauss, which is ample to cause rotation of the arc at a speed which prevents substantial erosion of material from the arcing surface, the force exerted on the arc and the speed of rotation thereof being a function of the product of the magnetic field strength and the arc current.

Particular reference is made to FIG. 2, a cross section along the line II-II of FIG. 1. The annular passageway 44 is seen both on the outside and inside of the permanent magnet 48. The hollow central depression in the electrode tip resulting from its annular ring configuration is seen at 61.

Particular reference is made now to FIG. 3 which shows an electrode according to a second embodiment of our invention, only one half of the tip being shown as needed to fully illustrate this embodiment of the invention. In FIG. 3 the shell of the tip is shown at 65 having an annular substantially flat bottom portion forming an arcing surface with a recessed control closure portion 85, and disposed within the shell are radially spaced permanent magnets 71 and 72 both being in the form of rings with their upper ends oppositely poled as shown, the magnets being separated by an annular spacer member 73 composed of any suitable diamagnetic material such for example as epoxy resin. An annular ring composed of iron or other ferromagnetic material is shown at 75 closing the flux path internal to the electrode. Members 71, 72, 73 and 75 are spaced from the adjoining inside walls of the shell 65 to provide a fluid passageway 77 around the entire tip for the flow of cooling fluid to conduct heat flux from the arcing surface. Any suitable means, not shown for convenience of illustration, may be employed for holding the two annular permanent magnets, the spacer 73, and the iron ring member 75 in position within the electrode tip. The fluid in passageway 77 which communicates with passageway 16, now shown, passes through the cylindrical space 79 within magnet ring 72, thence through the central passageway 80 of the iron ring 75 and into a passageway, not shown, corresponding to passageway 37, FIG. 1. As aforementioned, the upper opening at the outside portion of passageway 77 it is understood communicates with a fluid channeling passageway, not shown for convenience of illustration, between coaxially aligned cylinders and corresponding to passageway 16, FIG. 1.

The magnetic field illustrated at 81 extends between the lower south pole of outer ring magnet 71 and the lower north pole of inner ring magnet 72, extends across or transverse to the arcing surface and transverse to the arc path and exerts a force on the arc according to the left-hand rule or Fleming's rule which causes the arc to rotate in an annular path around the arcing surface. A ceramic heat shield 83 covers a portion of the outside wall of shell 65 which will not be used as part of the arcing surface. In FIG. 3 in addition to the ceramic coating or other heat shield material 83, the central hub portion 85 of the shell 65 is seen to be covered by coating 86 of ceramic or other refractory material to assist in protecting the portion 85 from heat of radiation and convection of the arc and hot gases, since this portion 85 may not be as well cooled by the circulating fluid as are the portions of the electrode tip and shell adjacent the U-shaped passageway 77.

The relating polarities of magnets 71 and 72 may be reversed, if desired.

Particular reference is made now to FIG. 4. The shell 88 forming the tip may be substantially cylindrical in shape and the magnets 71' and 72' are separated by the spacer 73' of diamagnetic material and the iron ring 75' provides a closed flux path within the electrode. It is understood that members 71', 72', 73' and 75' are supported and maintained in position by any suitable means, not shown for convenience of illustration. A ceramic coating 83' extends along the entire length of the outside wall of shell 88 and extends a predetermined distance toward the axial center of the tip as shown. A disc-shaped coating 91 of ceramic material is also provided on the under surface of the tip, the outer edge of the disc-shaped portion 91 being spaced from the inwardly extending edge of ceramic coating 83' to provide an exposed arcing surface 93 of predetermined width from which the arc 94 takes place. The magnetic field is shown at 95; it is seen to extend between member 71' and 73' transversely across the arcing surface 93 and exerts a force on the arc which causes the arc 94 to rotate in a substantially annular path around the arcing surface.

Particular reference is made to FIG. 5 in which an arc heater is shown employing two axially spaced electrodes, both being similar to the electrode of FIG. 1 and generally designated 101 and 102 respectively. Electrode 101 has a tip 104, a permanent magnet 105, and a fluid passageway 106. Electrode 101 is held in position within the pressure vessel 108 by an annular ring and supporting member 110 electrically insulated from the electrode by an insulating sleeve 111. The ring support and spacing member 110 has a plurality of peripherally spaced bores or passageways extending axially therethrough, two of these being shown at 112 and 113, for admitting gas to be heated into the arc chamber 114 between the electrodes.

The aforementioned second electrode 102, which is the downstream electrode, has a tip 116, a permanent magnet 117, and a passageway 118 for the flow of cooling fluid. Leads 121 and 122 connect the electrodes 101 and 102 to terminals of opposite polarity of a source of potential to produce and sustain the arc 123 between electrodes. The aforementioned downstream electrode 102 is mounted and held in position within the pressure vessel 108 by an annular ring member 124 which may be composed of insulating material or may be composed of metal in which case a sleeve 125 composed of electrically insulating material is interposed between the electrode and the support member 124.

The construction of the downstream electrode differs slightly from that of the upstream electrode. The central opening formed by the annular ring configuration of the tip 104 of electrode 101 is seen to be closed at 127, whereas the inside wall of the smaller diameter of the tip or shell 116 of electrode 102 forms a cylindrical space in which is fixedly secured a generally cylindrical nozzle member 129 having an exhaust vent 130 communicating between the arc chamber 114 and the outside of the pressure vessel, and through which gas heated by the arc 123 exits from the arc heater.

In the operation of the apparatus of FIG. 5 the two ring-shaped permanent magnets may be poled as shown, magnet 105 setting up a field which is transverse to the arcing surface of tip 104 and magnet 117 of electrode 102 setting up a magnetic field which is transverse to the arcing surface of tip 116. It is seen that the inside wall surface of smaller diameter of magnet 105 has the same magnetic polarity as the inside wall surface of smaller diameter of magnet 117; the field is set up at the two electrodes tend to oppose each other and enhance the strength of the transverse component of the field which lies across each arcing surface. Both magnets exert a force on the arc 123 which cause the arc to rotate in an annular path between electrodes. It is to be noted that the forces exerted on the arc 123 by the two magnets are such as to add and cause the arc 123 to rotate in the same angular direction between electrodes.

In accordance with long-established practice, the permanent magnets may be solid or laminated solid magnets being shown for ease of illustration.

Particular reference is made to FIG. 6. Discrete radially extending peripherally spaced magnetic bars 150, which may extend perpendicular to the axis of the electrode, have all their inner ends of like polarity and all their outer ends of like polarity. A magnetic field transverse to the arcing surface and similar to fields 57 and 58, FIG. 1, is set up. Preferably the bars extend at least the major portion of the distance between the wall of smaller diameter of the tip and the wall of larger diameter of the tip.

In the arc heater of FIG. 5, the permanent magnet configurations and tip configurations of FIGS. 3 and 4 may be substituted for those shown.

The foregoing written description and the drawings are illustrative only and are not to be interpreted in a limiting sense.

We claim as our invention:

1. An electrode comprising, in combination, an electrode tip forming an arcing surface, the tip being hollow and generally cylindrical in shape, a supporting column for the electrode tip secured thereto, permanent magnet means mounted within the electrode tip and spaced from the adjacent inner wall surfaces of the tip at all points therearound to provide a passageway within the tip between the permanent magnet means and the wall of the tip for the flow of cooling fluid to conduct heat flux from the tip, the electrode being adapted to be connected to a terminal of one polarity of a source of potential to produce an arc from the tip to a surface of opposite polarity, the permanent magnet means within the tip setting up a magnetic field which is transverse to the arcing surface and which has lines of force which extend in a radial direction from the axis of the tip, said magnetic field exerting a force on the arc which causes the arc to move substantially continuously around the arcing surface of the tip.

2. An electrode according to claim 1 in which said tip is additionally characterized as being annular in shape and generally U-shaped in cross section with an outer wall portion of larger diameter and an inner wall portion of relatively smaller diameter, and the permanent magnet means is a single ring-shaped permanent magnet disposed within the tip and spaced therefrom to provide said fluid flow passageway, one magnetic pole surface of the permanent magnet being the inside annular wall of smaller diameter thereof and the other magnetic pole surface of the permanent magnet being the outside annular wall of larger diameter thereof, the permanent magnet setting up a magnetic field transverse to the arcing surface around the entire tip, said transverse magnetic field causing the arc therefrom to rotate.

3. An electrode according to claim 2 in which the supporting column is additionally characterized as including two radially spaced coaxially aligned tubes forming a cylindrical fluid flow passageway therebetween which communicates with the passageway within the tip, the inner of said tubes having at the lower end thereof a portion of substantially increased outside diameter with a bottom surface contoured to receive the upper surface of the permanent magnet and to support the permanent magnet in position within the tip.

4. An electrode according to claim 1 in which the permanent magnet means includes first and second radially spaced coaxially aligned annular permanent magnets oppositely poled with respect to each other in an axial direction, and diamagnetic spacer means interposed between the first and second permanent magnets, the first and second permanent magnets and the spacer means all being spaced from the adjacent wall portions of the tip to provide said fluid flow passageway.

5. An electrode according to claim 4 additionally characterized as having a coating of refractory material on the outside surface of the tip wall, said coating extending on the bottom of the tip inwardly a predetermined distance and terminating along a circular line a predetermined radial distance from the axis of the tip, additional refractory material covering the central portion of the bottom of the tip and extending a predetermined radial distance from the axis thereof to terminate in a circular line of smaller radius than said first named circular line to thereby form an exposed arcing surface portion of the tip annular in shape and of a predetermined width extending around the entire electrode, the arc from the tip taking place from said last-named portion, the magnetic field between the first and second permanent magnets extending transversely across said arcing surface portion.

6. In an electrode adapted to be connected to a terminal of one polarity to produce an arc to a surface of opposite polarity, of the type having a fluid-cooled tip generally annular in shape and generally U-shaped in cross section with an outer generally annular wall of larger diameter and an inner generally annular wall of smaller diameter, with magnetic field producing means in the tip for producing a field which exerts a force on an arc from the tip and causes said arc to move substantially continuously around the tip, the improvement which comprises a permanent magnet in the tip for setting up said magnetic field, the permanent magnet being spaced from adjacent inside wall surfaces of the tip to provide a passageway for the flow of cooling fluid, the permanent magnet being generally annular in shape with an outside wall of larger diameter and an inside wall of relatively smaller diameter, the outside wall of the magnet forming one magnetic pole around the entire periphery thereof and the inside wall of the magnet forming the other magnetic pole around the entire periphery thereof, the lines of force of the magnetic field extending generally radially from the axis of the magnet and transverse to the arcing surface.

7. In an electrode adapted to be connected to a terminal of one polarity to produce an arc to a surface of opposite polarity, of the type having a fluid-cooled tip generally annular in shape and generally U-shaped in cross section with an outer generally annular wall of larger diameter and an inner generally annular wall of smaller diameter, with magnetic field producing means in the tip for producing a field which exerts a force on an arc from the tip and causes said arc to move substantially continuously around the tip, the improvement which comprises permanent magnet means in the tip for setting up said magnetic field, the permanent magnet means consisting of a plurality of substantially axially aligned peripherally spaced bar magnets each extending in a radial direction from the axis of the tip and extending at least a major portion of the distance between the wall of smaller diameter and the wall of larger diameter of the tip, all of the bar magnets having the ends thereof adjacent the wall of smaller diameter of the same magnetic polarity and all of the bar magnets having the ends thereof adjacent the wall of larger diameter of the same opposite magnetic polarity, the lines of force of the magnetic field extending generally radially from the axis of the tip and transverse to the arcing surface.

8. In an electrode adapted to be connected to a terminal of one polarity to produce an arc to a surface of opposite polarity of the type having a fluid-cooled tip generally annular in shape and generally U-shaped in cross section with an outer generally annular wall of large diameter and an inner generally annular wall of relatively smaller diameter, with magnetic field producing means in the tip for producing a field which exerts a

force on an arc from the tip and causes said arc to move substantially continuously around the tip, the improvement which comprises permanent magnet means in the tip for setting up said magnetic field, the permanent magnet means including two radially spaced coaxially aligned permanent ring magnets each having axially spaced magnetic poles at the upper and lower surfaces thereof, the two ring magnets being oppositely poled with respect to each other, the ring members being spaced from adjacent inside wall surfaces of the tip to provide a passageway within the tip for the flow of cooling fluid, the magnetic lines of force between the lower magnetic pole of one ring magnet and the other opposite lower magnetic pole of the other ring magnet extending generally radially from the axis of the ring magnets and transverse to the arcing surface.

9. An electrode according to claim 8 including in addition a ring of iron or other ferromagnetic material extending between the top surfaces of both the ring magnets and forming a closed magnetic circuit between the upper poles of both ring magnets.

10. An electrode according to claim 8 including in addition ring spacer means composed of diamagnetic material interposed between and spacing the two ring magnets from each other, said spacer means being spaced from adjacent inside wall surfaces of the top and bottom of the tip.

11. An electrode comprising, in combination, a generally cylindrical electrode tip having at least a partially closed bottom and forming an arcing surface, the electrode tip having at least one space therein extending around the entire periphery of the tip, at least a portion of the space forming fluid passageway for the flow of cooling fluid to conduct heat flux from the arcing surface, at least one permanent magnet mounted in the tip and occupying at least some of the remainder of the space in the tip, and a supporting column for the tip secured thereto and including means for conducting fluid to and from the passageway in the tip, the electrode being adapted to be connected to a terminal of one polarity of a source of potential to produce an arc from the tip to a surface of opposite polarity, the permanent magnet within the tip

setting up a magnetic field which is transverse to the arcing surface and which has lines of force which extend in a radial direction from the axis of the tip, said magnetic field exerting a force on the arc which causes the arc to move substantially continuously around and over the arcing surface of the tip.

12. An electrode according to claim 11 in which the permanent magnet is ring-shaped with a substantially flat inner wall surface of smaller diameter and a substantially flat outer wall surface of larger diameter, the wall surfaces being substantially parallel to the axis of the electrode, the inner wall surface and the outer wall surface forming the opposite magnetic poles of the permanent magnet.

13. An electrode according to claim 11 including two radially spaced substantially axially aligned permanent magnets mounted within the space within the electrode tip, the axial end surfaces of both permanent magnets forming the magnetic poles thereof, the poles of one magnet being oppositely disposed with respect to the corresponding poles of the other magnet.

14. An electrode according to claim 13 including in addition diamagnetic means mounted between the two permanent magnets and spacing the same from each other.

15. An electrode according to claim 14 in which the diamagnetic means spacing the two permanent magnets is an epoxy resin.

16. An electrode according to claim 13 including in addition a coating of ceramic material covering at least a portion of the arcing surface to limit the width of the arc track as the arc moves around and over the arcing surface.

17. An electrode according to claim 13 including in addition a pole piece across the top ends of both permanent magnets forming a low reluctance path.

18. An electrode according to claim 11 in which the permanent magnet consists of a plurality of radially extending bar magnets disposed around the entire periphery of the tip at peripherally spaced intervals, all of the inner ends of the bar magnets being of like magnetic polarity.

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