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CONSUMABLE ANODE ELECTRODE ARC WELDING

Original Filed April 12, 1965

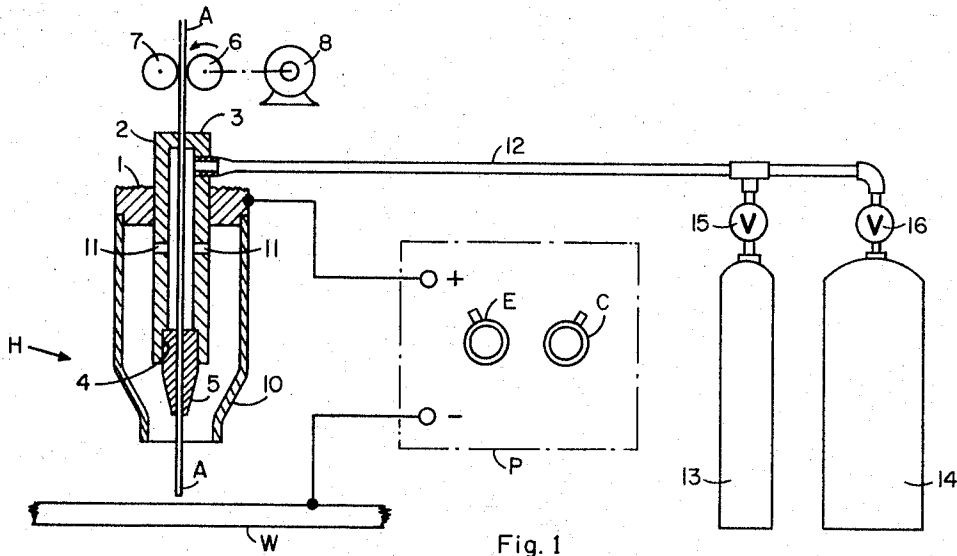


Fig. 1

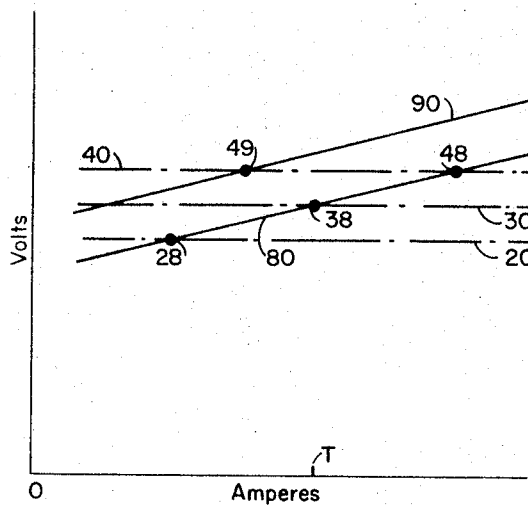


Fig. 2

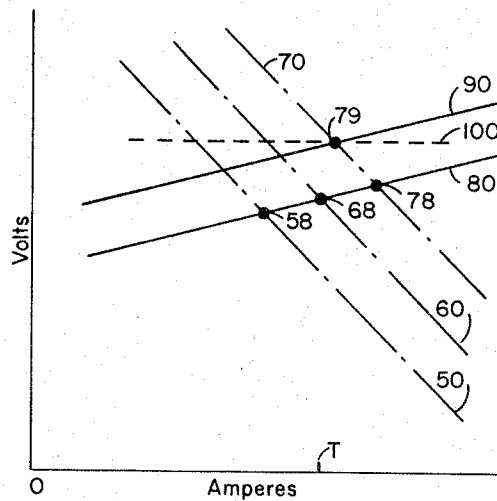


Fig. 3

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CONSUMABLE ANODE ELECTRODE ARC
WELDING

Charles T. Jacobs, Box 362, Bernardsville, N.J. 07924
Continuation of abandoned application Ser. No. 461,579,
Apr. 12, 1965. This application June 13, 1966, Ser.
No. 557,322

12 Claims. (Cl. 219—74)

This application is a continuation of my application Ser. No. 461,579, filed Apr. 12, 1965, and since abandoned, which in turn was a continuation-in-part of my application Ser. No. 446,570, filed Apr. 8, 1965, and since abandoned.

This invention relates to electric arc welding with a consumable anode electrode in a shielding atmosphere of gas.

In such welding with argon as the shielding gas it is known that at lower values of arc current the electrode material is transferred from the anode electrode to the work cathode as a succession of rather large globules and with rather weak force, while at higher values of arc current the electrode material is transferred as a spray of fine droplets and with relatively strong force—these contrasting transfers being commonly said to be of globular nature and of spray nature, respectively. In a process of increasing the arc current the transition from globular to spray transfer occurs when that current reaches a particular value (i.e., a value which is inherently predetermined by the basic parameters of the system, including the composition and diameter of the consumable anode electrode); it is an abrupt transition, which I have chosen herein to term a "snap-over" of the electrode-material transfer from the one to the other nature.

For many welding tasks an electrode-material transfer of spray nature is considered a highly desirable one. On the other hand in many of those tasks it is often for other reasons preferred to use a gas other than argon—but, with an anode electrode, efforts to achieve spray transfer with various other gases whose use would otherwise be preferred have failed; the transfer has remained globular no matter to what value the arc current has been increased. Among such other gases may be mentioned helium, often found preferable for reasons having to do with the work, and carbon dioxide, attractive for many tasks for reasons of economy. Sometimes such other gases have been mixed with argon, but when mixed in more than minor proportion they have foreclosed the ability to achieve spray transfer.

(The inability to achieve spray transfer with helium has been especially curious, in view of the fact that it, like argon, is an inert monatomic gas of the Zero Group of the Periodic Table.)

It is known that so long as the electrode-material transfer remains of a globular nature the anode end of the arc is simply the toward-the-work end of the electrode (or the toward-the-work surface of a globule formed at the end of the electrode)—but that when the transfer is of a spray nature the anode end of the arc is the whole end portion of the electrode, up to an approximate circle around the electrode at a distance from its end comparable with or even greater than its diameter, even though this results in a substantially greater average arc length. Insofar as I am aware the occupation by the arc of the whole end portion of the electrode has been considered an incident of the spray nature of the transfer. I have determined that it is the cause of that nature, and must itself in turn have been caused by a still more underlying impulsion. I have further determined that with an anode electrode in argon such more underlying impulsion is a sudden shift (occurring when the current becomes suffi-

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ciently high) of the ionization taking place in the anode-fall space, from ionization of the argon to ionization of vaporized electrode material. (In the case of spray transfer from an emissively coated cathode electrode, which is known to be achievable, the impulsion to occupation by the arc of the whole end portion of the electrode is no doubt the propensity of the arc to reach up for emissive coating—an obviously altogether different impulsion, though leading to a parallel result.)

It have observed that once there has occurred the shift of anode-fall-space ionization to ionization of vaporized anode material (a material which is obviously independent of the shielding gas) then thereafter the shielding gas may be changed, without destroying the spray nature of the anode-material transfer, to one in which spray transfer could not initially have been started—provided that throughout that change the arc current be maintained at least as great as the current at which the snap-over to spray transfer previously occurred.

My invention, accordingly, is one relating to electric arc welding with a consumable anode electrode in a shielding atmosphere consisting of gas in which a snap-over of the anode-electrode-material transfer to spray nature does not occur at any value of arc current, and the invention comprises the method of causing the anode-electrode-material transfer to be of spray nature which includes the steps of (1) establishing an anode-electrode-material transfer of spray nature in a shielding atmosphere consisting of gas in which snap-over of the transfer from globular to spray nature does occur when the arc current is raised to a particular value, and (2) thereafter, and while maintaining the arc current at least as great as said particular value, changing the shielding atmosphere to said first-mentioned atmosphere. Preferably, to provide a margin of safety and to guard against possible second-order influences, step (2) will be carried out while maintaining the arc current at least slightly greater than said particular value.

Since the combined positive-column and cathode-fall-space voltage drops may be greater in the first-mentioned gas than in the gas used in step (1) it may be desirable in step (1) to establish the arc current at a value substantially greater than said particular value. For allied reasons it may be desirable that at least during the performance of step (2) the arc current be supplied from a source having a substantially drooping volt/ampere characteristic. If to the arc of the final state of affairs it be desired that the arc current be supplied from a source having a less drooping, or a "constant potential" or even a rising, characteristic then subsequent to step (2) there may be performed the step of (3) shifting the output volt/ampere characteristic while continuing to maintain the arc current at least as great as said particular value. In a preferred practice of the invention the gas of which the shielding atmosphere referred to in step (1) consists may be argon.

Various objects of the invention have been made apparent in the foregoing brief description; allied and other objects will become apparent from the following detailed description and the appended claims.

In the detailed description reference is made to the accompanying drawing, in which:

FIGURE 1 is a simplified cross-sectional view of a welding head with which my invention may be practiced, together with a reduced-scale view of associated gas-supplying means and a schematic view of an associated power supply;

FIGURE 2 is a set of curves to which reference is made in describing the effects of a shift of shielding atmosphere when the power supply is of a "constant potential" variety; and

FIGURE 3 is a set of curves to which reference is made regarding a supply of a "drooping characteristics" variety.

Reference being had to FIGURE 1, there will be seen a fractional showing of a welding head H typical of that with which my invention may be employed. Therein 1 represents the bottom portion of a cylindrical element which may be supported in any convenient manner and which in turn supports the other illustrated portions of the head. Centrally through 1 there may extend the tubular member 2, which has an upper end element 3 centrally apertured to permit the passage therethrough of the consumable anode electrode A. At its bottom the member 2 may be formed to provide a socket 4 into which there may be inset an elongated tubular electrode-guiding-and-contacting member 5 through which the consumable electrode A passes axially. That electrode, which may be in the form of a wire, may be propelled downwardly through the element 3 and member 5 in any convenient manner; apparatus for propelling it has been schematically illustrated as a driving roller 6 and a backing roller 7 between which the electrode A is pinched, the driving roller 6 being itself driven by a suitable regulable-speed motor 8.

From the element 1 there may extend downwardly, for example to somewhat below the lower end of the member 5, a nozzle 10 into the interior of which there open ports 11 passing through the wall of the tubular member 2. Shielding gas may be fed into the interior of the member 2, from which it will pass through the ports 11 into the interior of the nozzle 10, through the tubular line 12. The line 12 is shown as supplied with gas from either of two cylinders 13 and 14 through respective regulating valves 15 and 16 each of which may be adjusted either to closed condition or to cause the supply from the respective cylinder of gas at any predetermined pressure.

Cooling of head H by water circulating in suitable jackets (not shown) may if desired be employed as known in the art.

Spacedly below the head H will be seen the work W, which is electrically connected to the negative output terminal of the power supply or "welding machine" P. The positive terminal of the power supply P is electrically connected to the element 1, and through it and the members 3 and 5 to the anode electrode A. On the power supply P there are shown two control knobs E and C, of which the former may be considered as commanding a control of the overall arc voltage and the latter as commanding a control of the volt/ampere characteristic of the power supply.

Other than possibly for the presence of a second cylinder and valve and of the control knob C, the apparatus as thus described will be recognized as conventional and its operation as well known. The valve 15 being adjusted to supply gas (for example argon) from cylinder 13 at a predetermined pressure, the power supply P being in operation, the anode electrode A being steadily propelled toward the work by the motor 8, and appropriate steps (themselves well known) having been taken to initiate an arc between the end of the electrode A and the work, such an arc—shielded by gas emerging from the nozzle 10—will be maintained and will progressively consume and transfer to the work the material of the anode electrode A. It will also be understood that if the gas from cylinder 13 be an appropriate one (for example argon) then as the control knob E is adjusted for progressively higher values of arc current the anode-electrode-material transfer will at some particular value of arc current snap over from a transfer of globular nature to one of spray nature, which will be maintained as the arc current is further increased. Unless that current be very greatly increased over the particular value abovementioned the spray will be essentially axial of the electrode A (though at extremely high current values it may, as is known, develop a rotating or corkscrew" tendency).

As introductorily stated, I have determined that with an anode electrode in argon the underlying impulsion which causes the arc to occupy the whole end portion of the electrode (rather than merely its end proper), of which occupation the spray transfer is in turn a result, is a sudden shift (occurring when the current becomes sufficiently high) of the ionization taking place in the anode-fall space, from ionization of argon to ionization of vaporized anode material. My explanation of this, and of why no corresponding shift occurs with such gases as for example helium or carbon dioxide, is as follows:

The anode-fall space, which makes up the most anodeward portion of the arc path, is one of relatively minute length along that path but of very high voltage gradient. In it there are required to be created by ionization not only ions but also enough electrons per unit of time so that, with the addition of those entering the anode-fall space from the electron cloud between that space and the positive column and after the subtraction of those which will recombine in that space, the net will be just that number of electrons per unit of time which equals the arc current (which at the anode itself is wholly an electron current). This creation of electrons by ionization requires the sufficiently strong acceleration of electrons into the anode-fall space from the electron cloud abovementioned, which in turn requires the arc to develop across the anode-fall space a voltage slightly in excess of the ionization potential of the most easily ionized atmospheric component in that space—unless that component be one characterized by a metastable potential, in which event the opportunity for ionization by successive impact affords a possibility that the arc need develop across that space only a voltage slightly in excess of that metastable potential. That possibility, however, can materialize only if the energy in the positive column—which the arc is inherently committed to maximize—will actually be greater in the case of the lower (metastable potential) voltage across the anode-fall space.

Argon, helium and carbon dioxide are respectively characterized by potentials as follows:

	Ar	He	CO ₂
E_i , Ionization Potential, volts.....	15.755	24.58	14.4
E_m , Metastable Potential, volts.....	11.55	20.96	None

There is good evidence that with an argon atmosphere the energy in the positive column is greater when the arc develops across the anode-fall space only a voltage slightly in excess of argon's metastable potential of 11.55 volts, while there are strong indications that with a helium atmosphere the energy in the positive column is greater when the arc develops across the anode-fall space a voltage slightly in excess of helium's ionization potential of 24.58 volts—and such voltages are therefore those to be expected across that space in those two respective cases. In the case of carbon dioxide, which has no metastable potential, the voltage to be expected across that space is of course one slightly in excess of carbon dioxide's ionization potential of 14.4 volts.

The implicit commitment of the arc to maximize the energy in the positive column may be shown to result in a maximum energy in any electrode reaching the anode as follows: (1) If the most easily ionized atmospheric component in the anode-fall space has no metastable potential, about $.05E_i$; (2) if that component has a metastable potential but the voltage across the anode-fall space is slightly in excess of its ionization, potential, about $1.05E_i - E_m$; and (3) if that component has a metastable potential and the voltage across the anode-fall space is slightly in excess of that metastable potential, about $2.05E_m - E_i$ —i.e., about $1.05E_m - [E_i - E_m]$.

Taking the data of the last two paragraphs collectively, it is apparent that the maximum energy of any electron reaching the anode is, when the most easily ionized at-

mospheric component in the anode-fall space is carbon dioxide, about 0.72 volt; when that component is helium, about 4.84 volts; and when that component is argon, about 7.92 volts.

Taking into account the fact that typical anode-electrode materials are not characterized by any metastable potentials, it is axiomatic that ionization of vaporized such anode-electrode material cannot be expected unless the energy of at least some electrons reaching the anode be at least equal to the ionization potential of that material. For typical anode materials the ionization potentials are: for aluminum, 5.984 volts; for nickel, 7.633 volts; for copper, 7.724 volts; for iron, 7.90 volts. It is immediately apparent that both in the case of carbon dioxide and in the case of helium (as the most easily ionized atmospheric component of the anode-fall space) the maximum energy of any electron reaching the anode is insufficient—but that on the other hand in the case of argon that maximum energy is sufficient—to ionize any of those typical anode materials. Herein lies the explanation for the fact that no snap-over to spray transfer can be achieved with such shielding gases as helium or carbon dioxide.

Reverting to the case of argon as the most easily ionized atmospheric component in the anode-fall space, by explanation of the snap-over itself is as follows:

Previously, to snap-over the anode end of the arc is only at the end of the anode. With increasing arc current and resultant increasing anode-electrode heating, an anode-electrode-temperature condition is reached at which anode-electrode-material atoms being to be vaporized from the anode and obviously they, while at an infinitesimal distance from the anode but nevertheless forming part of the atmosphere within the anode-fall space, will be susceptible to ionization by electrons reaching the anode with sufficient energy. It has just been seen that some electrons do reach the anode with sufficient energy to ionize those atoms—nevertheless no appreciable such ionization will at first take place since such ionization would divert from the anode the energy of electrons which would otherwise strike it at substantial velocity and contribute to its heating, and such diversion would cool the anode and thereby shut off the vaporization. But inevitably with increasing current there will be reached an anode-electrode-temperature condition at which the anode, even taking into account the diversion of energy which would result, will vaporize its material at a sufficient rate so that the arc could be maintained with ionization in the anode-fall space of vaporized anode-electrode material only. Then the arc is afforded an opportunity, by reducing the voltage across the anode-fall space from a voltage of slightly in excess of 11.55 volts (for example, from about 12.12 volts) to some voltage only slightly over the ionization potential of the anode-electrode material (for example to about 8.29 volts [i.e., 1.05 times iron's ionization potential] in the case of iron, and lower yet in the case of other typical electrode materials), greatly to increase the energy in the positive column. This opportunity the arc, in obedience to its inherent commitment to maximize the energy in the positive column, at once seizes.

The rate of vaporization of anode-electrode material from any one anode region being at this time limited, the arc in order to seize this opportunity spreads itself over a larger area, extending from the end of the electrode up onto its sides—the handsome addition to positive-column energy made available by the sudden lowering of the voltage across the anode-fall space having greatly weakened the constraint previously exerted by the arc's effort to maximize positive-column energy by keeping itself as short as possible. Herein lies the explanation for the introductorily mentioned spreading of the arc so that its anode end is the whole end portion of the anode electrode. The explanation of the itself-known phenomenon

of snap-over to spray transfer in an argon atmosphere may be briefly rounded out as follows:

Upon this sudden spreading of the discharge there is created the unusual condition of a single intense current having two sequential path portions intersecting each other at somewhere near a right angle—i.e., the current passing linearly along the anode-electrode's end portion and the electron flow passing principally radially toward that end portion. The linearly passing current sets up a strong circumferential magnetic field and the radially passing current (electron flow) cuts across that field. The situation thereby created is essentially the inverse of that set up in a moving coil-loudspeaker, in which the magnetic field is radial and a circumferential current cuts across it; the inversion makes no difference in the net result—which is an axial mechanical force on the element which carries the current relative to the element which sets up the magnetic field. It follows that the anode-fall space is subjected to such a force relative to the anode; obviously, that space cannot respond to that force by moving away from the anode, but it can and does respond by exerting a force on the surface layer of the anode electrode which tends to wrest away from the anode its detachable material and to propel that material toward the work. Herein lies as well the explanation for the force with which the spray transfer occurs.

I have observed that once the ionization in the anode-fall space has been shifted to ionization of the vaporized anode-electrode material then, so long as there is maintained an arc current sufficient to maintain the vaporization of sufficient anode-electrode material and the ionization of that material, the phenomena in the anode-fall space will be independent of the shielding gas. A sufficient such arc current is one equal to the current at which snap-over to spray transfer occurred in the first place. Thus according to my invention the shielding gas may be changed, from that (e.g., argon) in which it was initially possible to achieve snap-over to spray transfer, to one in which it would never have been possible to achieve such snap-over (e.g., helium or carbon dioxide), provided that during the change of shielding gas the arc current is maintained at least equal to the current at which snap-over to spray transfer initially occurred. Such a change will not destroy the spray nature of the anode-electrode-material transfer, or in other words will not entail the reversion of that transfer to one of globular nature.

The overall voltage across the arc is made up of the voltage across the anode-fall space, less the voltage representing the work function of the anode material, plus the voltage across the positive column plus the voltage across the cathode-fall space. It will of course be appreciated that when the shielding atmosphere is changed the last two of those voltages (though not the first two) will change, and it will further be appreciated in the light of the foregoing disclosure that, if not suitably allowed for, the change may frustrate compliance with the proviso of the preceding paragraph.

This matter may be conveniently elaborated with reference to FIGURES 2 and 3. In FIGURE 2 curve 80 is a typical volt/ampere characteristic of a consumable-anode-electrode arc of some particular arc length taking place in a shielding atmosphere of a gas, for example argon, in which snap-over to spray transfer does occur when the arc current is raised to a particular value of current designated on the scale of abscissae as T. Curve 20 is a volt/ampere characteristic of a typical "constant potential" power supply at a modest output-voltage adjustment; it intersects curve 80 at point 28, the abscissa of which represents the value of arc current which will flow with that voltage adjustment—and since that value is less than T, the anode-electrode-material transfer will be of globular nature. Curves 30 and 40 are volt/ampere characteristics of the same power supply at progressively higher voltage adjustments, curve 30 intersecting curve

80 at a point 38 whose abscissa is just T and curve 40 intersecting curve 80 at a point 48 whose abscissa is substantially greater. If the power-supply voltage be adjusted upwardly from that portrayed by 20 to that portrayed by 40, then it will be as it passes through the voltage portrayed by 30 that the snap-over to spray transfer will occur—and the transfer will continue to be of that nature as the voltage portrayed by 40 is approached and reached.

In the same figure curve 90 is a typical volt/ampere characteristic of a hypothetical arc in all respects similar to that of curve 80 excepting (1) that the shielding atmosphere is another gas (a) in which snap-over to spray transfer does not occur at any arc-current value and (b) whose combined positive-column and cathode-fall-space voltage is greater than that of the gas of curve 80, and (2) that the anode-fall-space voltage is limited to equality with that in the arc of curve 80 taken under spray-transfer conditions. [Still another curve, not shown, generally parallel with but itself higher than curve 90 would depict the characteristic of the same arc, then no longer a hypothetical one, in the absence of the last-stated specification (2).] Curve 90 is intersected by curve 40 at the point 49, whose abscissa is much less than T. If while the power-supply voltage is adjusted for the output characteristic of curve 40 the shielding gas be changed from that of curve 80 to that of curve 90, the arc current will undertake a reduction along curve 40 from the value represented by the abscissa of point 48 to that represented by the abscissa of point 49—but before the current reaches the latter value the electrode-material transfer will have changed from spray to globular (and the reduction of current will proceed to the still lower represented by the abscissa of the intersection between the curve 40 and the unshown curve last mentioned). It will do no good thereafter to increase the power-supply voltage to still more than portrayed by curve 40, since the gas of curve 90 is one in which no snap-over to spray transfer can ever occur.

The same curves 80 and 90, with the same significances, are reproduced in FIGURE 3. But in FIGURE 3, instead of curves 20, 30 and 40, there appear the curves 50, 60 and 70, which are drooping volt/ampere characteristics typical of a "drooping characteristic" power supply (of which the limiting case is of course a "constant current" power supply); they intersect the curve 80 at the respective points 58, 68 and 78, whose respective abscissae are less than, equal to and greater than T. Let it now be assumed that it is the curves 50, 60 and 70 of FIGURE 3 (rather than 20, 30 and 40 of FIGURE 2) which portray the output of the power supply P at various adjustments of the control knob E.

In analogy to the action above described for FIGURE 2 the electrode-material transfer with the power-supply adjustment portrayed by curve 50 will be globular; in further analogy, if the power-supply adjustment be changed from that portrayed by curve 50 to that portrayed by curve 70, then it will be as it passes through the adjustment portrayed by curve 60 that there will occur the snap-over of the electrode-material transfer to spray nature—a nature which will continue as the adjustment portrayed by curve 70 is approached and reached.

But, in contrast to FIGURE 2, curve 90 is now intersected by the highest-shown one of the three power-supply characteristics (i.e., by curve 70) at a point, 79, whose abscissa is of a value only modestly less than that of point 78 and—most importantly—greater than T. If now while the power supply is adjusted for the output characteristic of curve 70 the shielding gas be changed from that of curve 80 to that of curve 90 the arc current, undertaking a reduction along curve 70 from the value represented by the abscissa of point 78 to that represented by that of point 79, will reach the latter value while remaining above the value T and there will be no interruption of the spray nature of the transfer.

Obviously, the achievement of persistence of the spray nature of the transfer during the change of the shielding atmosphere has been contributed to by the establishment of the transfer in the first gas (e.g., argon) at a value substantially greater than the particular value at which it originally snapped over to spray transfer in the first gas (although that procedure, if solely relied on, would have required inordinately high-voltage and high-resulting-current adjustment in the "constant potential" case of FIGURE 2). It has also been contributed to by the drooping of the output volt/ampere characteristic of the power supply (which alone would be sufficient in the limiting "constant current" case). Preferably, and as illustrated by the curves of FIGURE 3, it is contributed to by both those factors jointly.

The drooping nature of the power-supply output volt/ampere characteristic above referred to is of importance, to the persistence of the spray nature of the transfer, only during the change of the shielding atmosphere; thereafter—so long as the value of the arc current be not permitted to fall below T—that drooping nature may be reduced, eliminated or even reversed into a rising characteristic (one or another of which may for some particular welding purpose be desirable). It is for that reason that I have shown the control C, whose appropriate adjustment after the change of shielding atmosphere may serve to shift the power-supply output volt/ampere characteristic from the drooping one portrayed by curve 70 toward, to or even beyond the "constant potential" characteristic portrayed in FIGURE 3 by the curve 100. During that adjustment of the control C the control E will of course if necessary be manipulated so as to maintain the arc current at and preferably somewhat above a minimum value of T.

Any of the gases referred to above, although there discussed as though it were an individual pure gas, may of course unless the context otherwise requires be a mixture of gases.

The ionization and metastable potentials (other than the ionization potential of carbon dioxide) set forth above for illustrative and comparative purposes are taken from page 7-14 of the American Institute of Physics Handbook (1957); the ionization potential of carbon dioxide has been taken from page 2649 of The Chemical Rubber Company Handbook of Chemistry and Physics (1962).

The designation of the anode as the electrode will be recognized as specifying what is commonly referred to in this country as "reverse polarity" (the use of which term throughout the specification has been avoided since it does not necessarily carry the same connotation in all foreign countries).

The cylinder 13 in FIGURE 1 has already been referred to as being typically for the supply, through the regulating valve 15, of a shielding atmosphere of such a gas as argon. The cylinder 14 may be one for the supply, through the regulating valve 16, of the gas (above described) in which a snap-over of the electrode-material-transfer to spray nature does not occur at any value of arc current. The valves 15 and 16 may if desired be suitably interlinked or integrated so that a single manipulation phases out the supply of gas from cylinder 13 and phases in the supply from cylinder 14—preferably while keeping the total gas pressure in the line 12 constant.

It will of course be understood that a gas other than helium or carbon dioxide may be the gas in which a snap-over to spray transfer does not occur at any value of arc current.

While I have disclosed my invention in terms of particular examples thereof I do not thereby intend any unnecessary limitations. Modifications in many respects will be suggested by my disclosure to those skilled in the art, and such modifications will not necessarily constitute departures from the spirit of the invention or from its scope, which I undertake to define in the following claims.

I claim:

1. In the electric arc-welding of work with a consumable anode electrode continuously advancing toward the work and in a shielding atmosphere consisting of gas in which a snap-over of the transfer of anode-electrode material to the work from globular to spray nature does not occur at any value of arc current, the method of causing the anode-electrode-material transfer to be of spray nature which includes the steps of (1) establishing, from the advancing electrode to the work, an anode-electrode-material transfer of spray nature in a shielding atmosphere consisting of gas in which snap-over of the transfer from globular to spray nature does occur when the arc current is raised to a particular value, and (2) thereafter, and while maintaining the arc current at least as great as said particular value, changing the shielding atmosphere to said first-mentioned atmosphere.

2. The subject matter claimed in claim 1 wherein the anode-electrode-material transfer established in step (1) is established at a value of arc current substantially greater than said particular value.

3. The subject matter claimed in claim 1 wherein the gas of which the shielding atmosphere referred to in step (1) consists is characterized by a combined positive-column and cathode-fall-space voltage less than that characterizing the gas of which said first-mentioned atmosphere consists.

4. The subject matter claimed in claim 1 wherein the gas of which the shielding atmosphere referred to in step (1) consists is essentially argon.

5. The subject matter claimed in claim 1 wherein the gas of which said first-mentioned atmosphere consists is essentially carbon dioxide.

6. The subject matter claimed in claim 4 wherein the gas of which said first-mentioned atmosphere consists is essentially carbon dioxide.

7. The subject matter claimed in claim 1 wherein the gas of which said first-mentioned atmosphere consists is essentially helium.

8. The subject matter claimed in claim 4 wherein the gas of which said first-mentioned atmosphere consists is essentially helium.

9. The subject matter claimed in claim 1 wherein at least during the performance of step (2) the arc current is supplied from a power supply whose output volt/ampere characteristic is a substantially drooping characteristic.

10. The subject matter claimed in claim 2 wherein at least during the performance of step (2) the arc current is supplied from a power supply whose output volt/ampere characteristic is a substantially drooping characteristic.

11. The subject matter claimed in claim 9 further including subsequent to said step (2) the step of (3) shifting the output volt/ampere characteristic of said power supply away from said substantially drooping characteristic while continuing to maintain the arc current at least as great as said particular value.

12. The subject matter claimed in claim 10 further including subsequent to said step (2) the step of (3) shifting the output volt-ampere characteristic of said power supply away from said substantially drooping characteristic while continuing to maintain the arc current at least as great as said particular value.

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35 RICHARD M. WOOD, *Primary Examiner*.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,309,491

March 14, 1967

Charles T. Jacobs

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 52, for "organ" read -- argon --; line 68, for "sill" read -- still --; column 3, line 2, for "characteristics" read -- characteristic --; line 75, for "corkscrew" read -- "corkscrew --; column 4, line 68, for "ionization," read -- ionization --; column 5, line 25, for "by" read -- my --; line 31, for "being" read -- begin --; column 6, line 13, for "moving coil-loudspeaker" read -- moving-coil loudspeaker --; column 10, line 24, for "volt-ampere" read -- volt/ampere --.

Signed and sealed this 21st day of November 1967.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents