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Boom

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[54] APPARATUS FOR HEAT TREATMENT OF SUBSTRATES

[75] Inventor: Abraham A. Boom, Martinsville, N.J.

[73] Assignee: Celanese Corporation, New York, N.Y.

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Primary Examiner—C. L. Albritton

Assistant Examiner—Gale R. Peterson

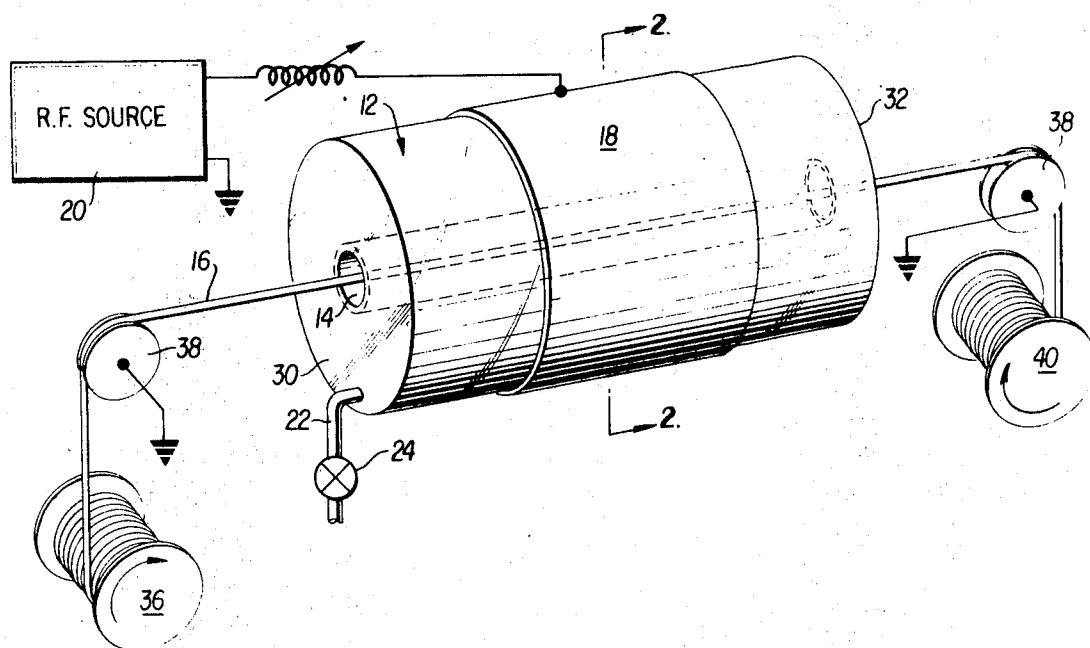
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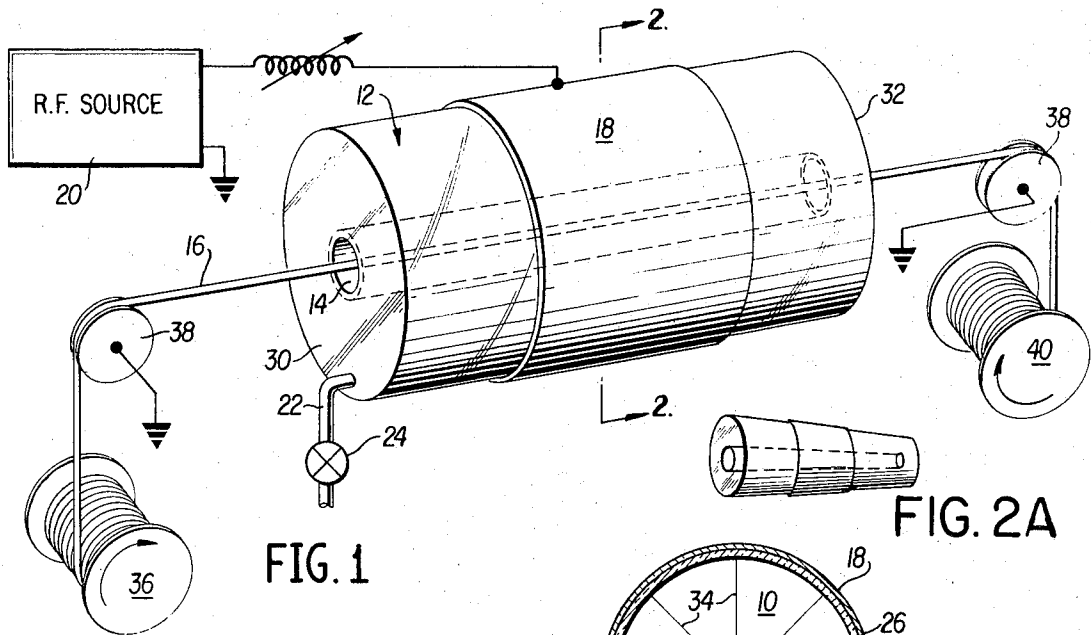
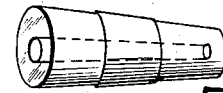
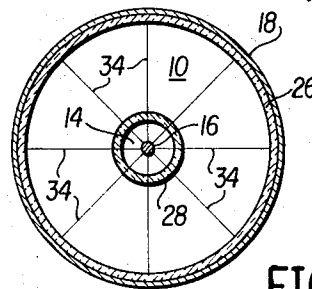
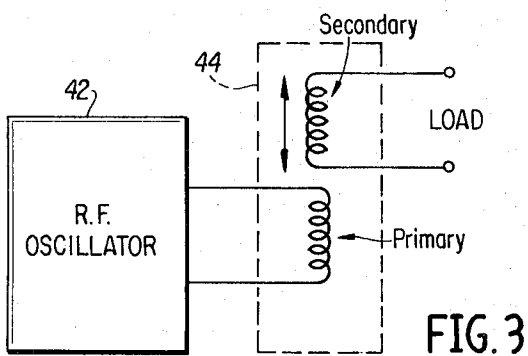
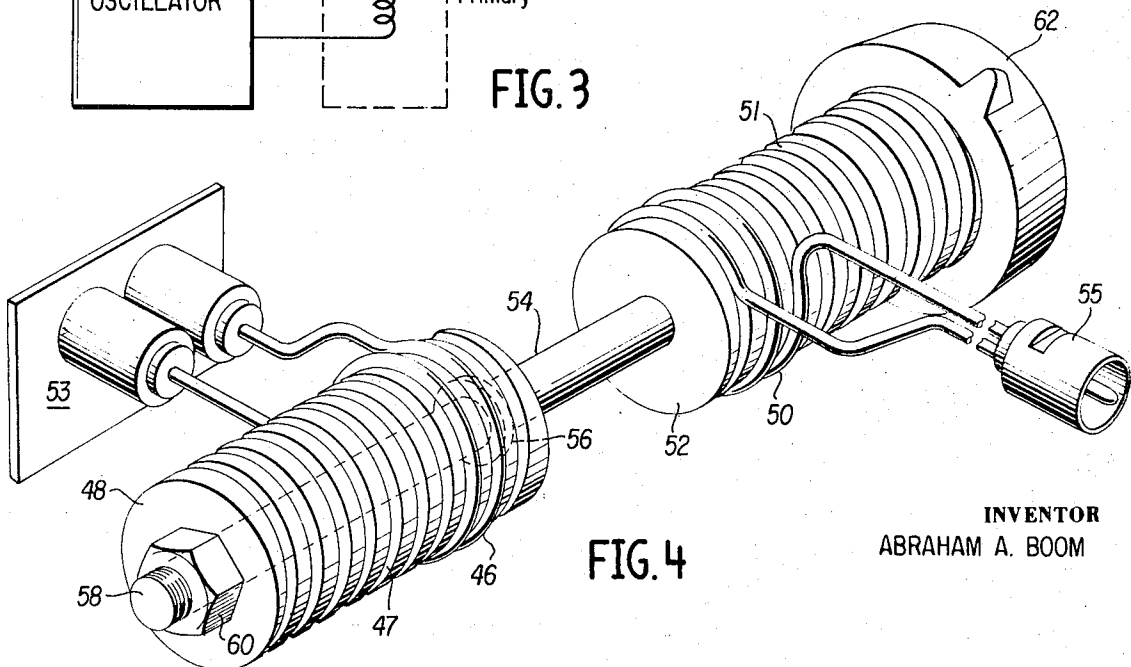
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ABSTRACT

An apparatus for more efficiently creating high temperatures, particularly for the treatment of substrates. A central passage extends through the envelope and one electrode is disposed in the central passage. A second electrode is disposed around the envelope so that the electrodes are separated at least in part by the envelope. The gas conditions within the envelope are made to differ from the gas conditions exteriorly thereof and a radio frequency signal applied to the electrodes to excite the gas within the envelope to thereby generate a gaseous plasma. The amplitude of the radio frequency signal is, however, insufficient to generate a plasma outside the chamber defined by the envelope. Since the plasma does not contact the electrodes, the current flow between the electrodes is minimized and contamination of the gas by the electrodes is prevented. In addition, the surface area of the electrode in the central passage is substantially less than the surface area of the outer electrode thereby creating a plasma within the envelope which is more concentrated in the vicinity of the centrally disposed electrode. The plasma appears to induce a current in the centrally disposed electrode transverse to the axis thereof. This current is an order of magnitude higher than the average RF current between the electrodes and localized heating of the substrate is thus provided. A radio frequency balun transformer is provided for adjusting the power applied to the electrodes.

19 Claims, 5 Drawing Figures





INVENTOR
ABRAHAM A. BOOM

APPARATUS FOR HEAT TREATMENT OF SUBSTRATES

BACKGROUND OF THE INVENTION

The present invention relates to an apparatus for highly concentrated electrical heating and more specifically to an apparatus for efficiently heating a substrate through the generation of a plasma in the vicinity of the substrate.

It is often desirable to heat various substrates at elevated temperatures to obtain desired substrate characteristics or to aid in the coating of the substrate. For example, in the manufacture of carbonaceous fibrous materials, carbon graphite fibers may be treated at elevated temperatures to modify the surface or overall characteristics of the fiber.

In the past, substrates have been heated in various manners to provide the desired modification of the substrate characteristics. For example, resistance heating, i.e., passing an electrical current through the fiber, has been frequently used to obtain the elevated temperatures required. However, the current flow and therefore the cost of heating fibers by resistance heating may necessarily be excessively high in order to reach the temperatures required.

Other conventional electrical methods for heating substances may include indirect heating through the use of resistively or inductively heated elements in an oven or other enclosed or semi-enclosed space. The efficiency of these methods may also suffer due to the necessity of heating the element from which heat is transferred to the substrate.

It is accordingly an object of the present invention to provide a novel apparatus for electrically generating high temperatures.

It is another object of the present invention to provide a novel apparatus for generating high temperatures in a relatively confined heating zone for the treatment of substrates.

It is a further object of the present invention to provide a novel apparatus for electrically heat treating substrates wherein the substrate is heated through a combination of direct and indirect heating, for example, radiantly, resistively, inductively and through conduction.

It is yet another object of the present invention to provide a novel balun output transformer structure for selectively coupling RF power to the heating chamber.

These and other objects and advantages of the present invention will become apparent to one skilled in the art to which this invention pertains from a perusal of the following detailed description when read in conjunction with the appended drawings.

THE DRAWINGS

FIG. 1 is a schematic representation of a heating chamber constructed in accordance with the principles of the present invention;

FIG. 2 is a view in cross section of the heating chamber of FIG. 1, taken along the line 2—2;

FIG. 2A is a schematic representation of a second embodiment of a heating chamber constructed in accordance with the principles of the present invention;

FIG. 3 is a functional diagram of the RF source of FIG. 1; and,

FIG. 4 is a perspective view of the output transformer of FIG. 3.

DETAILED DESCRIPTION

Referring to FIGS. 1 and 2 wherein a preferred embodiment of the heating chamber constructed in accordance with the present invention is illustrated, a plasma chamber 10 is formed within a central passage 14 extending into a substantially gas impervious, generally electrically nonconductive or insulative envelope 12. The substrate to be heated provides a central electrode 16 which extends through the central passage 14 and is isolated from the chamber 10 by the radially inward wall of the envelope 12. An electrode 18 is disposed radially outward of the envelope 12 and is separated at least in part from the centrally disposed electrode 16 by at least a portion of the envelope 12, thereby defining an area within the envelope 12, i.e., at least a portion of the chamber 10, which is disposed between the electrodes 16 and 18.

High frequency electrical potential is applied between the electrodes 16 and 18 from a suitable source such as a variable frequency and amplitude radio frequency (RF) source 20 to thereby subject the chamber defined by the envelope 12 between the electrodes 16 and 18, to a selectable time varying electrical field. A suitable fill tube 22 may be provided communicating with the chamber 10 through the envelope 12 and having a valve or other suitable closure means 24 therein to selectively control the gas pressure and gas constituency within the envelope 12.

With continued reference to FIGS. 1 and 2, the envelope 12 defining the chamber 10 preferably comprises an outer elongated hollow glass cylindrical member 26, an inner elongated hollow glass cylindrical member 28, and apertured end plates 30 and 32 sealed therebetween in a suitable conventional manner. The cylindrical member 28 illustrated is substantially coextensive with the member 26 and is disposed in telescoping relationship thereto coaxially within the member 26 to define a chamber annular in cross section as is shown in FIG. 2.

As was previously mentioned, the substrate to be heated preferably forms the central electrode 16. The substrate may be passed through the central passage 14 from a feed reel 36, over suitable guides such as the rollers 38, and onto a take-up reel 40. Either or both of the rollers 38 may be connected to one output terminal of the RF source, for example, by grounding the rollers 38 and one output terminal of the RF source as is illustrated in FIG. 1.

The outer electrode 18 is preferably a hollow cylindrical electrically conductive member circumferentially disposed round at least a portion of the insulative member 26 and may be, for example, a metallic foil conformed to the radially outer surface of the envelope. The central electrode 16 preferably extends axially into the central passage 14 sufficiently so that an elongated annular portion of the chamber 10 is located between the electrodes 16 and 18.

The application of a potential from the RF source 20 between the electrodes 16 and 18 creates an electric field between these electrodes, as is indicated by the lines 34 in FIG. 2. The electrode configuration, i.e., the relative positions of the electrodes and the relative dimensions thereof, cause the electric field to be more concentrated or dense in the vicinity of the central electrode 16 near the axis of the annular chamber 10.

If the intensity of the electric field is sufficient, the gas in the chamber 10 will be excited sufficiently to create a gaseous plasma in the chamber. The plasma generally comprises highly reactive species such as ions, electrons and neutral fragmented particles in highly excited states. Since the exciting of the gas by the electric field creates the plasma, the plasma concentration or density generally conforms to the electric field concentration or density. Thus, the concentration or density of the plasma generated within the gas impervious envelope 12 varies between the outer cylindrical member 26 and the inner cylindrical member 28 in a manner related to the electric field concentration or density.

The relationship between the gas conditions within the envelope 12 and the gas conditions exteriorly thereof is desirably such that the plasma may be confined to the chamber 10. The electric potential applied to the electrodes 16 and 18 may thus be lower and the current density will be correspondingly less. This desirable relationship may be obtained by utilizing selected gases at predetermined pressures within the chamber 10, while exposing the electrodes outside the envelope 12 to the atmosphere.

By way of example, a monatomic inert gas, such as argon or helium at atmospheric or slightly less than atmospheric pressure may be utilized in the chamber 10. When the RF signal is applied to the electrodes 16 and 18, a plasma will be more readily generated within the chamber 10 than exteriorly thereof. With the potential of the RF signal applied to the electrodes set at a value above the potential required to generate a plasma within the chamber 10, but below the potential required to generate a plasma in the vicinity of the electrodes 16 and 18 externally of the chamber 10, the current which flows between the electrodes 16 and 18 will depend primarily upon the capacitive coupling between the electrodes rather than on the ion flow within the plasma.

When an RF signal of sufficient amplitude is applied to the substrate forming the electrode 16 and the electrode 18, a gaseous plasma, concentrated about the inner cylindrical member 28, is generated within the chamber 10. The temperature of the plasma is extremely high due to the scattering of the energy gained from the electrical field set up between the electrodes 16 and 18, and the temperature may be controlled within practical limits in direct relation to the field intensity.

The current flowing through the substrate causes resistive heating of the substrate apparently due to the intense magnetic and electrical fields in the plasma.

The heating of the substrate as described above results in highly efficient use of the energy supplied by the RF source 20. Thus, the required substrate temperature may be achieved more efficiently than by other conventional heating methods and the substrate temperature may be easily controlled in a number of ways, for example, by controlling the amplitude of the RF signal, varying the diameter of the inner cylindrical member 28, or varying the distance between the electrodes along the length of the envelope 12 as shown in FIG. 2A.

As was previously described, the RF source 20 of FIG. 1 preferably supplies a high frequency RF signal at selectable power levels to the heating apparatus of FIG. 1. As is illustrated in FIG. 3, the RF source 20 may include a high power RF oscillator 42 connected to the

load (e.g. the electrodes 16 and 18 of FIG. 1) through a balun transformer 44. For example, the balun transformer 44 may form a portion of the tank circuit of the oscillator 42. Maximum power transfer between the oscillator 42 and the load is thus obtained when an impedance match exists between the oscillator tank circuit and the load impedance reflected back to the tank circuit. Since it may be desirable to vary the oscillator output power and frequency to suit the requirements of the heating apparatus, it may be necessary to vary the oscillator output impedance to retain the desired impedance match.

Impedance matching for maximum efficiency and control of the power transfer to the load is preferably accomplished by providing a balun transformer arrangement as is illustrated in FIG. 4.

With reference now to FIG. 4, the balun transformer 44 of FIG. 3 preferably includes a primary coil 46 wound in a helical groove 47 on an electrically insulative core 48. A secondary coil 50 is wound in a helical groove 51 on an electrically insulative core 52 disposed coaxially with respect to the core 48.

The coils 46 and 50 may be, for example, helically wound, hollow copper tubes generally conforming to the shapes of the helical grooves in the respective cores 48 and 52. The coil 46 may be secured to a pair of output terminal blocks 53 and the coil 50 may be terminated with a suitable transmission line connector 55 such as a 50 ohm connector.

The core 52 may be fixedly connected to a shaft 54 which extends through a central passage in the core 48 so that the core 48 is freely rotatable on the shaft 54. A shoulder 56 may be provided on the shaft 54 to insure a fixed spacing between the cores 48 and 52, and the end 58 of the shaft 54 may be threaded and may protrude out of the core 48 so that a nut 60 may be utilized to prevent removal of the shaft 54 from the central passage in the core 48.

An insulative knob 62 having a position indicator 64 thereon may be connected to the core 52 to facilitate the rotation of the core 52 and to provide an indication of the relative positions of the cores 48 and 52. As the knob 62 is rotated, the secondary coil 50 moves axially along the core 52 varying the spacing between the coils and thereby varying the mutual inductance between the coils. Thus, at a particular frequency setting, the coil spacing may be varied until an impedance match and/or a desired output power is obtained as may be indicated on a suitable wattmeter (not shown).

It should be noted that the axial spacing between the cores 48 and 52 remains substantially constant as the core 52 is rotated. Thus, the minimum spacing between the coils cannot be decreased below a predetermined distance, preventing accidental arcing between the coils. Moreover, the grooves which receive the coils aid in preventing arcing by interposing a material having a higher dielectric strength than that of air at least partially between the coils 46 and 50 and between adjacent coil windings.

While only the core 52 rotates in the embodiment of FIG. 5, it is apparent that the axial spacing between the coils may be varied in other manners. For example, the cores 48 and 52 may be connected for axial rotation together with the cores being grooved in opposite directions, i.e., a left-handed thread or groove on the core 48 and a right-handed thread or groove on the core 52.

Thus, the coils may both be movable axially in response to the rotation of the cores.

GENERAL SUMMARY OF ADVANTAGES

It is apparent from the foregoing description that the present invention is particularly advantageous for the efficient and controlled electrical heating of substrates such as conductive fibers or wire. The substrate is heated both directly and indirectly, thereby making the most efficient use of the electrical power supplying the heating energy. Moreover, the generated energy of the plasma acting indirectly on the substrate through thermal conduction and radiation is concentrated in the vicinity of the substrate and also acts indirectly on the substrate to improve the heating efficiency.

The balun transformer used in conjunction with the present invention provides a convenient way to maximize power transfer and to control the power applied to the electrodes between which the plasma is generated. Moreover, the entire transformer core assembly may be easily and inexpensively constructed by conventional molding techniques and the coils may be constructed from commercially available tubing and commercially available fittings. Also, accidental arcing between the transformer windings is prevented by the novel structure of the transformer.

The present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The presently disclosed embodiment is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed is:

1. Apparatus comprising:

electrically insulative means defining a gas impervious envelope having a central passage extending thereinto;

a first electrode disposed wholly exteriorly of said envelope; said electrode being disposed in part within said central passage;

a second electrode disposed exteriorly of said envelope and separated at least in part from said first electrode by said envelope; and

means for applying a radio frequency electrical signal to said electrodes to thereby generate a plasma within said envelope.

2. The apparatus of claim 1 wherein said first electrode is a substrate to be heated without exposure to the plasma generated within said envelope.

3. The apparatus of claim 2 wherein said substrate comprises a plurality of electrically conductive fibers and wherein said radio frequency electrical signal is applied to said substrate through a rotating member in contact with said substrate.

4. The apparatus of claim 1 including means for reducing the pressure within said envelope to a value less than the value of the pressure within said central passage; and,

wherein said radio frequency electrical signal has a potential sufficient to generate a plasma between said electrodes within said envelope but insufficient to generate a plasma between said electrodes externally of said envelope.

5. The apparatus of claim 4 wherein said central passage communicates with the atmosphere on opposite sides of said envelope; and,

including means for reducing the pressure within said envelope below atmospheric pressure.

6. The apparatus of claim 5 wherein the surface area of one of said electrodes is large relative to the surface area of the other of said electrodes whereby the plasma generated within said envelope is concentrated in the proximity of said other of said electrodes.

7. The apparatus of claim 6 wherein the distance between said electrodes is substantially constant over the length of said envelope.

8. The apparatus of claim 1 wherein the surface area of said second electrode is large relative to the surface area of said first electrode whereby the plasma generated within said envelope is concentrated in the proximity of said first electrode.

9. The apparatus of claim 8 wherein the distance between said electrodes included in said envelope varies over the length of said envelope.

10. The apparatus of claim 1 wherein said gas impervious envelope comprises:

a first elongated hollow member;

a second elongated hollow member telescoped within said first member; and,

means for establishing a gas impervious seal between said first and second members at spaced points along the length thereof to define said gas impervious envelope between said electrodes.

11. The apparatus of claim 10 wherein said first member is a hollow cylinder;

wherein said second member is a hollow cylinder substantially coextensive and coaxial with said first member; and,

wherein said second electrode is a hollow cylinder only slightly larger in diameter than said first member.

12. The apparatus of claim 11 wherein said second electrode is a thin layer of metal conformed to the radially outer external surface of said first member.

13. Apparatus for treating a substrate comprising: electrically insulative means defining a gastight chamber; and,

means including a first electrode and said substrate to be treated disposed exteriorly of said chamber on opposite sides thereof for generating a high frequency induced plasma within said chamber without generating a plasma exteriorly of said chamber.

14. The apparatus of claim 13 wherein the distance between said electrode and said substrate is substantially constant along the length of said chamber.

15. The apparatus of claim 14 wherein the surface area of said electrode is substantially greater than the surface area of said substrate.

16. The apparatus of claim 13 wherein said first electrode comprises:

an electrically conductive plate surrounding at least a portion of said chamber; and,

wherein said means for generating said high frequency induced plasma comprises:

means for generating a radio frequency signal;

circuit means for applying said radio frequency signal to said substrate and said electrically conductive plate.

17. The apparatus of claim 16 wherein said generating means includes:

a source of radio frequency signal; and,

7

transformer means for coupling said radio frequency signal from said source to said circuit means, said transformer means including primary and secondary coils, and means for varying the mutual inductance of said coils.

18. The apparatus of claim 17 wherein said means for varying the mutual inductance of said coils comprises: first and second elongated, axially spaced, insulative cores disposed substantially coaxially relative to each other, said primary and secondary coils each being wound on one of said cores coaxially therewith;

means for axially rotating one of said cores relative to the other; and,

8

means responsive to the relative rotation of said cores for varying the axial spacing between said coils.

19. The apparatus of claim 18 wherein said means for varying the axial spacing between said coils comprises a helical groove running generally circumferentially along at least a portion of the length of said one of said cores, said groove generally conforming in shape to said coil wound on said one of said cores, said groove receiving said coil wound on said one of said cores whereby said coil moves axially along said one of said cores responsively to the rotation of said one of said cores.

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