219-121 SEARCH ROOM

Dec. 7, 1965 K. C. RICHARDS 3,222,568

CONTROL OF PLASMA

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FIG. 1

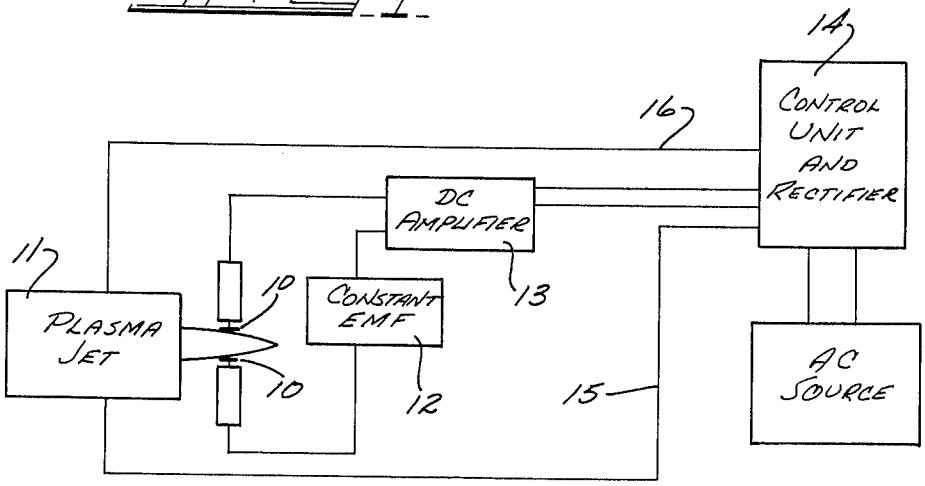
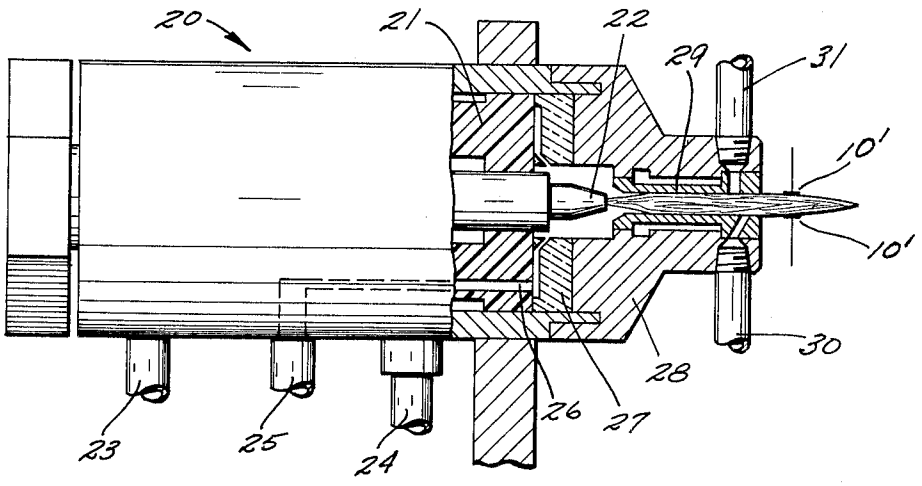


FIG. 2



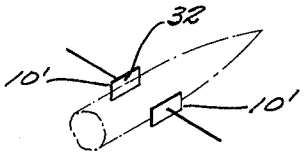


FIG. 4

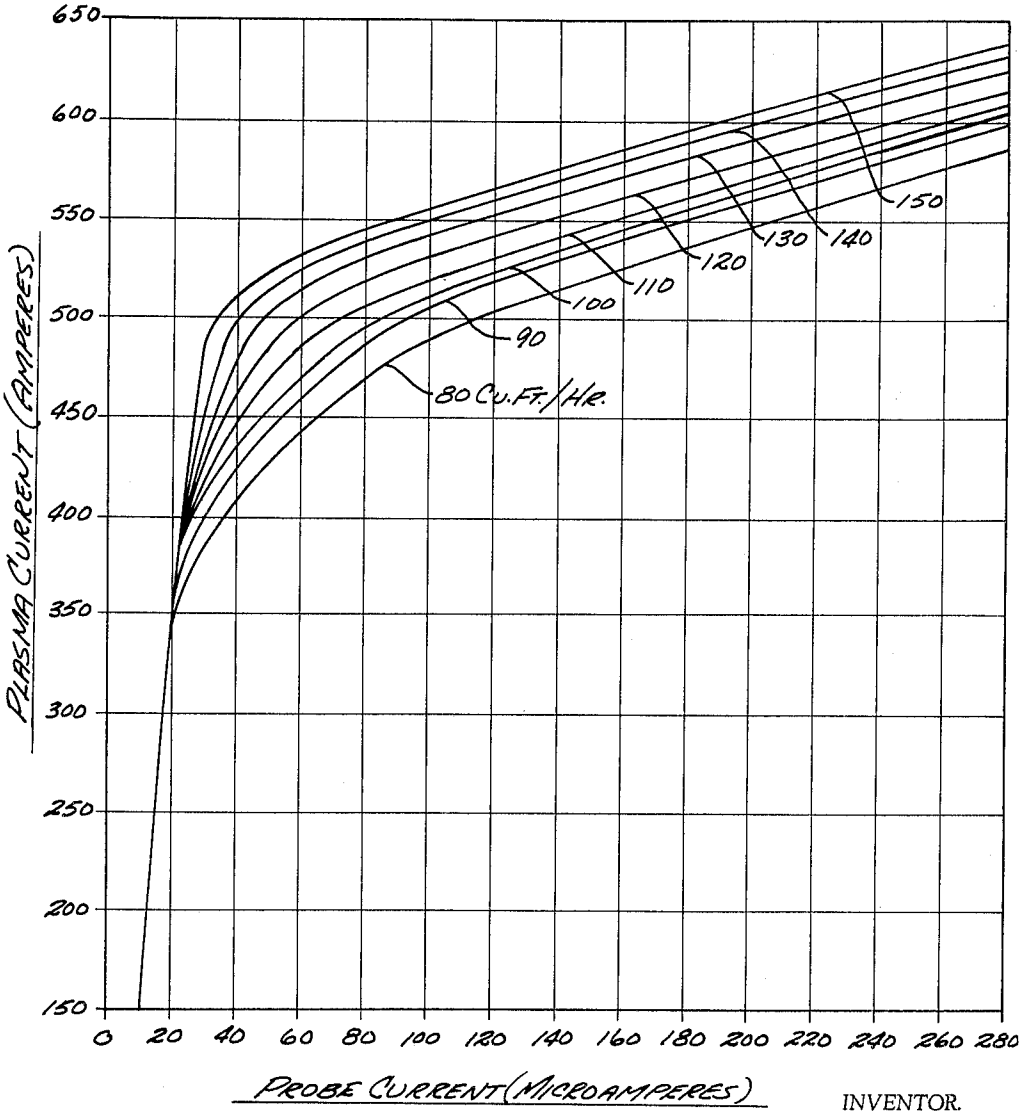
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FIG. 2



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3,222,568

CONTROL OF PLASMA

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6 Claims. (Cl. 315—111)

This invention relates to the generation of plasma and particularly to the problem of controlling plasma.

In the utilization of a plasma flame or jet, it is desirable to maintain the heat content and ionization level of the plasma jet substantially constant. It has heretofore been suggested that this might be achieved indirectly by measuring the temperature of the plasma jet and controlling the generation of the plasma jet in response to variations in temperature. However, such a control has not been found to produce proper control.

It is an object of this invention to provide a method and apparatus for controlling the generation of a plasma jet and maintaining the heat content and ionization level of the plasma jet substantially constant.

It is a further object of the invention to provide an apparatus which is relatively simple and low in cost.

In the drawings:

FIG. 1 is a diagrammatic view of a plasma generator system embodying the invention.

FIG. 2 is a part sectional view of a plasma generator embodying the invention.

FIG. 3 is a set of curves of plasma current versus probe current in an apparatus embodying the invention.

FIG. 4 is a schematic, perspective view of the electrodes of FIG. 2.

Referring to FIG. 1, the invention comprises positioning a pair of oppositely disposed probes **10**, such as platinum electrodes, in a comparatively cool portion of the plasma jet that is generated by plasma generator **11**. The electrodes **10** are connected in a circuit including a constant source **12** of voltage. Variations in current flow between the electrodes **10** are amplified by a direct current amplifier **13** and utilized to activate a control system **14** which controls the application of electric power through lines **15**, **16** to the plasma generator **11**. The control unit utilized in the device **14** preferably comprises a saturable core reactor to which the amplified and reversed polarity current from the direct current amplifier **13** is applied.

If, for example, a reduction in current between the electrodes **10** is noted, the control unit and rectifier **14** causes an increase in application of electric power to **11**, in turn, increasing the generation of plasma and bringing the electric current between the electrodes **10** back to its original level. If the current between the electrodes **10** increases, the electric power applied to the plasma generator **11** is decreased to return the current between the electrodes **10** to its original value.

It can thus be seen that, in accordance with the invention, the current between the electrodes **10** is maintained substantially constant. Since the current between the electrodes will depend upon the ionization level of the plasma jet, it is thereby possible to directly control the ionization level of the plasma jet. Further, since the heat content of the plasma jet is a function of the ionization level, in accordance with the invention, the heat content of the plasma jet as well as the ionization level is being controlled.

It is thus possible in any specific application of the plasma jet to maintain the ionization level and heat content substantially constant. For example, in spheroidizing and crystal growth, the heat content is the major condition which causes variations in the product and it is possible with the present invention to maintain the heat content substantially constant and thus accurately control the major production parameter. In chemical synthesis,

ionization is an important consideration and it is possible with the present invention to maintain ionization substantially constant or accurately control the ionization level.

For any particular application of the plasma jet system embodying the invention, the system must be calibrated. Thus, for any spheroidizing, crystal growth or chemical synthesis application, a set of calibration curves must be established, as presently described.

Referring to FIG. 2, a typical plasma generator **20** comprises that known as an F–40 plasma flame torch made by Thermal Dynamics Corporation of Lebanon, New Hampshire. Such a generator **20** consists of a main brass body in which a nylon body **21** is mounted and supports a cathode **22** which may comprise 2 percent thoriated tungsten. A cooling water inlet and cathode connection **23** is provided on the body **20** and a cooling water outlet and anode connection **24** is also provided on the body **20**. The plasma gas inlet **25** provides gas through a passage **26** adjacent a ceramic gas ring **27** to the area of the cathode **22**. A nozzle anode **28** is provided adjacent and surrounding the plasma jet that is formed. This anode **28** carries an internal copper sleeve **29**. The generator **20** includes inlets **30**, **31** adjacent the periphery of the plasma jet through which various ingredients that are to be acted upon by the plasma jet can be introduced. In accordance with the invention, the electrodes **10^1** are provided adjacent the periphery in a relatively cool portion of the plasma jet.

As shown in FIG. 4, the electrodes **10^1** are preferably rectangular in shape and have flat surfaces **32**.

The aforementioned description of the plasma generator shown in FIG. 2 is conventional and well known in the art, except for the electrodes **10^1**.

In a typical example of a plasma generator system embodying the invention, a pair of electrodes **10^1** having a dimension of one-eighth inch by one-quarter inch were positioned a half inch in front of the nozzle with a gap between the electrodes of about three-eighths inch. The plasma generator had a voltage of 160 volts applied thereto and argon gas supplied at varying rates. FIGURE 3 is a plot of curves obtained by maintaining the plasma generator at 160 volts and systematically varying argon flow rate from 80 cubic feet per hour to 150 cubic feet per hour.

It can be appreciated that for any particular operation wherein added materials are being fed through inlets **31** to the plasma generator, a new set of calibration curves will have to be developed which will be applicable to the new conditions.

I claim:

1. In a plasma generator wherein a plasma jet is formed and maintained between a cathode and an anode by the application of electric power to the cathode and anode, a control device comprising

a pair of oppositely disposed electrodes adapted to be placed in a relatively cool portion of the plasma jet,

means for measuring variations in conductivity across said electrodes when the electrodes are in position,

and means for controlling the current flow between the cathode and anode of the plasma generator in response to variations in conductivity between the electrodes to maintain the current between the electrodes substantially constant and, in turn, the ionization level and heat content of the plasma jet constant.

2. In a plasma generator wherein a plasma jet is formed and maintained between a cathode and an anode by the application of electric power to the cathode and anode, a control device comprising

a pair of oppositely disposed electrodes adapted to be placed in a relatively cool portion of the plasmas jet,

means for applying a substantially constant voltage across said electrodes,

means for measuring variations in conductivity across said electrodes when the electrodes are in position, and means for controlling the current flow between the cathode and anode of the plasma generator in response to variations in conductivity between the electrodes to maintain the current between the electrodes substantially constant, and in turn, the ionization level and heat content of the plasma jet constant.

3. In a plasma generator wherein a plasma jet is formed and maintained between a cathode and an anode by the application of electric power to the cathode and anode, a control device comprising

a pair of oppositely disposed electrodes adapted to be placed in a relatively cool portion of the plasma jet,

means for applying a substantially constant voltage across said electrodes,

means for measuring variations in conductivity across said electrodes when the electrodes are in position,

means for increasing the current flow between the cathode and anode of the plasma generator in response to reductions in the conductivity of the plasma jet and for decreasing the current flow between the cathode and anode in response to increases in the conductivity of the plasma jet in order to maintain the conductivity of the plasma jet substantially constant and, in turn, the ionization level and heat content of the plasma jet constant.

4. The combination set forth in claim 3 wherein said last-mentioned means comprises a saturable core reactor.

5. In a plasma generator wherein a plasma jet is formed and maintained between a cathode and an anode by the application of electric power to the cathode and anode, a control device comprising

a pair of oppositely disposed electrodes adapted to be placed in a relatively cool portion of the plasma jet,

means for measuring variations in conductivity across said electrodes when the electrodes are in position,

means for increasing the current flow between the cathode and anode of the plasmas generator in response to reductions in the conductivity of the plasma jet and for decreasing the current flow between the cathode and anode in response to increases in the conductivity of the plasma jet in order to maintain the conductivity of the plasma jet substantially constant and, in turn, the ionization level and heat content of the plasma jet constant.

6. In a plasma generator wherein a plasma jet is formed and maintained between a cathode and an anode by the application of electric power to the cathode and anode, a control device comprising

means for applying a substantially constant voltage across a relatively cool portion of the plasma jet,

means for measuring variations in conductivity across said relatively cool portion of the plasma jet,

and means for controlling the current flow between the cathode and anode of the plasma generator in response to variations in conductivity to maintain the current across the relatively cool portion of the plasma jet substantially constant, and, in turn, the ionization level and heat content of the plasma jet constant.

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