

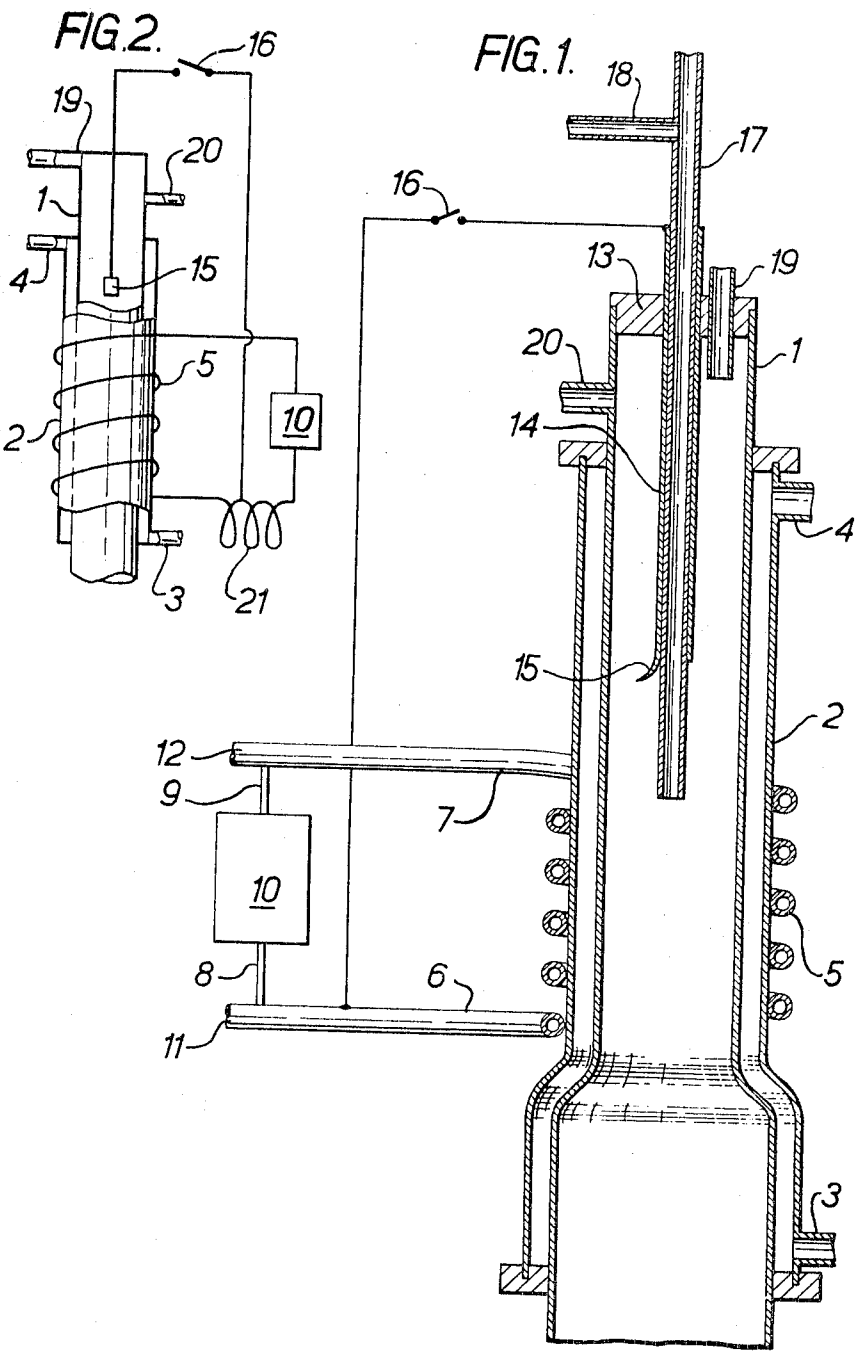
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INDUCTION COUPLED PLASMA GENERATORS

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INDUCTION COUPLED PLASMA GENERATORS
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The present invention relates to induction coupled plasma generators.

A known induction coupled plasma generator operates by passing a stream of gas, suitably confined in a tube, through an induction coil which is arranged to be connected to the output of a radio frequency generator. Hereinafter such plasma generator will be referred to as "a plasma generator of the type described." The gas may be at a pressure of the order of one atmosphere and in a typical case the generator may supply about 6 kw. of power at a frequency of 2.4 mc./s. (which will suffice to form and maintain a plasma in a gas such as argon flowing through a tube of 1" internal diameter. A use for such a plasma generator is described in our French Patent 1,328,697.

In order to initiate the plasma discharge in an arrangement as described in said patent, it is necessary to insert a mass of graphite or some similar refractory conducting material within the field of the coil and then to withdraw it when the plasma discharge forms. It appears that the mass of graphite is heated by the coil and generates a sufficient number of ions under the voltage gradients in the coil field to initiate the plasma discharge which then becomes self-sustaining due to the very high temperature. It is inconvenient for many purposes to have to withdraw the graphite from the vicinity of the plasma discharge after the discharge has been initiated and consequently it is an object of the present invention to provide an alternative means for initiating plasma discharges of the above described induction coupled type.

According to the present invention there is provided a method for the initiation of a plasma discharge in a plasma generator of the type described comprising mo-

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mentarily connecting an electrically conducting body located upstream of the induction coil to the end of the induction coil which is furthest removed from said conducting body.

According to a further aspect of the present invention there is also provided a plasma generator of the type described with an electrically conducting body located within the generator upstream of the induction coil (of the said plasma generator), and means to connect said conducting body to the end of the induction coil which is furthest removed from said conducting body.

The conducting body may be arranged to be connected directly to said end of the induction coil or by way of a portion of a second coil which is connected in series with the induction coil.

The term "upstream" refers to the direction of gas flow in the tube within the induction coil. However, it should be appreciated that the plasma discharge generators with which the present invention is concerned operate at substantially atmospheric pressure, and thus it is normal that the tube within which they are generated should be substantially vertical, for otherwise, the very high temperature involved might cause melting of the tube, and consequently the induction coil which normally surrounds the tube also has its axis generally vertical. Consequently the electrically conducting body which is located upstream of the induction coil and which may, for example, be of tungsten or carbon, may be located vertically above the induction coil. The advantage of the present invention is that the conducting body may be located sufficiently far away from the induction coil to prevent it being necessary to remove the conducting body when the plasma has been initiated. It is thought probable that a discharge takes place between the electrically conducting body and the upper part of the coil somewhat in the manner of a capacitive discharge and that this discharge provide a sufficiency of ions to initiate the induction coupled plasma.

It has been found moreover that the present invention permits the initiating and maintaining of the plasma discharge in larger tubes than has hitherto been possible with the same radio frequency generator and the following figures illustrate the result of comparative experiments.

Minimum striking requirements of induction coupled plasma

Internal Dia. and type of Torch	Ordinary Method						
	Before Starting			After Starting			
	V ₁	V ₂	C	V ₁	V ₂	C	P
1" aircooled.....	4.3	4.2	1.0	1.8	4.0	1.9	3.6
1" water cooled.....	8.2	7.0	1.2	2.0	6.8	>4	19.6
1 1/4" aircooled.....				Pulled overload on striking			
2 1/2" aircooled.....				Not started			

Internal Dia. and type of Torch	New Method						
	Before Starting			After Starting			
	V ₁	V ₂	C	V ₁	V ₂	C	P
1" aircooled.....	3.2	3.2	0.7	1.8	3.1	0.98	0.9
1" water cooled.....	4.8	4.2	0.72	2.5	4.2	1.6	3.6
1 1/4" aircooled.....	3.2	3.22	0.62	1.5	3.1	1.1	1.57
2 1/2" aircooled.....	2.8	2.6	0.38	1.2	2.6	0.55	.35

where:

V_1 =Peak kilovolts R.F. across coil using capacitance and resistance voltage divider. Harmonics believed to be negligible from wave form.

V_2 =D.C. kilovolts in power supply.

C =Total D.C. anode current in amps.

P =Approximate additional power in kilowatts supplied to oscillator valves due to presence of plasma.

A further feature of the present invention is that the conducting member may be connected to a tapping on a further coil connected in series with the induction coil. The importance of this is that in many cases the induction coil acts as the tank coil of the radio frequency generator and the very high coupling in the induction coil when the plasma discharge is present may cause difficulties in the operation of the generator. If the load on the generator is formed by two coils in series as suggested then without the arrangement of the present invention it becomes difficult to initiate the plasma, due to the lower voltage which appears across the induction coil.

In order that the invention may more readily be understood, two embodiments of the same will now be described by way of example and with reference to the accompanying drawings in which:

FIG. 1 is a diagrammatic section showing the associated electrical circuit using a single coil.

FIG. 2 is a diagrammatic representation of the apparatus using a split coil.

Referring firstly to FIG. 1 the plasma generator comprises a vertical silica tube 1, which is widened out in a "bell" shape at its lower end. The tube 1 is surrounded for the greater part of its length by a water jacket 2, having inflow and outflow pipes 3 and 4 respectively, the water jacket 2 also being "bell" shaped to correspond to the shaping of the tube 1.

A coil 5 of hollow copper tubing surrounds the water jacket 2, the coil 5 being placed immediately above the "bell" shaped lower end of the water jacket 2. Although only five turns are shown, a larger number of turns is preferred, ten turns being a convenient number. The ends 6 and 7 of the coil 5 are connected by leads 8 and 9 to a suitable radio frequency generator 10. Also connected to the ends 6 and 7 of the coil 5 are water inlet and outlet connections 11 and 12, so that cooling water may be supplied to the coil 2.

The top of the tube 1 has a plug 13 sealed thereto, this plug 13 having an axial bore into which is sealed a brass sleeve 14 which terminates a short distance above the coil 5 and which carries at its lower end a tungsten probe 15. At its upper end, the sleeve 14 is connected through a switch 16 to the lower end 6 of the coil 5. A silica tube 17 passes co-axially through the sleeve 14, and terminates in the region of the upper end 7 of the coil 5.

The tube 17 is sealed to the sleeve 14 and may be connected to a vibrating hopper (not shown) which contains, in powder form, the material which is to be treated within the plasma. The tube 17 is provided with a side arm 18, through which a suitable gas, for example, argon, may be introduced and mixed with the powder, prior to its passing into the plasma. The plug 13 also carries a gas inlet connection 19, through which the gas producing the plasma is passed. It may also be considered desirable to provide a gas inlet connection 20 to the top of the tube 1 above the water jacket 2, the gas passing through the connection 20 providing a blanket between the plasma and the tube 1.

In order to use the apparatus, the gas flow through the connections 18, 19 and 20 is turned on and the flow of cooling water through the water jacket 2 and coil 5 is started. The radio-frequency supply to the coil 5 is then turned on and the plasma is initiated by momentarily closing the switch 16. When the switch 16 is closed the probe 15 is electrically connected to the lower end 6 of the coil 5 and the plasma is initiated very quickly. Once the plasma has been set up, the connection between the

probe 15 and the coil 5 may be broken, and the switch 16 is therefore opened. The closing and opening of the switch 16 may be done manually or it may be preferred to do it automatically, in which case a photo cell may be focused on the region of the generator in which the plasma is to be induced, such photo cell being electrically connected to the switch 16 in such a manner that the increase in the intensity of illumination of the cell caused by the initiation of the plasma causes the switch 16 to be opened.

In FIG. 2, the generator is shown in a simple diagrammatic form, the detailed construction being as for the generator hereinbefore described, corresponding parts being similarly numbered. The coil 5, which acts as the tank coil of the radio frequency generator 10, is connected in series to a second coil 21. The coils 5 and 21 will each have a given impedance which will depend on the nature of the coil itself. When a plasma is established in the coil 5 there will be a certain amount of coupling between the coil and the plasma and this will affect the effective inductance of the coil 5. The inductance of the coil 21 will however remain constant and thus the total inductance will not change by the same relative amount with the two coils present, than if only coil 5 had been in the circuit. Since changes in the inductance will tend to affect the frequency, the effect will be less with the coil 21 present than if it were absent. The coil 21 will therefore be effective to keep the frequency more constant than would be the case with coil 5 alone, although it will not necessarily ensure that the frequency is constant. The coil 21 thus reduces variations in the frequency. The coil 21 may consist of 2 or 3 turns 9-12 inches diameter. The conducting probe 15 is connected through the switch 16 to a tapping on the coil 21, the tapping being in a position such as to obtain a suitable voltage for the initiation of the plasma discharge. The method of operating this apparatus is as hereinbefore described with reference to a plasma generator having only one coil.

Once the plasma has been initiated, either generator may be used in a manner similar to that described in our said patent.

It should be noted that the arrangement with a split coil is conveniently used in the larger diameter, for example about 2 inches diameter, generators, whilst the arrangement with a single coil may be applied to the smaller generators.

I claim:

1. An induction coupled plasma generator comprising a tube, an induction coil arranged to be connected to the output of a radio frequency generator, said induction coil surrounding part of the said tube, means to introduce a stream of gas into said tube, means having an outlet to introduce a stream of particulate solid into the said tube in the vicinity of the induction coil, an electrically conducting body located within said tube and upstream of both the said outlet and said induction coil and means to connect said conducting body directly to the end of the induction coil which is furthest removed from said conducting body.

2. An induction coupled plasma generator according to claim 1 in which said electrically conducting body is made of tungsten.

3. An induction coupled plasma generator according to claim 1 in which said electrically conducting body is made of carbon.

4. An induction coupled plasma generator comprising a tube, an induction coil arranged to be connected to the output of a radio frequency generator, said induction coil surrounding part of said tube, a second coil connected in series with said induction coil, means having an outlet to introduce a stream of gas into said tube in the vicinity of the induction coil, means to introduce a stream of particulate solid into said tube, an electrically conducting body located within said tube and upstream of both the said outlet and the said induction coil, and means to connect said conducting body through a portion of said second

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coil to the end of said induction coil which is furthest removed from said conducting body.

5. An induction coupled plasma generator according to claim 4 in which said electrically conducting body is made of tungsten.

6. An induction coupled plasma generator according to claim 4 in which said electrically conducting body is made of carbon.

7. A method of initiating a plasma discharge in an induction coupled plasma generator which comprises the steps of passing a gas in which the plasma is to be established along the central axis of an induction coil, passing a high frequency alternating current through said induction coil, passing the high frequency alternating current through a second coil having a tapping connected in series

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with the said induction coil, connecting a body located in the gas flow upstream of the induction coil to said tapping, the tapping being located at the end of the induction coil furthest removed from said body and disconnecting the body from the coil when the plasma has been initiated.

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