

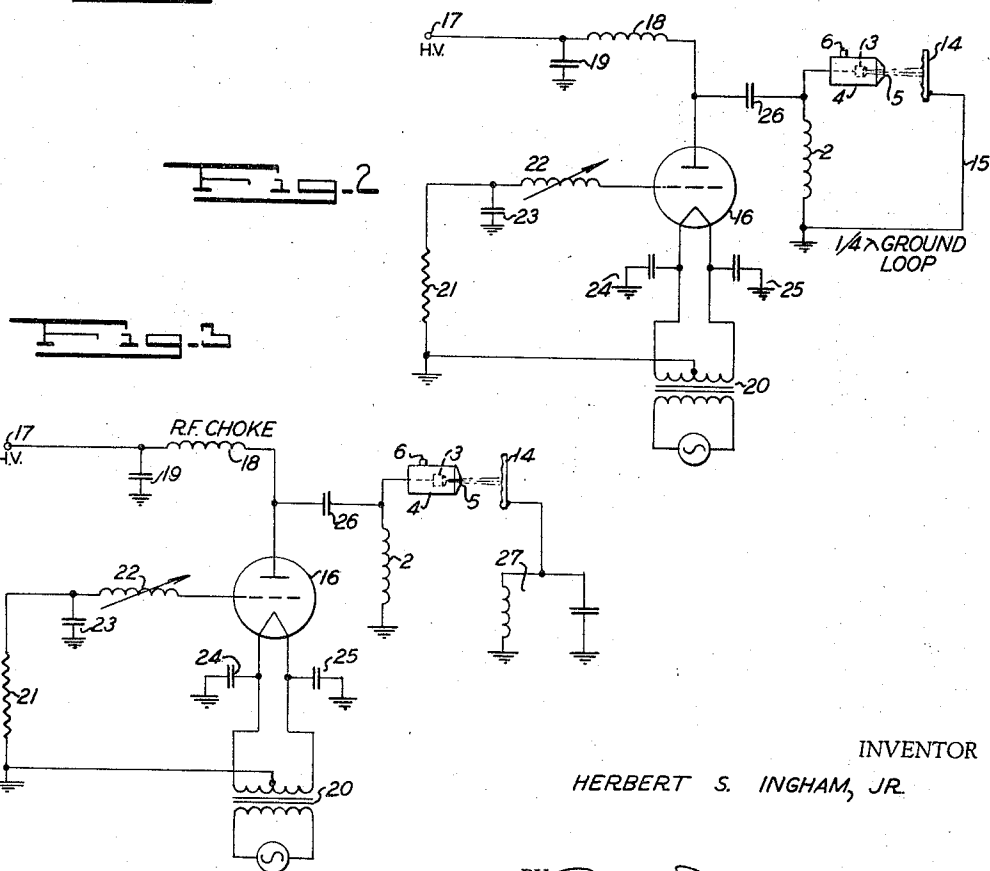
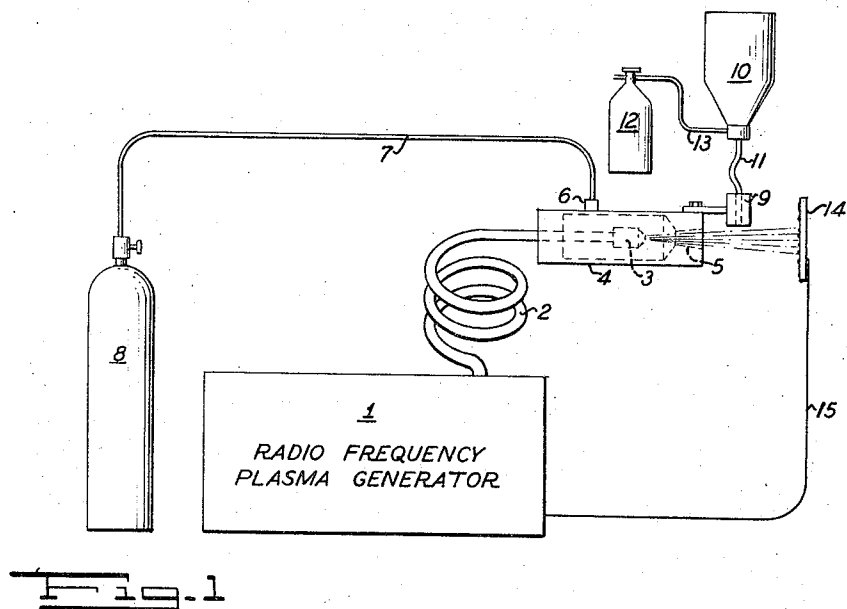
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RADIO FREQUENCY PLASMA FLAME SPRAYING

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RADIO FREQUENCY PLASMA FLAME SPRAYING

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This invention relates to radio frequency plasma flame spraying. The invention more particularly relates to a method and apparatus which allows the use of a radio frequency generated plasma flame as the heat source in flame spraying. The expression "radio frequency," or RF, as used herein has the usual meaning, and designates any frequency in the range from approximately 10 kilocycles per second to approximately 300,000 megacycles per second.

Flame spraying, which is sometimes referred to as metallizing, involves the spraying of a melted or heat-softened, heat-fusible material, such as a metal or ceramic, against the surface in order to form a coating. Flame spraying is widely practiced commercially and in industry in order, for example, to build worn surfaces on machine parts and the like and/or to provide protective or resistant coatings.

Flaming spraying is effected with a device known as a flame spray gun which must be provided with some means for heating the heat-fusible material to at least heat-softened condition. In the past the flame spray guns most commonly utilized a flame formed from burning a fuel, such as acetylene, propane or the like, generally utilizing oxygen. In more recent years in order to generate higher temperatures, flame spray guns have utilized plasma flames formed from an electric arc as the heat source. Such guns are commonly known as plasma flame spray guns. In these guns an electric arc is generally struck between a rod electrode and a nozzle electrode, and a plasma-forming gas is passed in contact with the arc, as for example constricting the arc, and out through the nozzle. The heat-fusible material, for example in the form of a powder, is introduced into the plasma thus formed and is heat-softened and sprayed thereby.

It is also known to generate a plasma by means of radio frequency, and devices which produce plasma in this manner are referred to as radio frequency plasma torches. In devices of this type a high-power radio frequency field is generated from an electrode or coil which excites and accelerates free electrons in a gas in this field, these electrons colliding with the gas molecules during each cycle, and thus generating the plasma flame. The flame is thus formed with little or no arcing from or to an electrode. The generator may produce the radio frequency field capacitively or inductively.

While radio frequency plasma torches are commercially available and have been proposed for use in various heating applications, the same have not proven suitable for flame spraying. When the heat-fusible material is introduced into the flames produced by these torches for spraying, it has not been possible to produce satisfactory spray coatings, and for example, it is not possible to cause the sprayed particles to be properly propelled toward or stick to the base.

One object of this invention is the utilization of a radio frequency generated plasma flame for flame spraying.

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This and still further objects will become apparent from the following description read in conjunction with the drawings in which:

FIG. 1 is a diagrammatic elevation, partially in section, showing an embodiment of an arrangement in accordance with the invention for flame spraying utilizing a radio frequency plasma generator;

FIG. 2 is a simplified circuit diagram showing an embodiment of a circuit useful for radio frequency plasma flame spraying in accordance with the invention, and

FIG. 3 is a further simplified circuit diagram showing a further circuit arrangement for radio frequency plasma flame spraying in accordance with the invention.

In accordance with the invention I have discovered that a radio frequency generated plasma flame, and preferably a flame which is capacitively induced, may be utilized for flame spraying if such a radio frequency plasma flame is directed against a surface to be sprayed, if the heat-fusible material to be sprayed is introduced into the radio frequency plasma flame; and if the surface being coated is coupled to the generator to form a second sympathetic oscillating circuit, causing diffuse RF arcing against the surface. The surface against which the plasma flame is directed is preferably one which has been roughened sufficiently to provide multiple electrical discharge points as higher RF voltages are required to cause the diffuse arcing to occur against a smooth surface.

The diffused RF arcing formed in this manner is believed to be a high voltage, low current arcing which will very rapidly heat the spray particles as they are being deposited on the base, causing a high bonding and even interfacial alloying without a detrimental heating of the base. The individual arc discharges forming the diffuse RF arcing are of extremely small time duration and transfer their heat almost instantaneously, thus imparting a superheat to the sprayed layer without detrimentally heating the base. This causes an excellent fusion of the depositing layers to the base, and the previously deposited layers, forming a dense coating which is often self-bonding and without the heat damage which would ordinarily occur if the layers were heated to the required temperatures in the conventional manner, with the usual transfer rate of the heat into the base raising the temperature thereof.

The radio frequency plasma generator useful in accordance with the invention may be of the known and conventional construction, and is preferably of the capacitance type in which the RF field is induced by capacitance from at least one electrode tip. For use in accordance with the invention a jacket or sleeve with a nozzle outlet should be provided around the discharge electrode of the generator, and a plasma-forming gas, for example a gas such as air or nitrogen and preferably argon, should be directed around the electrode and out through the nozzle. The RF plasma flame may be started in the conventional manner, for example by touching the electrode tip momentarily with a conductive object such as a wire at the end of a stick, and drawing the same off, or by feeding the spray powder into the gas stream. With the gas flow of the flame assumes the appearance of a long licking, soft flame, which may for example be directed horizontally for spraying. The heat-fusible material to be sprayed, such as metal or ceramic in the form of a rod, wire or preferably pow-

der, is introduced into this flame either before, within, or past the nozzle. The object to be sprayed is positioned so that the flame strikes the same and is coupled to the generator so as to form a secondary oscillating circuit which sympathetically oscillates at the same frequency as the plasma generator, but at a half cycle phase difference between the torch tip and the substrate, which will allow diffuse RF arcing against the surface. With the surface being sprayed roughened so as to provide multiple discharge points under the conditions described above, or with sufficiently high RF voltage, the characteristics of the flame will suddenly change to a hard, more intense flame, with the diffused RF arcing and with a substantial drop in the current being drawn from the power supply. The spraying then proceeds with the heat-fusible material depositing as a dense adherent coating which is often self-bonding. The spray may be distributed by moving the plate and the flame spray stream relative to each other by moving the plate and/or the electrode.

The surface roughening so as to provide the multiple electric discharge points may be effected by roughening the plate in any desired manner, for example by grit-blasting with angular steel grit with mesh size SAE G-25 blasted with compressed air at 100 p.s.i. through a $\frac{3}{8}$ " nozzle to produce a surface roughness approximately 200 microinches as measured with a "Profilometer." The exact degree of roughening required is determined by trial and depends on the RF voltage at the tip, the exact nature of the gas flow, the plasma flame temperature and the electrode-surface distance. Generally less or even no roughening is needed for higher RF voltage and/or shorter electrode-surface distance.

The coupling of the surface to the generator to form the secondary oscillating circuit, causing the diffused RF arcing, may be effected by suitably grounding the workpiece to the generator, forming a ground loop or path of a length which approximates one-fourth the wave length for the frequency of the generator or a multiple thereof. It is also possible to ground the workpiece through a tank circuit so as to provide the required ground loop oscillations.

With the suitable coupling of the workpiece to the generator by the appropriate ground loop, and with the other necessary conditions such as the roughened surface of the workpiece, the contacting of the workpiece with the soft RF plasma flame and the introduction of the heat-fusible material, the distance of the workpiece from the generator electrode required to initiate the secondary oscillations with the RF arcing will depend on the particular power output and will generally vary inversely therewith. The distance, however, may be very easily empirically determined as the initiation of these oscillations is readily determined by the change of the flame from the soft licking flame to the hard flame, the appearance of the RF arcing, and the current drop in the power supply. The workpiece may thus be moved slowly toward the electrode until these conditions occur.

Referring to the embodiment of FIG. 1 of the drawing, 1 represents a radio frequency plasma generator of conventional construction operating, for example, within a frequency range between 0.02 and 1000, and preferably 0.5 and 100 megacycles, and most preferably between 25 and 30 megacycles, with a power between 5 and 100, and preferably 10 and 40 kw. RF output. The tank coil 2 of the generator may be, for instance, constructed of concentric copper tubing, as for example, $\frac{1}{4}$ " and $\frac{1}{2}$ ", internally provided with water cooling. The end of the tank coil 2 terminates as a torch tip 3, which is conically tapered. The torch tip as shown is directed horizontally. Surrounding the torch tip 3 is a sleeve 4, for example of insulated, ungrounded metal and preferably of RF insulating material, for example polystyrene, which is provided with the outlet opening 5, the sleeve and the outlet opening forming a nozzle. A gas inlet 6 extends into the

rear portion of the sleeve 4 and is connected by means of the flexible hose 7 to the gas pressure supply tank 8 provided with a gas, as for example, air or nitrogen, or preferably argon. A powder feed nozzle 9 is attached to the sleeve 4 above, and in front of, the nozzle 5. A conventional powder feed device for flame spray guns, 10, is connected to the powder feed nozzle 9 by means of the flexible tube 11. A gas supply 12, as for example, a nitrogen bottle, is connected to the powder feed 10 by means of the line 13 in order to supply the carrier gas for the powder being fed. The workpiece, for example the roughened steel plate 14, is mounted in front of the nozzle 5 and is coupled to the generator 1 by means of the line 15.

One type of radio frequency plasma generator is shown in FIG. 2. This plasma generator is provided with an oscillator of the tuned plate, tuned-grid design. The plate of the oscillator tube 16 is connected to a high voltage D.C. source 17 through the radio frequency choke 18 provided with the grounded condenser 19. The filament of the oscillator tube is powered by means of the AC transformer 20 and a central tap from the secondary winding of the transformer provides the grid current for the tube through the resistor 21 and the grid coil 22. The grid circuit is provided with the grid by-pass condenser 23 which may constitute a number of condensers, in parallel, in order to handle the high currents in the grid circuit. The filament leads are by-passed by the condensers 24 and 25. The tank coil 2 is coupled to the plate circuit by means of the coupling condenser 26. The workpiece 14 is coupled to the oscillator through the ground loop 15, which is approximately one-quarter the wave length of the generator. Alternatively, as shown in FIG. 3, the coupling to form the secondary oscillating circuit may occur through the grounded L-C tank 27, or any other equivalent circuit.

In operation a high voltage (D.C.) source is connected at 17, and the transformer 20 powered with alternating current, for example from a conventional 60-cycle, 110-volt source. The induction of the grid coil 22 is adjusted to provide the required output. Gas is caused to flow from supply tank 8 through pipe 7 through the inlet 6 and out through the nozzle 4, 5. The torch is ignited by touching a wire to the torch tip 3 and withdrawing the same, which will produce a licking, soft flame. With the workpiece to be coated in position, this flame will spread over the surface of the workpiece. Powder to be sprayed is introduced through the powder feed nozzle 9, from the feeder 10, through the line 11, utilizing carrier gas from the source 12. With the coupling of the workpiece 14 to the generator, as shown, and with the surface of the workpiece sufficiently roughened to provide multiple electric discharge points, as the plate 14 is moved toward the nozzle 5, a point will be reached where the characteristics of the flame will suddenly change to a harder, thicker, more intense, more uniform flame, with a substantial drop in the power drawn from the power supply, for example a drop to as much as one-fourth or less. Fed powder will then deposit as a dense, adherent partially fused coating on the plate 14.

As a specific example the standard circuit illustrated in FIG. 2 is used, with the nozzle arrangement for the plasma flame as shown in FIG. 1. The generator operates at about 27 megacycles. The high voltage is provided with an Ecco High Frequency Corp. model PS-40 power supply, providing up to 10 kv., 4 ampere DC; and 115 volt, 60 cycle, alternating current is used for the transformer 20. The tank coil is cooled by supplying water to the outer concentric copper tubing and removing the same after flowing through the inner concentric tubing. The torch tip is $\frac{3}{8}$ " in diameter and the sleeve 4 is of polystyrene having a $\frac{3}{8}$ " ID., the entrance of the nozzle opening 5 is .218" diameter, the outlet .375" diameter, with conical tapering therebetween. As powder feed a Metco-type MP feeder is used, with a .093" diameter

powder feed orifice. As a workpiece a flat steel plate which was grit-blasted with SAE G-25 steel grit through a $\frac{3}{8}$ " nozzle at 100 p.s.i. air pressure is used. With the power supply on and with the argon supplied at about 200 cu. ft. per hour, the flame is ignited by touching the torch tip with a wire at the end of a stick. Without the workpiece in position the flame draws about 1 amp. at 6 kv. and is a long, soft licking flame. With the plate positioned so that it is struck and engulfed by the flame, the current rises to about 3-4 amps.

A spherical aluminum powder (Metco 54) is fed into the flame, using nitrogen as a carrier gas at 10 cu. ft. per hour, and with a powder feed rate of about 2 lbs. per hour. The sprayed powder simply bounces off the plate irrespective of the positioning of the plate with regard to the nozzle. The generator operates at about 27 megacycles. The workpiece is then coupled to the generator by means of a ground loop of a length between about 7 and 11 feet, roughly equal to about one-quarter wave length. The workpiece is then moved toward the nozzle, and at a distance of about 1", the characteristics of the flame radically changed to a thicker, more intense, more uniform looking flame, and the current draw drops to about 1 amp. The sprayed aluminum immediately begins depositing on the plate as a dense, partially fused, self-bonding coating and a uniform coating is built up by moving the plate in relationship to the nozzle, so that the surface thereof is uniformly covered. As soon as the ground loop is disconnected, the depositing of the spray ceases and the characteristic of the flame immediately changes.

The operation is then repeated with aluminum oxide, Metco 101 powder, and similar results are obtained. Additionally any of the conventional flame-spray materials may be sprayed on any desired metallic workpiece which may be conventionally flame-sprayed. In place of connecting the workpiece by means of the one-quarter wave length ground loop, a ground loop equal to an odd multiple of this may be used, or an equivalent connection may be effected by connecting the workpiece to ground through a suitably bound tank circuit, such as shown in FIG. 3.

While it was not possible to deposit a satisfactory sprayed coating with the normal flame produced by the radio frequency plasma flame generator with the equipment available, it would theoretically appear possible to effect a depositing of a sprayed coating with higher powered outputs. Nevertheless the invention offers a substantial advantage.

The plasma generator described herein is a specific example. Other types may be used, for example, the RF oscillations may be provided by a "magnetron" tube at the microwave frequency 2450 megacycles.

While the invention has been described in detail with reference to certain specific embodiments, various changes and modifications which fall within the spirit of the invention and scope of the appended claims, will become apparent to the skilled artisan. The invention therefore is only intended to be limited by the appended claims or their equivalents, wherein I have endeavored to claim all inherent novelty.

I claim:

1. A method for flame spraying with a radio frequency plasma which comprises flowing a gas and generating a radio frequency plasma flame from a radio frequency generator against a surface to be sprayed, introducing heat-fusible material to be sprayed into the radio frequency plasma flame, and coupling the surface to the generator through a path having an effective length approximately equal to a multiple of $\frac{1}{4}$ of the wave length of the radio frequency of the generator to form a secondary out of phase sympathetic oscillating circuit causing diffuse RF arcing against the surface thereby depositing the heat-fusible material on the surface.

2. Method according to claim 1 in which said coupling is effected through a ground loop.

3. Method according to claim 1 in which said coupling is effected through a ground loop having a length of about one-fourth the wave length of the radio frequency of the generator.

4. Method according to claim 1 in which the heat-fusible material is in the form of a powder.

5. Method according to claim 1 in which said coupling is effected through a sympathetic tank circuit connected to the surface.

6. Method according to claim 1 in which said radio frequency plasma flame is generated with an inert flowing gas.

7. Method according to claim 6 in which said inert gas is argon.

8. Method according to claim 1 in which said surface is roughened sufficiently to provide multiple electrical discharge points.

9. A method of flame spraying with radio frequency plasma which comprises directing a stream of gas toward a surface to be sprayed and capacitively converting said gas to a radio frequency plasma flame with radio frequency energy, introducing heat-fusible material to be sprayed into the flame, and maintaining said surface as part of a secondary out of phase sympathetic oscillating circuit causing diffuse RF arcing against the surface thereby depositing the heat-fusible material on the surface.

10. Method according to claim 9 in which said surface is maintained as part of an oscillating circuit by connecting said surface to the source of RF energy through a ground loop of an effective length approximating a multiple of $\frac{1}{4}$ the wave length of the radio frequency of the generator.

11. Method according to claim 9 in which said surface is maintained as part of an oscillating circuit by connecting the surface to the source of RF frequency through a ground loop having a length equal to about one-quarter of the wave length of the radio frequency.

12. Method according to claim 9 in which said stream of gas is an inert gas.

13. Method according to claim 9 in which said inert gas is argon.

14. Method according to claim 9 in which said heat-fusible material is in the form of a powder.

15. Method according to claim 9 in which said surface is connected to a grounded, tuned L-C tank circuit.

16. A radio frequency plasma torch having a torch tip capable of capacitively generating a radio frequency plasma flame, means for passing a stream of gas past said torch tip for conversion to a radio frequency plasma flame, means for introducing heat-fusible material to be sprayed into the plasma flame, and means for coupling a workpiece to be sprayed to the radio frequency plasma torch to form a secondary sympathetic oscillating circuit capable of causing diffuse RF arcing against such workpiece.

17. A torch according to claim 16 in which said means for passing heat-fusible material is means for passing powdered heat-fusible material.

18. In combination with a radio frequency plasma torch having a torch tip capable of capacitively generating an RF plasma flame, a nozzle of RF insulating material surrounding said tip, means for introducing a gas stream into said nozzle for flowing therethrough and conversion by the torch tip to an RF plasma flame, means for introducing heat-fusible material into the RF plasma flame, and means for coupling a workpiece to be sprayed to the plasma torch through a ground loop of about one-quarter the wave length of the radio frequency.

19. In combination with a radio frequency plasma torch having a torch tip capable of capacitively generating an RF plasma flame, a nozzle of RF insulating material surrounding said tip, means for introducing a gas

stream into said nozzle for flowing therethrough and conversion by the torch tip to an RF plasma flame, means for introducing heat-fusible material into the RF plasma flame, and means for coupling a workpiece to be sprayed to the radio frequency plasma torch, forming therewith a sympathetic secondary oscillating circuit capable of causing diffuse RF arcing against the workpiece so connected.

20. Combination according to claim 19 in which said

means for introducing heat-fusible material is means for introducing fusible powder.

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