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(57) Abstract

In an air–metal fuel cell battery (FCB) system, wherein metal–fuel tape, the ionically–conductive medium and the cathode structures are transported at substantially the same velocity at the locus of points at which the ionically–conductive medium contacts the moving cathode structure and the moving metal–fuel tape during discharging and recharging modes of operation. In a first generalized embodiment of the present invention, the ionically–conductive medium is realized as an ionically–conductive belt, and the metal–fuel tape, ionically–conductive belt, and movable cathode structure are transported at substantially the same velocity at the locus of points which the ionically–conducing belt contacts the metal–fuel tape and the cathode structure during system operation. In a second generalized embodiment of the present invention, the ionically–conductive medium is realized as a solid–state (e.g.) gel–like) film layer integrated with the metal–fuel tape, and the metal–fuel tape, ionically–conductive film layer and movable cathode structure are transported at substantially the same velocity at the locus of points which the ionically–conducing film layer contacts the metal–fuel tape and the cathode structure during system operation. In a third generalized embodiment of the present invention, the ionically–conductive medium is realized as a solid–state film layer integrated with the movable cathode structure, and the metal–fuel tape, ionically–conductive film layer and movable cathode structure are transported at substantially the same velocity at the locus of points which the ionically–conducing film layer contacts the metal–fuel tape and the cathode structure during system operation. By transporting the movable cathode structure, ionically contacting medium and metal–fuel tape within the system as described above, generation of frictional forces among such structures are minimized during system operation, and thus the damage to the cathode structure and metal–fuel tape is substantially reduced.

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METAL-AIR FUEL CELL BATTERY SYSTEMS EMPLOYING MOVING ANODE AND CATHODE STRUCTURES

BACKGROUND OF INVENTION

Technical Field

The present invention relates to metal-air fuel cell battery systems designed to produce electrical power from metal-fuel tape transported over the cathode structures of the system, and more particularly to such systems employing movable cathode structures having low friction characteristics.

Brief Description Of The Prior Art

In copending US Application Serial No. 08/944,507 entitled "High-Power Density Metal-Air Fuel Cell Battery System, Applicants disclose several types of novel metal-air fuel cell battery (FCB) systems. During power generation, metal-fuel tape is transported over a stationary cathode structure in the presence of an ionically-conductive medium, such as an electrolyte-impregnated gel (i.e. electrolyte-impregnated film). In accordance with well known principles of electro-chemistry, the transported metal-fuel tape is oxidized as electrical power is produced from the system.

FCB power generation systems of the type disclosed in US Application Serial No. 08/944,507 have numerous advantages over prior art electro-chemical power generation devices including, for example, the generation of electrical power over a range of output voltage levels selectable to particular electrical load conditions. Also, the oxidized metal-fuel tape can be reconditioned (i.e. recharged) during battery charging cycles carried out during electrical power generation, as well as separately therefrom.

In copending Application Serial No. 09/074,337 entitled "Metal-Air Fuel-Cell Battery Systems" filed May 7, 1998, Applicants disclose several novel systems and methods for reconditioning oxidized metal-fuel tape used in FCB systems. In theory, such technological improvements enable metal-fuel tape to be quickly recharged in an energy efficient manner for reuse in electrical power generation cycles. Such advances offer great promise in many fields of endeavor requiring electrical power.

The greatest limitation, however, with prior art metal-air FCB systems is that, as the metal-fuel tape is being transported over the stationary cathode structures within such systems, frictional (e.g. shear) forces are generated, causing a number of problems to arise.

One problem is that such frictional forces cause an increase in the amount of electrical power required to transport the metal-fuel tape through the system.

Another problem is that such frictional forces cause metal-oxide particles to be shed from metal-fuel tape during transport and to become embedded within the porous structure of the cathode, thereby preventing ionic transport between the cathode and ionically-conductive medium (i.e. referred to as “blinding”), and increasing the likelihood of damage (or destruction) to the surface of the cathode structure and metal-fuel tape.

In addition, when using prior art technology it has been very difficult to produce metal-air FCB systems having high volumetric power density characteristics measured, for example, in kilowatts/cm^3. Consequently, it has not been possible to generate large amounts of electrical power from FCB systems occupying relatively small volumes of physical space.

Overall, such problems tend to reduce the operational efficiency and utility of prior art metal-air FCB systems, as well as the life of the cathode structures and metal-fuel tape employed therein.

Thus, there is a great need in the art for an improved metal-air fuel cell battery system which avoids the shortcomings and drawbacks of prior art systems and methodologies.

DISCLOSURE OF THE INVENTION

Accordingly, it is a primary object of the present invention to provide an improved metal-air fuel cell battery (FCB) system which avoids the shortcomings and drawbacks of prior art systems and methodologies.

Another object of the present invention is to provide such a system, wherein both the metal-fuel tape, ionically-conductive medium and cathode structures are moved relative to each other during system operation in order to reduce frictional (e.g. shear) forces generated by relative movement among the cathode structure(s), metal-fuel tape and ionically-conductive medium during system operation.

Another object of the present invention is to provide such a system, wherein this reduction in frictional forces results in: a reduction in the amount of electrical power required to drive the cathode structure(s), the metal-fuel tape and ionically-conductive medium during system-operation; a reduction in the shedding of metal-oxide particles from metal-fuel tape and the embedding of such particles within the porous structure of the cathode; and a decrease the likelihood of damage to the cathode structures and metal-fuel tape employed in the system.

Another object of the present invention is to provide such metal-air fuel cell battery system, wherein a transport mechanism is used to transport the cathode structures, ionically-conductive medium and metal-fuel tape at substantially the same velocity at the locus of points at which the ionically-conductive medium contacts both the metal-fuel tape and the cathode structures during system operation in order to minimize the generation of frictional forces between the movable cathode structures, metal-fuel tape and ionically-conductive medium.

Another object of the present invention is to provide such a system, wherein velocity control of the metal-fuel tape, cathode structures and ionically-conducting medium can be realized in a variety of different ways.

Another object of the present invention is to provide such a system, wherein the cathode structure is realized as a rotating cathode cylinder having fine perforations formed in the surface thereof and a hollow central core which enables the transport of oxygen to the interface between the ionically-conductive medium and metal-fuel tape transported thereover.

Another object of the present invention is to provide such a

system, wherein the cylindrical cathode comprises a plastic hollow cylinder about which is attached is a cathode element made from nickel mesh fabric, for current collection, embedded within carbon, catalytic and binder material.

Another object of the present invention is to provide such a system, wherein the cylindrical cathode is rotated at a controlled angular velocity and the metal-fuel tape is transported over the surface of the rotating cathode so that both the metal-fuel tape and the cathode structure move at substantially the same velocity at the locus of points at which the ionically-conducing medium contacts both the metal-fuel tape and the cathode structure.

Another object of the present invention is to provide such a system, wherein the ionically-conductive medium is realized in the form of an ionically-conductive belt, transported (i.e. running) between two or more transport cylinders.

Another object of the present invention is to provide such a system, wherein the ionically-conductive belt is fabricated from an open-cell plastic material impregnated with an ionically-conductive material which enables ionic transport between the cathode and anode structures of the system.

Another object of the present invention is to provide such a system, wherein velocity control can be achieved in a variety of ways, for example: by driving the cylindrical cathode structure with a belt that is also used to transport the metal-fuel tape (i.e. between supply and take-up reels or hubs within a cassette type-device); or by driving the cylindrical cathode structure and supply and take-up hubs of a fuel cassette device using a set of speed controlled motors, or spring-driven motors.

Another object of the present invention is to provide such a system, wherein the ionically-conductive medium is realized as a solid-state (e.g. gel-like) film applied on the outer surface of the cylindrical cathode structure, and the metal-fuel tape is realized in the form of thin zinc tape, zinc power mixed with an binder and carried on a polyester substrate, or zinc powder impregnated within the substrate of the tape itself.

Another object of the present invention is to provide metal-air fuel cell battery system, wherein the rotatable cathode structure is realized as a cathode belt structure having ultrafine perforations in the surface thereof and a hollow central core for enabling oxygen transport to the interface between the ionically-conductive medium and the metal-fuel tape transported thereover.

Another object of the present invention is to provide such a system, wherein the cathode belt structure comprises an open-cell type plastic substrate, within which nickel mesh fabric is embedded with carbon and catalytic material.

Another object of the present invention is to provide such a system, wherein during system operation, the cathode belt structure is transported at a controlled velocity between two or more transport cylinders, while metal-fuel tape is transported over the surface of the cathode belt structure at substantially the same velocity at the locus of points at which the ionically-conducing medium contacts both the metal-fuel tape and the cathode structure.

Another object of the present invention is to provide such a system, wherein the ionically-conductive medium of the system is realized in the form of an ionically-conductive belt structure transported between the metal-fuel tape and the cathode belt structure at substantially the same velocity as the cathode belt structure and metal-fuel tape at the locus of points at which the ionically-conducing medium contacts both the metal-fuel tape and the cathode structure.

Another object of the present invention is to provide such a system, wherein the ionically-conductive medium of the system is realized in the form of a thin-film integrated with the outer surface of the cathode belt structure so as to establish contact with the anodic metal-fuel-tape transported thereover.

Another object of the present invention is to provide such a system, wherein the metal-fuel tape is realized in the form of thin zinc tape, zinc power mixed with an binder and carried on a polyester or like substrate, or zinc powder impregnated within the substrate itself.

Another object of the present invention is to provide a metal-air FCB system, wherein the surface tension between the metal-fuel tape and the ionically-conductive medium is sufficiently high (due to wetting of the metal-fuel tape, the ionically-conductive medium and the movable cathode structures) in order to create hydrostatic drag (i.e. hydrostatic attraction) between the metal-fuel tape and the ionically-conductive belt as well as between the cathode structure (e.g. cylinder or belt) and the ionically-conductive medium (e.g. belt or layer), thereby enabling coordinated movement among the metal-fuel tape, cathode structure (e.g. cylinder or belt) and ionically-conductive medium (e.g. belt or layer), with minimal slippage.

Another object of the present invention is to provide a FCB system employing hydrostatic drag between the metal-fuel tape and the ionically conductive medium and between the moving cathode structures and the ionically conductive medium so that all three of these movable system components can be transported (or moved) within the system by moving one or more of such system components (e.g. using spring-driven motor) thereby simplifying and reducing the cost of the system.

Another object of the present invention is to provide a system, wherein the metal-fuel tape, cathode structures and ionically-conductive medium are moved relative to each other so that frictional forces generated among the metal-fuel tape, cathode structures and ionically-conductive medium are substantially reduced, thereby reducing the amount of electrical power required to drive the cathode, metal-fuel tape and ionically-conductive medium and transport mechanisms, and decreasing the likelihood of damage to the cathode structure and metal-fuel tape, and permit reuse thereof over a large number of cycles without replacement.

Another object of the present invention is to provide a metal-air FCB system having improved volumetric power density (VPD) characteristics over prior art FCB systems.

Another object of the present invention, is to provide such a metal-air FCB system, wherein metal-fuel tape is transported over a plurality of moving cathode structures during system operation.

Another object of the present invention, is to provide such a FCB system, wherein the metal-fuel tape, ionically-conducting medium and cathode structures are moved at substantially the same velocity at points where the ionically-conducting medium contacts the cathode structures and the metal-fuel tape during discharging and recharging operations, thereby minimizing the generation of frictional (e.g. shear) forces among the cathode structures, ionically-conducting medium and metal-fuel tape in the system, and thus reduce the amount of electrical power required to drive the tape transport mechanism, the shedding of metal-oxide particles from metal-fuel tape which can become embedded within the cathode structures, and the likelihood of damage or destruction of the cathode structures and metal-fuel tape.

Another object of the present invention is to provide such a system, wherein velocity synchronization of the metal-fuel tape, cathode structures and ionically-conductive medium is realizable in a variety of ways.

Another object of the present invention is to provide such a system, wherein each moving cathode structure is realized as a cylindrically-shaped rotational structure having ultra-fine perforations formed in the surface thereof and a hollow air-flow passageway extending from one end thereof to the other end thereof in order to permit oxygen transport to the interface between the ionically-conducting medium and metal-fuel tape during system operation.

Another object of the present invention is to provide such a system, wherein each rotating cylindrical cathode comprises a plastic hollow cylinder about which is attached is a cathode element made from nickel mesh sponge fabric embedded within carbon and catalyst material.

Another object of the present invention is to provide such a system, wherein during power generation operations, each cylindrical cathode structure is rotated at a controlled angular velocity, and a continuous supply of metal-fuel tape is transported over the surface of the rotating cathode cylinders at a velocity, at which the metal-fuel tape, ionically-conducting medium and cathode cylinders move at substantially the same velocity at the points (i.e locus) of contact thereamong in the system.

Another object of the present invention is to provide such a system, wherein the ionically-conducting medium is realized in the form of an ionically-conducting belt that runs over each rotating cathode cylinder in the system, between the cathode surface and metal-fuel tape transported thereover.

Another object of the present invention is to provide such a system, wherein the ionically-conducting belt is made from an open-cell plastic material impregnated with ionically-conducting material capable of supporting ionic transport between the moving cathode and anode (metal-fuel) structures in the system.

Another object of the present invention is to provide such a system, wherein the ionically-conducting medium is realized in the form of a solid-state-film applied to the outer surface of each rotating cathode cylinder, and the metal-fuel tape is realized in the form of zinc-fuel tape realized as a thin strip of zinc, or zinc power mixed with an binder and carried on a polyester substrate, or zinc powder impregnated within a substrate.

Another object of the present invention is to provide such a system, wherein each cathode structure is realized as a rotating cathode cylinder having ultrafine perforations formed in the surface thereof and a hollow central core which enables the transport of oxygen to the interface between the ionically-conductive medium and metal-fuel tape.

Another object of the present invention is to provide such a

system, wherein each cylindrical cathode comprises a plastic hollow cylinder about which is attached is a cathode element made from nickel mesh fabric (for current collection) embedded within carbon, catalytic and binder material.

Another object of the present invention is to provide such a system, wherein each cylindrical cathode is rotated at a controlled angular velocity and the metal-fuel tape is transported over the surface of the rotating cathode so that both the metal-fuel tape and the cathode structure move at substantially the same velocity at the locus of points at which the ionically-conducing medium contacts both the metal-fuel tape and the cathode structure.

Another object of the present invention is to provide such a system, wherein the ionically-conductive medium is realized in the form of an ionically-conductive belt, transported (i.e. running) between two or more transport cylinders.

Another object of the present invention is to provide such a system, wherein the ionically-conductive belt is fabricated from an open-cell plastic material impregnated with an ionically-conductive material which enables ionic transport between the moving cathode and anode structures in the system.

Another object of the present invention is to provide such a system, wherein velocity control can be achieved in a variety of ways, for example: by driving each cylindrical cathode with the gears of a neighboring cathode cylinder; by driving each cylindrical cathode structure with a belt that is also used to transport the metal-fuel tape (i.e. between supply and take-up reels or hubs within a cassette type-device); by driving each cylindrical cathode structure and supply and take-up hubs of a fuel cassette device using a set of synchronously controlled motors.

Another object of the present invention is to provide such a system, wherein the ionically-conductive medium is realized as a solid-state film applied on the outer surface of the cylindrical cathode structure, and the metal-fuel tape is realized in the form of thin zinc tape, zinc power mixed with an binder and carried on a polyester substrate, or zinc powder impregnated within the substrate of the tape itself.

Another object of the present invention is to provide a metal-air fuel cell battery system, wherein each rotatable cathode structure is realized as a cathode belt structure having ultrafine perforations in the surface thereof and a hollow central core for enabling oxygen transport to the interface between the ionically-conductive medium and the metal-fuel tape.

Another object of the present invention is to provide such a system, wherein each cathode belt structure comprises an open-cell type plastic substrate, within which nickel mesh fabric or like material is embedded within carbon and catalytic material.

Another object of the present invention is to provide such a system, wherein during system operation, each cathode belt structure is transported at a controlled velocity between two or more transport cylinders, while metal-fuel tape is transported over the surface of the cathode belt structure at substantially the same velocity at the locus of points at which the ionically-conducing medium contacts both the metal-fuel tape and the cathode structure.

Another object of the present invention is to provide such a

system, wherein the ionically-conductive medium of the system is realized in the form of an ionically-conductive belt structure transported between metal-fuel tape and each cathode belt structure at substantially the same velocity as the cathode belt structure and metal-fuel tape at the locus of points at which the ionically-conductive medium contacts both the metal-fuel tape and the cathode belt structure.

Another object of the present invention is to provide such a system, wherein the ionically-conductive medium of the system is realized in the form of a solid-state film integrated with the outer surface of the cathode belt structure so as to establish contact with the anodic metal-fuel tape transported thereover.

Another object of the present invention is to provide such a system, wherein the metal-fuel tape is realized in the form of thin zinc tape, zinc power mixed with a binder and carried on a polyester substrate, or zinc powder impregnated within the substrate itself.

Another object of the present invention is to provide a system, wherein the metal-fuel tape, cathode structures and ionically-conductive medium are moved relative to each other so that frictional (e.g. shear) forces generated among the metal-fuel tape ionically-conductive medium and cathode structures are substantially reduced.

Another object of the present invention is to provide a metal-air FCB system, wherein a condition of hydrostatic drag is maintained between the metal-fuel tape and the ionically-conductive medium (e.g. belt or layer) as well as between the cathode structure (e.g. cylinder or belt) and the ionically-conductive medium (i.e. belt or layer) so that all three of these moving system components can be moved at substantially the same velocity (at points where the ionically-conductive medium contacts the metal-fuel tape and the cathode structure) when only one or more of these moving system components are actively transported or rotated using a motor driven by mechanical (e.g. spring-wound), electrical, or pneumatic forces.

Another object of the present invention is to provide a metal-air FCB system comprising a metal-fuel discharging subsystem, wherein discharge parameters, such as cathode-anode voltage and current levels, partial pressure of oxygen within the discharging cathode, relative humidity at the cathode-electrolyte interface, and where applicable, the speed of metal-fuel tape are automatically detected, recorded and processed in order to generate control data signals for use in controlling discharging parameters on a real-time basis, so that metal-fuel material can be discharged in a time and energy efficient manner.

Another object of the present invention is to provide a metal-air fuel cell battery system comprising a metal-fuel recharging subsystem, and wherein recharge parameters, such as cathode-anode voltage and current levels, partial pressure of oxygen within the recharging cathode, relative humidity at the cathode-electrolyte interface, and where applicable, the speed of metal-fuel tape are automatically detected, recorded and processed in order to generate control data signals for use in controlling recharging parameters on a real-time basis so that discharged metal-fuel material can be recharged in a time and energy efficient manner.

Another object of the present invention is to provide such a system, wherein the metal-fuel material to be discharged and/or recharged is contained within a cassette-type device insertable within the storage bay of the system.

Another object of the present invention is to provide such a system, wherein the metal-fuel material to be discharged and/or recharged comprises multiple metal-fuel tracks for use in generating different output voltages from the system.

Another object of the present invention is to provide novel apparatus in the form of a metal-air fuel cell battery system comprising a metal-fuel discharging subsystem and a metal-fuel recharging system managed by a system controller, wherein discharge parameters, such as cathode-anode voltage and current levels, partial pressure of oxygen within the discharging cathode, relative humidity at the cathode-electrolyte interface, and where applicable, the speed of metal-fuel tape are automatically detected recorded during the discharging mode of operation, and automatically read and processed in order to generate control data signals for use in controlling recharging parameters during the recharging mode of operation so that discharged metal-fuel material can be recharged in a time and energy efficient manner.

Another object of the present invention is to provide such a system, wherein recharge parameters, such as cathode-anode voltage and current levels, partial pressure of oxygen within the recharging cathode, relative humidity at the cathode-electrolyte interface, and where applicable, the speed of metal-fuel tape are automatically detected (e.g. sensed) and recorded during the recharging mode of operation, and automatically read and processed in order to generate control data signals for use in controlling discharging parameters during the discharging mode of operation so that metal-fuel material can be discharged in a time and energy efficient manner.

Another object of the present invention is to provide such a system, wherein each zone or subsection of metal fuel material is labelled with a digital code, through optical or magnetic means, for enabling the recording of discharge-related data during discharging mode of operation, for future access and use in carrying out various types of management operations, including rapid and efficient recharging operations.

Another object of the present invention is to provide such a system, wherein, during recharging operations, recorded loading condition information is read from memory and used to set current and voltage levels maintained at the recharging heads of the system.

Another object of the present invention is to provide such a system and method, wherein discharging conditions are recorded at the time of discharge and used to optimally recharge discharged metal-fuel material during recharging operations.

Another object of the present invention is to provide such a system, wherein, during tape discharging operations, optical sensing of bar code or like graphical indicia along each zone of metal-fuel material is carried out using a miniaturized optical reader embedded with the system.

Another object of the present invention is to provide such a system, wherein, during tape recharging operations, optical sensing of bar code data along each zone of discharged metal-fuel material is carried out using a miniaturized optical reader embedded with the system.

Another object of the present invention is to provide such a system, wherein information regarding the instantaneous loading conditions along each zone (i.e. frame) of the metal-fuel material are recorded in memory by the system controller.

Another object of the present invention is to provide such a system with an assembly of discharging heads, each of which comprises an electrically conductive cathode structure, an ionically conductive medium, and an anode contacting structure.

Another object of the present invention is to provide such a system with an assembly of recharging heads are provided, each of which comprises an electrically conductive cathode structure, an ionically conductive medium, and an anode contacting structure.

Another object of the present invention is to provide an improved method and system for generating electrical power from metal-air FCB systems so that the peak power requirements of electrical loads connected thereto can be met in a satisfactory manner while overcoming the shortcomings and limitations of prior art technologies.

Another object of the present invention is to provide an electrical power generation system based on metal-air FCB technology which can be used as an electrical power plant that can be installed in virtually any system, device or environment in which there is a need to satisfy the peak power requirements of an electrical load (e.g. engines, motors, appliances, machinery, tools, etc.) independent of the total amount of unconsumed metal-fuel remaining within the electrical power generation system.

Another object of the present invention is to provide such a system, wherein a network of metal-air FCB subsystems are connected to an output power bus structure and controlled by a network control subsystem associated with a network-based metal-fuel management (database) subsystem.

Another object of the present invention is to provide such a system for installation aboard a transportation or like vehicle, and supplying power to a plurality of electrical motors that are used to propel the vehicle over a long range of distances without recharging.

Another object of the present invention is to provide such a system, wherein the electrical power output produced therefrom is controlled by enabling selected metal-air FCB subsystems to supply electrical power to the output power bus structure of the system.

Another object of the present invention is to provide such a system, wherein the metal-fuel within each of the FCB subsystems is managed so that, on the average, each such FCB subsystem has substantially the same amount of metal-fuel available for power production at any instant in time.

Another object of the present invention is to provide such a system, wherein metal-fuel among the network of metal-air FCB subsystems is managed according to the metal-fuel equalization principle whereby, on the average, the amount of metal-fuel available for discharge at any instant of time is substantially equal in each FCB subsystem.

Another object of the present invention is to provide an electrical power generation system which can be used as an electrical power plant that can be installed in virtually any system, device or environment in which there is a need to satisfy the peak power demand of an electrical load (e.g. motor, appliance, machinery, tools, etc.) independent of the total amount of unconsumed metal-fuel remaining within the electrical power generation system.

Another object of the present invention is to provide such a system, wherein only one or a few metal-air FCB subsystems, referable as power cylinders, are enabled into operation when the host system, such as a transport vehicle, is travelling along flat land or downhill, and many or all of the power cylinders are enabled into operation when the host system is attempting to pass another vehicle or is travelling uphill.

Another object of the present invention is to provide such a system, wherein metal-fuel among the network of metal-air FCB subsystems is managed so that information regarding unconsumed (or inefficiently-consumed) amounts of metal-fuel remaining within any metal-air FCB subsystem is produced within metal-air fuel cell subsystem and provided to a network-based metal-fuel management database which is used by a network control subsystem to transport unconsumed amounts of metal-fuel into the discharge head assemblies of such subsystems while managing metal-fuel consumption in accordance with the metal-fuel equalization principle.

Another object of the present invention is to provide such a system, wherein peak power requirements of the host system can always be met regardless of the total quantity of metal-fuel remaining within the network of metal-air FCB subsystems.

Another object of the present invention is to provide such a system, wherein all metal-fuel containing within the network of metal-air FCB subsystems can be utilized by the system to produce electrical power in quantities sufficient to satisfy peak power requirements of the host system.

Another object of the present invention is to provide such a system, wherein metal-fuel contained within each of the metal-air FCB subsystems is realized in the form of a supply of metal-fuel tape which can be transported through its discharging head assembly in a bi-directional manner while the availability of metal-fuel therealong is automatically managed in order to improve the performance of the system.

Another object of the present invention is to provide such a system, wherein the metal-fuel tape to be discharged comprises multiple metal-fuel tracks for use in generating different output voltages from a metal-air FCB subsystem.

Another object of the present invention is to provide such a system, wherein each zone or subsection of metal fuel along the length of each metal-fuel tape track is labelled with a digital code, through optical or magnetic means, for enabling the recording of discharge-related data and the computation of metal-fuel availability along each such zone of metal-fuel tape during discharging operations within the respective metal-air FCB subsystem.

Another object of the present invention is to provide such a system, wherein metal-fuel tape can be transported through its recharging head assembly in a bi-directional manner while the presence of metal-oxide therealong is automatically managed in order to improve the performance of the system during the recharging operations carried out within respective metal-air FCB subsystems.

Another object of the present invention is to provide such a system, wherein the oxidized metal-fuel tape to be recharged comprises multiple metal-fuel tracks for use in generating different output voltages from the network of metal-air FCB subsystems.

Another object of the present invention is to provide such a

system, wherein each zone or subsection of metal fuel along the length of each metal-fuel tape track is labelled with a digital code, through optical or magnetic means, for enabling the recording of recharge-related data and the computation of metal-oxide presence along each such zone of metal-fuel tape during recharging operations carried out within respective metal-air FCB subsystems.

These and other objects of the present invention will become apparent hereinafter and in the Claims To Invention.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the Objects of the Present Invention, the following detailed Description of the Illustrative Embodiments Of the Present Invention should be read in conjunction with the accompanying Drawings, wherein:

Fig. 1A is a schematic representation of a first generalized embodiment of the metal-air fuel-cell battery (FCB) system of the present invention, wherein the ionically-conductive medium is a viscous electrolyte that is free to move at the same velocity as the metal-fuel tape and cathode structure(s) of the system, at the locus of points at which the ionically-conducing medium contacts the metal-fuel tape and the cathode structure during system operation:

Fig. 1B is a schematic representation of a second generalized embodiment of the (FCB) system of the present invention, wherein the ionically-conductive medium is integrated with the metal-fuel tape and transported at substantially the same velocity as the cathode structure at the locus of points at which the ionically-conducing medium contacts the metal-fuel tape and the cathode structure during system operation;

Fig. 1C is a schematic representation of a third generalized embodiment of the system of the present invention, wherein the ionically-conductive medium is integrated with the cathode structure, and transported at substantially the same velocity as the metal-fuel tape at the locus of points at which the ionically-conducing medium contacts the metal-fuel tape and the cathode structure during system operation;

Fig. 2 is a first illustrative embodiment of the FCB system, wherein metal-fuel tape is passed over a rotating cathode cylinder having an ionically-conductive coating (e.g. gel-like or solid-state film) applied thereover, and wherein the anode-contacting structure of the system engages the inner surface of the metal-fuel tape;

Fig. 2A is a partially broken away perspective view of the cylindrical cathode structure of the present invention shown in Fig. 2, in which an ionically-conductive film layer is applied over the outer surface thereof;

Fig. 2B is a cross-sectional view of the cylindrical cathode structure shown in Fig. 2, taken along the line 2B-2B of Fig. 2A;

Fig. 2C is a cross-sectional view of a section of the metal-fuel tape shown used in the system of Fig. 2;

Fig. 3 is a second illustrative embodiment of the FCB system, wherein metal-fuel tape is passed over a second embodiment of the cylindrical cathode structure hereof which is driven an angular velocity equalized to the velocity of the metal-fuel tape, and wherein the anode-contacting structure engages the inner surface of the metal-fuel tape and the metal-fuel tape has an ionically-conductive coating applied thereon;

Fig. 3A is a partially broken away perspective view of the cylindrical cathode structure of the present invention shown in Fig. 3, in which the cathode structure thereof is exposed to the ambient environment;

Fig. 3B is a cross-sectional view of the cylindrical cathode structure shown in Fig. 3, taken along the line 3B-3B of Fig. 3A;

Fig. 3C1 is a cross-sectional view of a section of a first type of metal-fuel tape that can be used in the system of Fig. 3C, showing an ionically-conductive film layer applied to the surface of a thin layer of metal fuel;

Fig. 3C2 is a cross-sectional view of a section of a second type of metal-fuel tape that can be used in the system of Fig. 3C, showing a substrate material embodying an ionically-conductive medium and metal-fuel particles;

Fig. 4 is a third illustrative embodiment of the FCB system, in which metal-fuel tape is passed over the cylindrical cathode structure hereof driven an angular velocity equalized to the velocity of the metal-fuel tape and having an ionically-conductive coating applied thereover, and wherein the anode-contacting structure engages the outer surface of the metal-fuel tape;

Fig. 4A is a partially broken away perspective view of the cylindrical cathode structure of the present invention shown in Fig. 4, in which the cathode structure thereof has an ionically-conductive coating applied thereover;

Fig. 4B is a cross-sectional view of the cylindrical cathode structure shown in Fig. 3, taken along the line 4B-4B of Fig. 4A;

Fig. 4C is a cross-sectional view of a section of metal-fuel tape that can be used in the system of Fig. 4;

Fig. 5 is a fourth illustrative embodiment of the FCB system, in which metal-fuel tape is passed over a fourth embodiment of the cylindrical cathode structure hereof driven at an angular velocity equalized to the velocity of the metal-fuel tape, and wherein the anode contacting structure engages the outer surface of the metal-fuel tape and the metal-fuel tape has an ionically-conductive coating applied thereon;

Fig. 5A is a partially broken away perspective view of the cylindrical cathode structure of the present invention shown in Fig. 5, in which the cathode structure thereof is exposed to the ambient environment;

Fig. 5B is a cross-sectional view of the cylindrical cathode structure shown in Fig. 5, taken along the line 5B-5B of Fig. 5A;

Fig. 5C1 is a cross-sectional view of a section of a first type of metal-fuel tape that can be used in the system of Fig. 5C, showing an ionically-conductive film layer applied to the surface of a thin layer of metal fuel;

Fig. 5C2 is a cross-sectional view of a section of second type of metal-fuel tape that can be used in the system of Fig. 5C, showing an ionically-conductive medium embodied within a substrate material embodying metal-fuel particles;

Fig. 6 is a fifth illustrative embodiment of the FCB system, wherein metal-fuel tape is passed over the second embodiment of the cylindrical cathode structure hereof which is driven an angular velocity equalized to the velocity of the metal-fuel tape while an ionically-conductive belt is transported between the metal-fuel tape and the cylindrical cathode structure, and wherein the anode-contacting structure engages the outer surface of the metal-fuel tape;

Fig. 6A is a cross-sectional view of the ionically-conductive belt structure shown in Fig. 6;

Fig. 6B is a cross-sectional view of a section of a first type of metal-fuel tape that can be used in the system of Fig. 6, realized in the form of thin layer of metal fuel;

Fig. 6C is a cross-sectional view of a section of a second type of metal-fuel tape that can be used in the system of Fig. 6, realized by depositing metallic powder and binder on a substrate;

Fig. 6D is a cross-sectional view of a section of a third type of metal-fuel tape that can be used in the system of Fig. 6, realized by impregnating metallic powder within a substrate material;

Fig. 7 is a sixth illustrative embodiment of the FCB system, wherein metal-fuel tape is transported over the ionically-conductive solid-state film layer on a cathode belt structure, at substantially the same velocity as the cathode belt structure at the locus of points at which the ionically-conductive film layer contacts both the cathode belt structure and the metal-fuel tape, and wherein the anode-contacting structure engages the outer surface of the metal-fuel tape between the cylindrical support structure and the cathode-contacting structure is disposed opposite the anode support structure and engages the inner surface of the cathode belt structure;

Fig. 7A is a cross-sectional view of the cathode belt structure shown in Fig. 7;

Fig. 7B is a cross-sectional view of a section of a first type of metal-fuel tape that can be used in the system of Fig. 7, realized in the form of thin layer of metal fuel;

Fig. 7C is a cross-sectional view of a section of a second type of metal-fuel tape that can be used in the system of Fig. 7, realized by depositing metallic powder and binder on a substrate;

Fig. 7D is a cross-sectional view of a section of a third type of metal-fuel tape that can be used in the system of Fig. 7, realized by impregnating metallic powder within a substrate material;

Fig. 8 is a seventh illustrative embodiment of the FCB system, wherein metal-fuel tape is transported over the ionically-conductive solid-state film layer on a cathode belt structure, at substantially the same velocity as the cathode belt structure at the locus of points at which the ionically-conductive film layer contacts both the cathode belt structure and the metal-fuel tap, and wherein the cathode-contacting structure engages the outer surface of the cathode belt structure passing over a cylindrical cathode roller and the anode-contacting structure is disposed adjacent the cylindrical cathode roller and engages the inner surface of the cathode belt structure;

Fig. 8A is a cross-sectional view of the cathode belt structure shown in Fig. 8;

Fig. 8B is a cross-sectional view of a section of a first type of metal-fuel tape that can be used in the system of Fig. 8, realized in the form of thin layer of metal fuel;

Fig. 8C is a cross-sectional view of a section of a second type of metal-fuel tape that can be used in the system of Fig. 8, realized by depositing metallic powder and binder on a substrate;

Fig. 8D is cross-sectional view of a section of a third type of metal-fuel tape that can be used in the system of Fig. 8, realized by impregnating metallic powder within a substrate material;

Fig. 9 is an eighth illustrative embodiment of the FCB system, wherein metal-fuel tape having a solid-state ionically-conductive film layer applied thereto is transported over a cathode belt structure at substantially the same velocity as the metal-fuel tape at the locus of points at which the ionically-conductive film layer contacts both the metal-fuel tape and the cathode belt structure, and wherein the anode-contacting structure engages the outer surface of the metal-fuel tape between the cathode belt transport cylinders and the cathode-contacting structure is disposed opposite the anode-contacting structure between the cathode belt transport cylinders and engages the inner surface of the cathode belt structure;

Fig. 9A is a cross-sectional view of the cathode belt structure shown in Fig. 9;

Fig. 9B is a cross-sectional view of a section of a first type of metal-fuel tape that can be used in the system of Fig. 9, realized in the form of thin layer of metal fuel carrying an ionically-conductive film layer;

Fig. 9C is a cross-sectional view of a section of a second type of metal-fuel tape that can be used in the system of Fig. 9, realized by metallic powder and binder on a substrate carrying an ionically-conductive layer;

Fig. 9D is a cross-sectional view of a section of a third type of metal-fuel tape that can be used in the system of Fig. 9, realized by impregnating metallic powder within a substrate material carrying an ionically conductive layer;

Fig. 10 is a ninth illustrative embodiment of the FCB system, wherein metal-fuel tape is transported over an ionically-conductive belt which is transported over a cathode belt structure at substantially the same velocity at the locus of points at which the ionically-conductive belt contacts both the metal-fuel tape and the cathode belt structure, and wherein the cathode-contacting structure engages the outer surface of the cathode belt structure passing over a cathode belt transport cylinder and the anode-contacting structure is disposed adjacent the cathode belt transport cylinder and engages the inner surface of the cathode belt structure;

Fig. 10A is a cross-sectional view of a first type of cathode belt structure that can be used in the system shown in Fig. 10;

Fig. 10B is a cross-sectional view of a second type of cathode belt structure that can be used in the system shown in Fig. 10;

Fig. 10C is a cross-sectional view of a section of a first type of metal-fuel tape that can be used in the system of Fig. 10, realized in the form of thin layer of metal fuel;

Fig. 10D is a cross-sectional view of a section of a second type of metal-fuel tape that can be used in the system of Fig. 10, realized by depositing metallic powder and binder on a substrate;

Fig. 10E is a cross-sectional view of a section of a third type of metal-fuel tape that can be used in the system of Fig. 8, realized by impregnating metallic powder within a substrate material;

Fig. 11A is a schematic representation of a first illustrative embodiment of the metal-air fuel-cell battery (FCB) system of the present invention, wherein a plurality of cathode cylinders are rotatably mounted within a compact support fixture (i.e. housing), and metal-fuel tape stored within a cassette-type cartridge is transported over the surface of the rotatably mounted cathode cylinders with an ionically-conductive medium disposed between the metal-fuel tape and cathode cylinders at the locus of points at which the ionically-conductive medium contacts each cathode cylinder and metal-fuel tape;

Fig. 11B is an elevated side view of the FCB system depicted in Fig. 11, showing the path of travel of the metal-fuel tape through the compact support fixture, and the location of tape path guides and cathode and anode contacting elements mounted therewithin, wherein the ionically-conductive medium is either applied to the rotating cathode cylinders or moving metal-fuel tape as a viscous gel, or integrated with the metal-fuel tape or moving cathode cylinders as a solid-state film, that is transported at substantially the same velocity as the metal-fuel tape and moving cathode cylinders at the locus of points at which the ionically-conductive medium contacts the metal-fuel tape and the cathode cylinder during system operation;

Fig. 12A is a cross-sectional view of a section of a first type of metal-fuel tape that can be used in the system of Fig. 11, realized in the form of thin layer of metal fuel;

Fig. 12B is a cross-sectional view of a section of a second type of metal-fuel tape that can be used in the system of Fig. 11, realized by depositing metallic powder and binder on a substrate;

Fig. 12C is a cross-sectional view of a section of a third type of metal-fuel tape that can be used in the system of Fig. 11, realized by impregnating metallic powder within a substrate material;

Fig. 12D is a cross-sectional view of a cathode cylinder in the system of Fig. 11, in which an ionically-conductive solid-state film layer is applied over the outer surface thereof;

Fig. 13 is a schematic representation of a second illustrative embodiment of the metal-air fuel-cell battery (FCB) system of the present invention, wherein a plurality of cathode cylinders are rotatably mounted within a compact support fixture, and metal-fuel tape stored within a cassette-type cartridge is transported over the surface of the rotatably mounted cathode cylinders while an ionically-conductive belt structure is transported at substantially the same velocity as the metal-fuel tape and cathode cylinders at the locus of points at which the ionically-conductive belt contacts the cathode cylinders and metal-fuel tape;

Fig. 13A is an elevated side view of the (FCB) system depicted in Fig. 13, showing the path of travel of the metal-fuel tape through the compact support fixture, and the location of path guides and cathode and anode contacting elements mounted therewithin, relative to the ionically-conductive belt structure;

Fig. 14 is a cross-sectional view of a section of the ionically-conductive belt used in the system of Fig. 13;

Fig. 15A is a cross-sectional view of a section of a first type of metal-fuel tape that can be used in the system of Fig. 13, realized in the form of thin layer of metal fuel;

Fig. 15B is a cross-sectional view of a section of a second type of metal-fuel tape that can be used in the system of Fig. 13, realized by depositing metallic powder and binder on a substrate;

Fig. 15C is a cross-sectional view of a section of a third type of metal-fuel tape that can be used in the system of Fig. 13, realized by impregnating metallic powder within a substrate material;

Fig. 16 is a tenth illustrative embodiment of the FCB system, wherein metal-fuel tape is transported over a plurality of cathode belt structures at substantially the same velocity at the locus of points at which the ionically-conductive medium contacts the metal-fuel tape and the cathode belt structure, and wherein each cathode-contacting structure engages the outer surface of the cathode belt structure and each corresponding anode-contacting structure is disposed opposite the cathode-contacting structure;

Fig. 16A is an elevated side view of the FCB system shown in Fig. 16;

Fig. 16B is a partially cut-away perspective view of one pair of cathode and anode contacting structures employed in the system of Fig. 16, shown contacting the cathode belt structure and metal-fuel tape with ionically-conductive medium disposed therebetween;

Fig. 16C is a partially cut-away cross-sectional view of one pair of cathode and anode contacting structures employed in the system shown in Fig. 16B, shown rotatably mounted relative to the cathode belt structure and metal-fuel tape disposed therebetween;

Fig. 17A is a cross-sectional view of a section of a first type of metal-fuel tape that can be used in the system of Fig. 16, realized in the form of thin layer of metal fuel, and coated on one-side thereof with a thin layer of ionically-conductive gel or solid-state film;

Fig. 17B is a cross-sectional view of a section of a second type of metal-fuel tape that can be used in the system of Fig. 16, realized by depositing metallic powder and binder on a substrate, and coated on one-side thereof with a thin layer of ionically-conductive gel or solid-state film;

Fig. 17C is a cross-sectional view of a section of a third type of metal-fuel tape that can be used in the system of Fig. 16, realized by impregnating metallic powder within a substrate material, and coated on one-side thereof with a thin layer of ionically-conductive gel or solid-state film;

Fig. 18 is a cross-sectional view of a section of a first-type of cathode belt structure for use in the system of Fig. 16, on which an ionically-conductive viscous gel is applied during system operation, or an ionically-conductive solid-state film is applied during manufacture;

Fig. 19 is a eleventh illustrative embodiment of the FCB system, wherein double-sided metal-fuel tape is transported over a common solid-state, ionically-conductive belt structure which, in turn, is transported over a plurality of cathode belt structures at substantially the same velocity at the locus of points at which the ionically-conductive belt contacts both the metal-fuel tape and the cathode belt structure, and wherein each cathode-contacting structure engages the outer surface of the cathode belt structure and each corresponding anode-contacting structure is disposed opposite the cathode-contacting structure;

Fig. 19A is an elevated side view of the FCB system shown in Fig. 19;

Fig. 19B is a partially cut-away perspective view of one pair of cathode and anode contacting structures employed in the system of Fig. 19, shown rotatably mounted relative to the cathode belt structure and metal-fuel tape disposed therebetween;

Fig. 20 is a twelvth illustrative embodiment of the FCB system, wherein metal-fuel tape is transported over a plurality of cathode belt structures (each coated with an ionically-conductive film layer) at substantially the same velocity at the locus of points at which the ionically-conductive film coating contacts both the metal-fuel tape and the cathode belt structure, and wherein each cathode-contacting structure engages the outer surface of the cathode belt structure and each corresponding anode-contacting structure is disposed opposite the cathode-contacting structure;

Fig. 20A is an elevated side view of the FCB system shown in Fig. 20;

Fig. 20B is a partially cut-away perspective view of one pair of cathode and anode contacting structures employed in the system of Fig. 20, shown contacting the cathode belt structure and metal-fuel tape with ionically-conductive medium disposed therebetween;

Fig. 21 is a thirteenth illustrative embodiment of the FCB system, wherein double-sided metal-fuel tape is transported over a plurality of cathode belt structures (each coated with an ionically-conductive film layer) at substantially the same velocity at the locus of points at which the ionically-conductive film layer contacts both the metal-fuel tape and the cathode belt structure, and wherein a pair of cathode-contacting structures engages the outer surfaces of a pair of cathode belt structures between which a pair of ionically-conductive belts and double-sided metal-fuel tape are interposed with an anode-contacting element engaging the double-sided metal-fuel tape;

Fig. 21A is a partially cut-away perspective view of one set of cathode and anode contacting structures employed in the system of Fig. 24, shown contacting the cathode belt structures, with ionically-conductive belts and double-sided metal-fuel tape disposed therebetween; and

Fig. 22 is a fourteenth illustrative embodiment of the FCB system, wherein multiple streams of metal-fuel tape are simultaneously transported over a plurality of cathode belt structures, and simultaneously taken up on a take-up reel in order to reduce bending of metal-fuel tape during system operation;

Fig. 23A is a schematic representation of a transportation vehicle, wherein the electrical power generation system of the present invention is provided for the purpose of generating and supplying electrical power to electrically-driven motors coupled to the wheels of the vehicle, and wherein auxiliary and hybrid power sources are provided for recharging metal-fuel within the FCB subsystems thereof;

Fig. 23B is a schematic representation of the electrical power generation system of the present invention realized as a stationary electrical power plant having auxiliary and hybrid power sources for recharging metal-fuel within the FCB subsystems thereof;

Fig. 24A is a schematic representation of the electrical power generation system of a first illustrative embodiment, wherein a network of metal-air FCB subsystems are operably connected to a DC power bus structure and controlled by a network control subsystem in operable association with a network-based metal-fuel management subsystem;

Fig. 24B is a schematic representation of the electrical power generation system of a second illustrative embodiment, wherein the output DC power bus structure of Fig. 24A is operably connected to an output AC power bus structure by way of a DC-to-AC power converter, for supplying AC power to electrical loads;

Fig. 24C is a schematic representation of the database structure maintained by the network-based metal-fuel/metal-oxide management subsystem shown in Figs. 24A and 24B; and

Fig. 25 is a graphical representation showing how a additional metal-air FCB subsystems are enabled into operation in their discharge mode as a function of an increase in the output power requirements demanded by an electrical load which increases over time.

BEST MODES FOR CARRYING OUT THE PRESENT INVENTION

Referring now to the figures in the accompanying Drawings, the best modes for carrying out the present invention will now be described in great technical detail, wherein like elements are indicated by like reference numbers.

The present invention teaches transporting the metal-fuel tape, cathode structure(s) and ionically-conductive medium in a metal-air FCB system at substantially the same velocity at the locus of points at which the ionically-conductive medium contacts the cathode structures and the metal-fuel tape. This condition of operation substantially reduces the generation of frictional (e.g. shear) forces among the metal-fuel tape, cathode structures and ionically-conductive medium. In turn, this reduction in frictional (e.g shear) forces among such system components results in a reduction in: the amount of electrical power required to transport the cathode structures, metal-fuel tape and ionically-conductive medium during system operation; the shedding of metal-oxide particles from metal-fuel tape and the embedding of such particles within the porous structure of the cathode; and the likelihood of damaging of the cathode structures and metal-fuel tape used in the

FCB system. In Figs. 1A through 1C, this principle of operation is schematically illustrated for three different FCB system designs.

A first generalized embodiment of the metal-air FCB system of the present invention is generally depicted by reference numeral 1 shown in Fig. 1A. In this generalized embodiment of the present invention, the ionically-conductive medium (ICM) 2 is realized as a fluid or fluid-like substance which is free to move relative to both the metal-fuel tape 3 and the cathode structure(s) 4 employed within the system, while the metal-fuel tape and cathode structure(s) are transported at substantially the same velocity at the locus of points which the ionically-conducing medium contacts the metal-fuel tape and the cathode structure during tape discharging and recharging cycles. As shown, a cathode-contacting elements 5 establishes electrical contact with cathode structures 4 during system operation while an anode-contacting element 6 establishes electrical contact with metal-fuel tape (i.e. anode) 3.

A second generalized embodiment of the metal-air FCB system of the present invention is generally depicted by reference numeral 1 and shown in Fig. 1B. In this generalized embodiment of the present invention, the ionically-conductive medium 2 is integrated with the surface of the metal-fuel tape 3 (e.g. in the form of a (gel-like or solid-state film layer applied thereto), while the metal-fuel tape 3, ionically-conductive medium 2 and cathode structure(s) 4 are transported at substantially the same velocity at the locus of points at which the ionically-conductive medium 2 contacts both the metal-fuel tape 3 and the cathode structure 4 during system operation.

A third generalized embodiment of the metal-air fuel-cell battery (FCB) system of the present invention is shown in Fig. 1C, and generally depicted by reference numeral 1. In this generalized embodiment of the present invention (e.g. in the form of a gel-like or solid-state film layer applied thereto), while the metal-fuel tape 3, ionically-conductive medium 2, and cathode structure(s) 4 are transported at substantially the same velocity at the locus of points at which the ionically-conducing medium contacts the metal-fuel tape and the cathode structure during system operation.

There are various ways to realize the ionically-conductive medium in each of these generalized embodiments of the FCB system. Also, there are various ways in which to achieve velocity control (i.e. velocity equalization) in each of these generalized system embodiments. Depending on how the cathode structure is realized, the illustrative embodiments of the present invention disclosed herein can be classified into one of two groups to simplify description of the corresponding FCB systems.

For example, in the first group of illustrative embodiments, shown in Figs. 2 through 6D, the cathode structure is realized as a rotatable structure of cylindrical geometry having fine perforations in the surface thereof and a hollow central core enabling the transport of air (i.e. oxygen) to the interface between the metal-fuel tape and ionically-conductive medium. In the second group of illustrative embodiments, shown in Figs. 7 through 10D, the cathode structure is realized as a belt structure having ultrafine perforations in the surface thereof to permit oxygen transport to the metal-fuel tape and the ionically-conductive medium. The FCB systems classified into these two groups will now be described in detail below.

First Illustrative Embodiment Of The FCB System

In the first illustrative embodiment of the FCB system 10 shown in Figs. 2 through 2C, the cathode structure 4 is realized as a plastic cylindrical structure 11 having a hollow center 11A with fine perforations 12 in the surface thereof to permit oxygen transport to the interface formed between the ionically-conductive medium and metal-fuel tape 13 transported thereover. As shown, a cathode element 14 is mounted over the outer surface of the plastic hollow cylinder 11. The cathode element 14 is made from nickel mesh fabric 15 embedded within carbon and catalytic material 16. Preferably, the metal-fuel tape 13 is transported between a pair of supply and take-up reels as taught in Applicant's copending Application Serial No. 09/074,337. Also, the metal-fuel tape can be fabricated using any of the techniques taught in Application Serial No. 09/074,337.

In the event that the cathode cylinder 11 is employed within a Metal-Fuel Tape Discharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Discharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 2. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, the interior portion of the cathode cylindrical 11 shown in Fig. 2 can be equipped with an oxygen-injection chamber (connected to an air pump or oxygen source), one or more pO_2 sensors, one or more temperature sensors, discharging head cooling equipment, and the like, so that system controller 22 can control the pO_2 level within the cathode element 14, as well as maintain the temperature of the discharging head during discharging operations.

Similarly, in the event that the cathode cylinder 11 is employed within a Metal-Fuel Tape Recharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Recharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 2. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337, the interior portion of the cathode cylindrical 11 shown in Fig. 2 can be equipped with an oxygen-evacuation chamber (connected to a vacuum pump or like device), one or more pO_2 sensors, one or more temperature sensors, recharging head cooling equipment, and the like, so that system controller 22 can control the $p0_2$ level within the cathode element 14, as well as maintain the temperature of the recharging head during recharging operations.

As shown in Fig. 2, the cathode cylinder 11 is rotated about its axis of rotation at an angular velocity controlled by a cathode drive unit 17. As shown, the cathode drive unit 17 has a drive shaft 18 with a gear 19 that engages teeth formed on the edge of cylindrical structure 11. The metal-fuel tape 13 is transported over the surface of the cylindrical cathode element 14 by a fuel-tape transporter 21 operable during discharging and recharging operations. The cathode drive unit 17 and the fuel-tape transporter 21 are controlled by a system controller 22 so that the metal-fuel tape 13, the cathode structure 14 and ionically-conductive medium are transported at substantially the same velocity at the locus of points at which the ionically-conducing medium contacts the metal-fuel tape and the cathode structure. By controlling the relative movement between the metal-fuel tape, ionically-conductive medium and the cylindrical cathode structure, the system controller 22 effectively minimizes the generation of frictional (e.g. shear) forces therebetween and thus solves the problems associated with such forces.

In general, velocity control among the cathode structure, ionically-conductive medium and metal-fuel tape can be achieved in various ways in the FCB system of Fig. 2. For example, one way would be to drive the cylindrical cathode structure 11 using a belt that is also used to transport the metal-fuel tape 13 (e.g. between supply and take-up reels or hubs within a cassette type-device. Another way would be to drive the cylindrical cathode structure 11 using a first set of DC-controlled motors, while driving the supply and take-up hubs of the fuel cassette device using a second set of DC-controlled motors, synchronized with the first set of DC-controlled motors. Other ways of achieving velocity control will become apparent to those skilled in the art having had the benefit of reading the present disclosure.

In general, it will be desired in most applications to mount a plurality of pairs of "rotatable" cathode and anode contacting elements about the cylindrical cathode structure of the system of Fig. 2. Such an arrangement will enable maximum current collection from each rotating cathode in the system, at the generated output voltage. For clarity of exposition, however, only a single pair of cathode and anode contacting elements are shown mounted about the cathode cylinder in Fig. 2.

Specifically, as shown in Fig. 2, an electrically-conductive "cathode-contacting" element 23 is rotatably supported at each end of the cylindrical cathode structure 11 by a pair of brackets or like structures so that the cathode-contacting element 23 is arranged in electrical contact with the nickel mesh fabric 15 exposed on the outer edge portion 24 thereof and is permitted to rotate about the axis of rotation of the cathode-contacting element as the cylindrical cathode structure is rotated about the axis of rotation of the cylindrical cathode structure. Also as shown in Fig. 2, an electrically-conductive "anode-contacting" element 25 is rotatably supported by a pair of brackets 26 or like structures so that it is arranged closely adjacent the cylindrical cathode structure, in electrical contact with the underside surface of the metal-fuel tape 13, and permitted to rotate about the axis of rotation of the anode-contacting element as the metal-fuel tape is transported over the rotating cathode structure with the ionically-conductive medium disposed therebetween. As shown, the rotatable cathode and anode contacting elements 23 and 25 are electrically connected to electrical conductors (e.g. wiring) 27 and 28 which are terminated at an output power controller 29. In turn, the electrical load is connected to the output power controller 29 for receiving a supply of electrical power from the FCB system.

As shown in Fig. 2, oxygen-rich air is permitted to flow through the hollow central bore 11A formed through the cylindrical cathode structure 11 by passive diffusion, or by active forcing action created by a fan, turbine, or like structure. During tape discharging operations, the oxygen-rich air is permitted to flow through the perforations 12 formed in the cathode structure and reach the interface between ionically-conductive medium (e.g. electrolyte) 30 and the metal-fuel tape.

In the illustrative embodiment shown in Fig. 2, the ionically-conductive medium 30 is realized as an ionically-conductive fluid or viscous gel applied in the form of a thin film over the outer surface of the cathode cylinder 11. The ionically-conductive fluid/gel 30 can be applied to the surface of the cathode element or metal-fuel tape in either a continuous or periodic manner to ensure that ionically-conductive medium is sufficiently replenished during system operation and thus maintain an optimum level of hydroxide ion concentration at the interface between the ionically-conductive medium and metal-fuel tape. Notably, the required thickness of the ionically-conductive film layer will vary from application to application, but typically will depend on a number of factors including, for example, the electrical conductivity of the ionically-conductive medium, the current flow expected to be produced by the FCB system during discharging operations, the surface area of the cathode element, and the like.

Ionically-conductive fluid/gel 30 can be made using the following formula. One mole of potassium hydroxide (KOH) and one mole of calcium chloride are dissolved in 100 grams of water. The function of KOH is to provide a hydroxide ion source, whereas the function of calcium chloride is as a hygroscopic agent. Thereafter, one-half a mole of polyethylene oxide (PEO) is added to the mixture as an ion carrier. The mixture is then blended for about 10 minutes. Thereafter, 0.1 mole of cellulose methoxycarboxylic acid, a gellant, is added to the blended mixture. This formula results in the generation of an ionically-conductive gel suitable for application to the surface of the cathode element 14 or metal-fuel tape 13 of the FCB system.

Alternatively, ionically-conductive medium 30 can be realized as a solid-state ionically-conductive film applied to the outer surface of the cylindrical cathode element 14, or the inner surface of the metal-fuel tape. In this alternative embodiment of the present invention, the solid-state ionically-conductive film can be formed on the cathode element or the metal-fuel tape using either of the following formulas set forth below.

In accordance with the first formula, one mole of KOH, a hydroxide source, and 0.1 mole of calcium chloride, a hygroscopic agent, are dissolved in the mixed solvents of 60 milliliters of water and 40 milliliters of tetrahydrogen furan (THF). Thereafter, one mole of PEO is added to the mixture as an ion carrier. Then, the resulting solution (e.g. mixture) is cast (i.e. coated) as a thick film onto the outer surface of the cathode element 14, or as a thick film onto the underside surface of the metal-fuel tape 13, whichever the case may be. Using the above formulation, ionically-conductive film can be obtained with a thickness in the range of about 0.2 mm to about 0.5 mm. As the mixed solvents (i.e. water and THF) within the applied film coating are allowed to evaporate, an ionically-conductive solid state film is formed on the outer surface of the cathode element 14, or on the underside surface of the metal-fuel tape, whichever the case may be.

According to the second formula, one mole of KOH and 0.1 mole of calcium chloride are dissolved in the mixed solvents of 60 milliliters of water and 40 milliliters of tetrahydrogen furan (THF). The function of KOH is as an ion source, whereas the function of the calcium chloride is as a hygroscopic agent. Thereafter, one mole of polyvinyl chloride (PVC) is added to the solution in an amount sufficient to produce a gel-like substance. The solution is then cast (coated) as a thick film onto the outer surface of the cathode element 14, or as a thick film onto on the underside surface of the metal-fuel tape, whichever the case may be. Using the above formulation, ionically-conductive film can be obtained with a thickness in the range of about 0.2 mm to about 0.5 mm. As the mixed solvents (i.e. water and THF) within the applied coating are allowed to evaporate, an ionically-conductive solid state film forms on the outer surface of the cathode element 14, or on the underside surface metal-fuel tape, as the case may be.

When using the ionically-conductive media 30 as described hereinabove, it will necessary to provide a means for achieving "wetting" between (1) the ionically-conductive layer 30 and the metal-fuel tape 13, and (2) the ionically-conductive medium 30 and the movable cathode cylinder 11. One way of achieving wetting would be to continuously or periodically apply a coating of water (H_2O) and/or electrolyte make-up solution to the surface of the metal-fuel tape 13 (and/or ionically-conductive medium 30) during system operation to enable a sufficient level of ionic transport between the metal-fuel tape 13 and the ionically-conductive medium 30 and also between the movable cathode cylinder 11 and the ionically-conductive medium 30. Notably, the thickness of the water coating applied to the metal-fuel tape (and/or the ionically-conductive medium) will depend on the transport speed of the metal fuel tape, its water absorption properties, etc. In the illustrative embodiment shown in Fig. 2, wetting of the metal-fuel tape 13 and/or ionically-conductive medium 30 can be carried out using applicator 54 and dispensing mechanism 55. It is understood, however, that other methods of wetting the metal-fuel tape 13 (13', 13") and/or ionically-conductive medium 30 may be used with excellent results.

While the illustrative embodiments schematically depicted in Fig. 1 and described hereinabove are shown for use in single-cathode/single-anode type applications, it is understood that such system embodiments can be readily modified to include a plurality of electrically-isolated cathode elements formed about the plastic support cylinder 11 for use with multi-track metal-fuel tape of the type taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, supra. The primary advantage of such system modifications is that it will be possible to deliver electrical power at various output voltage levels required by particular electrical loads.

Second Illustrative Embodiment Of The FCB System

In the second illustrative embodiment of the FCB system shown in Figs. 2 through 2C, is similar to the FCB system shown in Fig. 2 except that the metal-fuel tape employed in the FCB System of Fig. 3 has a solid-state ionically-conductive coating 31 applied to the underside surface thereof, and not on the outer surface of the cathode structure as shown in Fig. 2.

In this alternative embodiment of the present invention, the metal-fuel tape employed in the FCB System of Fig. 3 can be realized in a variety of different ways. As shown in Fig. 3C1, a first type of metal-fuel tape 13' is formed by applying a ionically-conductive gel or gel-like (i.e. solid-state) layer 31 to the surface of a thin layer of metal-fuel 32. As shown in Fig. 3C2, a second type of metal-fuel tape 13" is formed by embodying an ionically-conductive medium 33 and metal-fuel particles 34 within a substrate material 35. Techniques for fabricating such forms of metal-fuel are described in copending Application Serial No. 09/074,377.

Third Illustrative Embodiment Of The FCB System

The third illustrative embodiment of the FCB system shown in Figs. 4 through 4C, is similar to the FCB system shown in Fig. 1 except that the rotatable anode-contacting element 25 is arranged to establish electrical contact with the outer surface of the metal-fuel tape 13. Consequently, the path of current flow through metal-fuel tape employed in the FCB system of Fig. 4 will be different from the path of current flow through metal-fuel tape employed in the FCB system of Fig. 2. All other respects, the FCB system of Fig. 4 is similar to the FCB system of Fig. 2.

Fourth Illustrative Embodiment Of The FCB System

The fourth illustrative embodiment of the FCB system shown in Figs. 5 through 5C2, is similar to the FCB system shown in Fig. 3 except that the rotatable anode-contacting element 25 is arranged to establish electrical contact with the outer surface of the metal-fuel tape 13', 13". Consequently, the path of current flow through metal-fuel tape 13', 13" employed in the FCB system of Fig. 5 will be different from the path of current flow through metal-fuel tape employed in the FCB system of Fig. 3. All other respects, the FCB system of Fig. 5 and its embodiments are similar to the FCB system of Fig. 3 and its embodiments.

Fifth Illustrative Embodiment Of The FCB System

In Fig. 6, a fifth illustrative embodiment of the FCB system of the present invention is shown. In this illustrative embodiment, the ionically-conductive medium is realized in the form of an ionically-conductive belt structure running between a belt transport cylinder and a cathode cylinder of the general type shown in Figs. 2, 3, 4, and 5.

As shown in Fig. 6, the ionically-conductive belt 35 is rotatably supported between cathode cylinder 11 as described hereinabove, and a belt transport cylinder 36 made of plastic or other electrically non-conductive material. As shown, a supply of metal-fuel tape 13 is transported over the ionically-conducing belt 35, between a pair of supply and take-up reels as taught in Applicant's copending Application Serial No. 09/074,337.

In the event that the cathode cylinder 11 is employed within a Metal-Fuel Tape Discharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Discharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 6. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, the interior portion of the cathode cylindrical 11 shown in Fig. 6 can be equipped with an oxygen-injection chamber (connected to an air pump or oxygen source), one or more $p0_2$ sensors, one or more temperature sensors, discharging head cooling equipment, and the like, so that system controller 22 can control the $p0_2$ level within the cathode element 14, as well as maintain the temperature of the discharging head during discharging operations.

Similarly, in the event that the cathode cylinder 11 is employed within a Metal-Fuel Tape Recharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Recharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 6. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337, the interior portion of the cathode cylindrical 11 shown in Fig. 6 can be equipped with an oxygen-evacuation chamber (connected to a vacuum pump or like device), one or more pO_2 sensors, one or more temperature sensors, recharging head cooling equipment, and the like, so that system controller 22 can control the $p0_2$ level within the cathode element 14, as well as maintain the temperature of the recharging head during recharging operations.

As shown in Fig. 6, the cathode cylinder 11 is rotated at a controlled angular velocity by a cathode drive unit 38, while the belt transport cylinder 36 is rotated at a controlled angular velocity by an drive unit 39. The metal-fuel tape 13 is transported over the surface of the ionically-conductive belt 35 and cathode cylinder 11 by operation of tape transport mechanism 21 during discharging and recharging operations.

The drive units 38 and 39 and tape transporter 21 are controlled by system controller 22 so that the metal-fuel tape 13, ionically-conductive belt 35 and the cathode cylinder 11 are maintained at substantially same velocity at the locus of points at which the ionically-conductive belt 35 contacts the metal-fuel tape 13 and the cathode cylinder 11 during system operation. By controlling the relative movement between the metal-fuel tape 13, ionically-conductive belt structure 35 and cylindrical cathode structure 11, the system controller 22 effectively minimizing the generation of frictional forces therebetween and thus reduces the likelihood of damage caused to the cathode element 14 and metal-fuel tape 13.

In general, velocity control can be achieved in various ways in the FCB system of Fig. 6. For example, one way might be to drive the cathode cylindrical 11 and transport cylinder 36 using a belt-like structure that is also used to transport the supply of metal-fuel tape (e.g. between supply and take-up reels or hubs within a cassette type-device). Another way would be to drive the cathode cylinder 11 and transport cylinder 36 with a pair of DC-controlled motors, while driving the supply and take-up hubs of the fuel cassette device using a second pair of DC-controlled motors, synchronized with the first pair of DC-controlled motors. Other ways of achieving velocity control will become apparent to those skilled in the art.

In general, it will be desired in most applications to mount a plurality of pairs of "rotatable" cathode and anode contacting elements about the cathode cylinder of the system of Fig. 6. Such an arrangement will enable maximum current collection from each rotating cathode in the system, at the generated output voltage. For clarity of exposition, however, only a single pair of cathode and anode contacting elements are shown mounted about the cathode cylinder in Fig. 6.

As shown in Fig. 6, a electrically-conductive "cathode-contacting" element 23 is rotatably supported at each end of cathode cylinder 11 by a pair of brackets so that cathode-contacting element 23 is arranged in electrical contact with the exposed nickel mesh fabric 20 on the edge portions of the cathode cylinder 11 as the cathode cylinder is rotated about its axis of rotation. Also, an electrically-conductive "anode-contacting" element 25 is rotatably supported by brackets 26 that are arranged closely adjacent the cathode cylinder, in electrical contact with the outerside surface of the metal-fuel tape 13, as cathode cylinder is rotated about its axis of rotation. The cathode and anode contacting elements 23 and 25 are electrically connected to electrical conductors (e.g. wiring) 28 and 28 which are terminated at an output power controller 29. An electrical load can be connected to the output terminals of the output power controller 29 in order to receive a supply of electrical power generated within the FCB system.

As shown in Fig. 6, oxygen-rich air is permitted to flow through the hollow central bore 11A formed through the cylindrical cathode structure 11 by passive diffusion, or by active forcing action created by a fan, turbine, or like structure. During tape discharging operations, the oxygen-rich air is permitted to flow through the perforations 12 formed in the cathode structure 11 and reach the interface between the metal-fuel tape and the ionically-conductive belt structure 35.

In the illustrative embodiment shown in Figs. 6 and 6A, the ionically-conductive belt 35 can be realized as flexible belt having ionic-conduction characteristics. Such a belt can be made from an open-cell polymer material having a porous structure and impregnated with an ionically-conductive material (e.g. KOH) capable of supporting ionic transport between the cathode and anode structures of the FCB system. In general, there will be many ways of making the ionically-conductive belt. For purposes of illustration, two formulas are described below.

In accordance with the first formula, one mole of KOH and 0.1 mole of calcium chloride are dissolved in the mixed solvents of 60 milliliters of water and 40 milliliters of tetrahydrogen furan (THF). The function of KOH is as a hydroxide ion source, whereas calcium chloride is as a hygroscopic agent. Thereafter, one mole of PEO is added to the mixture. Then, the solution is cast (or coated) as a thick film onto substrate made of polyvinyl alcohol (PVA) type plastic material. This material has been found to work well with PEO, although it is expect that other substrate materials having a surface tension higher than the film material should work as well with acceptable results. As the mixed solvents evaporate from the applied coating, an ionically-conductive solid state membrane (i.e. thick film) is formed on the PVA substrate. By peeling the solid state membrane off the PVA substrate, a solid-state ionically-conductive membrane or film is formed. Using the above formulation, it is possible to form ionically-conductive films having a thickness in the range of about 0.2 to about 0.5 millimeters. Then, the solid-state membrane can be cut into a shape required to form a belt-like structure transportable about two or more rotating cylinders. The ends of the shaped membrane can be joined by an adhesive, ultra-sonic welding, appropriate fasteners or the like to form a solid-state ionically-conductive belt structure 35 for use in the FCB systems of the present invention.

In accordance with the second formula, one mole of KOH and 0.1 mole of calcium chloride are dissolved in the mixed solvents of 60 millimeters of water and 40 milliliters of tetrahydrogen furan (THF). The function of KOH is as a hydroxide ion source, whereas calcium chloride is as a hygroscopic agent. Thereafter, one mole of polyvinyl chloride (PVC) is added to the mixture. Then, the resulting solution is cast (or coated) as a thick film onto substrate made of polyvinyl alcohol (PVA) type plastic material. This material has been found to work well with PVC, although it is expect that other substrate materials having a surface tension higher than the film material should work as well with acceptable results. As the mixed solvents evaporate from the applied coating, an ionically-conductive solid state membrane (i.e. thick film) is formed on the PVA substrate. By peeling the solid state membrane off the PVA substrate, a solid-state ionically-conductive membrane is formed. Using the above formulation, it is possible to form ionically-conductive films having a thickness in the range of about 0.2 to about 0.5 millimeters. Then, the solid-state film or membrane can be cut into a shape required to form a belt-like structure transportable about two or more rotating cylinders. The ends of the shaped membrane can be joined by an adhesive, ultra-sonic welding, appropriate fasteners or the like to form a solid-state ionically-conductive belt structure 35 for use in the FCB systems of the present invention.

When using the ionically-conductive belt 35 described hereinabove, it will necessary to provide a means for achieving "wetting" between (1) the ionically-conductive belt 35 and the metal-fuel tape 13 (13', 13"), and (2) the ionically-conductive belt 35 and the rotatable cathode cylinder 11. One way of achieving wetting would be to continuously or periodically apply a coating of water (H_2O) and/or electrolyte make-up solution to the surface of the metal-fuel tape (and/or ionically-conductive belt) during system operation to enable a sufficient level of ionic transport between the metal-fuel tape and the ionically-conductive belt and also between the movable cathode cylinder and the ionically-conductive belt. Notably, the thickness of the water coating applied to the metal-fuel tape (and/or the ionically-conductive belt) will depend on the transport speed of the metal fuel tape, its water absorption properties, etc. In the illustrative embodiment shown in Fig. 6, wetting of the metal-fuel tape and/or ionically-conductive belt can be carried out using applicator 54 and dispensing mechanism 55. It is understood, however, that other methods of wetting the metal-fuel tape and/or ionically-conductive belt may be used with excellent results.

While the illustrative embodiment shown in Fig. 6 is designed for single-cathode/single-anode type applications, it is understood that this system embodiment can be readily modified to include a plurality of electrically-isolated cathode elements formed about the cathode support cylinder for use with multi-track type metal-fuel tape, as taught in Applicant's copending Application Serial No. 08/944,507, supra.

In this alternative embodiment of the present invention, the metal-fuel tape for use in the FCB System of Fig. 6 can be realized in a variety of different ways. As shown in Fig. 6B, a first type of metal-fuel tape 13 is formed as a thin layer of metal-fuel material (e.g. zinc). A second type of metal-fuel tape 13' is formed by depositing a metallic powder (e.g. zinc powder) and binder (e.g. PVC) 31 on a polyester substrate 32. As shown in Fig. 6D, a third type of metal-fuel tape 13" is formed by impregnating metallic powder 33 (e.g. zinc powder) within a substrate material 34 such as PVC. Techniques for fabricating such forms of metal-fuel are described in copending Application Serial No. 09/074,337.

Sixth Illustrative Embodiment Of The FCB System

In Fig. 7, a sixth illustrative embodiment of the FCB system of the present invention is shown. In this illustrative embodiment, the moving cathode structure is realized as a cathode belt structure 40 running between a pair of cylindrical rollers 41 and 42, over which a supply of metal-fuel tape 13 (13', 13") is transported.

As shown in Fig. 7, the cathode belt structure 40 is rotatably supported between cylindrical rollers 41 and 42 driven by drive units 38 and 39, while a supply of metal-fuel tape 13 (13', 13") is transported over the cathode belt structure 40 and between a pair of supply and take-up reels as taught in Applicant's copending Application Serial No. 09/074,337. The drive units 38 and 39 and metal-fuel tape transporter 21 are controlled by system controller 22 so that the velocity of both the metal-fuel tape 13 (13',13") and the cathode belt structure 40 are maintained at substantially the same velocity at the locus of points which the ionically-conducing medium contacts the metal-fuel tape and the cathode structure during system operation. By controlling the relative movement between the metal-fuel tape and cathode belt structure between cylindrical rollers 41 and 42, the system controller 22 effectively minimizes the generation of frictional forces therebetween and thus reduces wearing and tearing of the metal-fuel tape 13.

The cathode belt 40 has ultrafine perforations in the surface thereof to permit oxygen transport to the anodic metal-fuel tape 13 (13',13") passing thereover. A preferred method of making the flexible cathode structure is to blend black Carbon powder (60%/weight), with a binder material such as Teflon emulsion(T-30 from Dupont) (20%/weight), and catalyst material such as magnesium dioxide MnO_2 (20%/weight) within 100 milliliters of water (solvent) and surfactant (e.g Triton X-10 from Union Carbide) 2.0%/weight in order to make a slurry. Then the slurry is cast or coated onto the nickel sponge (or mesh fabric material). The slurry-coated nickel mesh fabric is then air dried for about 10 hours. Thereafter, dried article is compressed at 200 [pounds/cm^2] in to form flexible cathodic material having a desired porosity (e.g. 30-70%) and about 0.5-0.6 millimeters. It is understood, however, that the thickness and porosity of the cathode material may vary from application to application. The cathode material is then sintered at about 280 degree C for about 2 hours to remove the solvent (i.e. water) and provide a flexible sheet of cathodic material which can then be cut into the desired dimensions to form a cathode belt structure for the FCB system under design. The ends of belt structure can be joined by soldering, fasteners, or the like to form a virtually seamless cathode surface about closed belt structure. The nickel mesh material can be exposed at the ends of the cathode belt structure 40 to allow cathode contacting elements 48 to establish electrical contact therewith during discharging and recharging operations.

When using the ionically-conductive media 53 described hereinabove, it will necessary to provide a means for achieving "wetting" between (1) the ionically-conductive medium 53 and the metal-fuel tape 13 (13', 13"), and (2) the ionically-conductive medium 53 and the movable cathode belt 40. One way of achieving wetting would be to continuously or periodically apply a coating of water (H_2O) to the surface of the metal-fuel tape (and/or ionically-conductive medium 53) during system operation to enable a sufficient level of ionic transport between the metal-fuel tape and the ionically-conductive medium 53 and also between the movable cathode belt 40 and the ionically-conductive medium 53. Notably, the thickness of the water coating applied to the metal-fuel tape 13 (and/or the ionically-conductive medium 53) will depend on the transport speed of the metal fuel tape 13, its water absorption properties, etc. In the illustrative embodiment shown in Fig. 7, wetting of the metal-fuel tape and/or ionically-conductive medium 53 can be carried out using applicator 54 and dispensing mechanism 55. It is understood, however, that other methods of wetting the metal-fuel tape and/or ionically-conductive medium 53 may be used with excellent results.

In general, velocity control can be achieved in various ways in the FCB system of Fig. 7. For example, one way might be to drive transport cylinders 41 and 42 with a belt structure that is also used to transport the metal-fuel tape 13 (e.g. between supply and take-up reels or hubs within a cassette type-device). Another way might be to drive transport cylinders 41 and 42 with a first pair of DC-controlled motors, while driving the supply and take-up hubs of the metal-fuel cassette device using a pair of DC-controlled motors, synchronized with the first and second DC speed-controlled motors. Other ways of achieving velocity control will become apparent to those skilled in the art.

In general, it will be desired in most applications to mount a plurality of pairs of "rotatable" cathode and anode contacting elements about the cathode belt structure of the system of Fig. 7. Such an arrangement will enable maximum current collection from each cathode belt structure in the system, at the generated output voltage. For clarity of exposition, however, only a single pair of cathode and anode contacting elements are shown mounted along the cathode belt structure in Fig. 7.

As shown in Fig. 7, the electrically-conductive "cathode-contacting" element 48 is rotatably supported by a pair of brackets 49 so that it is arranged in electrical contact with the exposed nickel mesh fabric 45 on the edge portions of the cathode belt structure 40 as it is transported between transport cylinders 41 and 42. Also, an electrically-conductive "anode-contacting" element 50 is rotatably supported by brackets 49 , above the metal-fuel tape 13 (13', 13") and opposite the cathode contacting element 48, so that anode-contacting element establishes electrical contact with the outerside surface of the metal-fuel tape, as shown in Fig. 7. The cathode and anode contacting elements 48 and 50 are electrically connected to electrical conductors (e.g. wiring) which are terminated at an output power controller 29. An electrical load can be connected to the output terminals of the output power controller 29 in order to receive a supply of electrical power generated within the FCB system.

In the event that the cathode belt 40 is employed within a Metal-Fuel Tape Discharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Discharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 7. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, a portion of the cathode belt structure 40 shown in Fig. 7, along which electrical current is generated, can be enclosed by an oxygen-injection chamber (connected to an air pump or oxygen source), and having one or more pO_2 sensors, one or more temperature sensors, discharging head cooling equipment, and the like, so that system controller 22 can control the $p0_2$ level within this section of the moving cathode belt structure 40, as well as maintain the temperature of the discharging head therealong during discharging operations.

Similarly, in the event that the cathode belt structure 40 is employed within a Metal-Fuel Tape Recharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Recharging

Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 7. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, a portion of the cathode belt structure 40 shown in Fig. 7, along which electrical current is generated, can be enclosed by an oxygen-evacuation chamber (connected to a vacuum pump or like device), and having one or more pO_2 sensors, one or more temperature sensors, recharging head cooling equipment, and the like, so that system controller 22 can control the $p0_2$ level within this section of the moving cathode belt structure 40, as well as maintain the temperature of the recharging head therealong during recharging operations.

As shown in Fig. 7, during tape discharging operations, oxygen-rich air is permitted or forced to flow through the fine perforations 21 formed in the cathode belt structure 40 and reach the interface between the metal-fuel tape 13', 13", and the ionically-conductive medium (e.g. electrolyte gel) 53. During tape recharging operations, oxygen liberated from the interface between the metal-fuel tape and the ionically-conductive medium (e.g. electrolyte gel) is permitted or forced to flow through the fine perforations 21 formed in the cathode belt structure 40, to the ambient environment.

In the illustrative embodiment shown in Figs. 7 and 7A, the outer surface of cathode belt structure 40 (i.e facing the metal-fuel tape transported thereover) is coated with a solid-state ionically-conductive film 53 capable of supporting ionic transport between the cathode belt structure 40 and the metal-fuel tape 13 (13',13") transported through the FCB system. Alternatively, the under surface of metal-fuel tape facing the cathode belt structure 40 can be coated with a solid-state ionically-conductive film 53 capable of supporting ionic transport between the cathode belt structure 40 and the metal-fuel material along the transported metal-fuel tape 13 (13', 13"). This approach would enable to the use of a simpler cathode belt structure within the FCB system of this illustrative embodiment.

Another alternative method of supporting ionic transport between the cathode belt structure 40 and the metal-fuel tape 13 (13',13") is to apply a film of an ionically-conductive gel (or liquid) 53 onto the underside surface 13A of the metal-fuel tape as it is being transported over the cathode belt structure 40. This can be achieved using applicator 54, disposed beneath the metal-fuel tape 13 (13', 13"), and fed by dispenser 55 governed by system controller 22. During operation, a thin layer of ionically-conductive gel 53 is dispensed from applicator 54 over the surface of the metal-fuel tape contacting the cathode belt 40. Notably, the required thickness of the ionically-conductive film layer will vary from application to application, but typically will depend on a number of factors including, for example, the electrical conductivity of the ionically-conductive medium, the current flow expected to be produced by the FCB system during discharging operations, the surface area of the cathode element, and the like.

While the illustrative embodiment shown in Fig. 7 is designed for single-cathode/single-anode type applications, it is understood that this system embodiment can be readily modified to include a plurality of electrically-isolated cathode elements (tracks) formed along the flexible cathode belt structures for use with multi-track metal-fuel tape, as taught in Applicant's copending Application Serial Nos. 08/944,507, supra.

In alternative embodiments of the present invention, the metal-fuel tape for use with the FCB system of Fig. 7 can be realized in a variety of different ways. As shown in Fig. 7B, the first type of metal-fuel tape 13 is formed as a thin layer of metal-fuel material (e.g. zinc). The second type of metal-fuel tape 13' shown in Fig. 7C is formed by depositing a metallic powder (e.g. zinc powder) and binder (e.g. polyethylene) 31 on a polyester substrate 32. As shown in Fig. 7D, a third type of metal-fuel tape 13" is formed by impregnating metallic powder 33 (e.g. zinc powder) within a substrate material 34 such as polyvinyl chloride PVC. Techniques for fabricating such forms of metal-fuel are described in copending Application Serial Nos. 08/944,507 and 09/074,337.

During system operation, the cathode belt structure 40 is transported at a controlled velocity between the transport cylinders 41 and 42. Therewhile, the supply of metal-fuel tape 13 (13',13") is transported over the surface of the cathode belt structure 40 at substantially the same velocity that the ionically-conducing medium contacts the metal-fuel tape and the cathode belt structure 40, and enables electrical power generation without slippage or causing damage to the cathode belt structure and metal-fuel tape.

Seventh Illustrative Embodiment Of The FCB System

In Fig. 8, a seventh illustrative embodiment of the FCB system is shown which is similar to the FCB system shown in Fig. 7. The primary difference between these two systems is that in Fig. 8, the cathode-contacting element 48 is placed close to the transport cylinder 41 so that it contacts the outer surface of the conductive belt-structure

40, whereas the anode-contacting element 50 is placed closely to the cathode-contacting electrode 48 and establishes contact with the underside of the supply of metal-fuel tape 13 (13',13") being transported over the cathode belt structure 40. Consequently, the path of electrical current flow through metal-fuel tape 13 (13',13") employed in the FCB system of Fig. 8 will be different from the path of current flow through metal-fuel tape 13 (13',13") employed in the FCB system of Fig. 7. All other respects, the FCB system of Fig. 8 is similar to the FCB system of Fig. 7.

Eighth Illustrative Embodiment Of The FCB System

In Fig. 9, an eighth illustrative embodiment of the FCB system is shown which is similar to the FCB system shown in Fig. 7. The primary difference between these two systems is that in Fig. 9, the ionically-conductive medium is realized as an ionically-conductive layer formed on the underside of the supply of the metal-fuel tape 13 (13',13"). As shown in Fig. 9B, the first type of metal-fuel tape 58 is formed as a thin layer of metal-fuel material (e.g. zinc) 59, onto which an ionically-conductive layer 60 is laminated. A second type of metal-fuel tape 58' shown in Fig. 9C is formed by depositing a metallic powder (e.g. zinc powder) and binder (e.g. PVC) 61 on a polyester substrate 62 , onto which an ionically-conductive layer 60' is laminated. As shown in Fig. 9D, a third type of metal-fuel tape 58" is formed by impregnating metallic powder 63 (e.g. zinc powder) within a substrate material 64 such as PVC, onto which an ionically-conductive layer 60 is laminated. Techniques for fabricating such forms of metal-fuel are described in copending Application Serial Nos. 08/9444,507 and 08/074,337. All other respects, the FCB system of Fig. 9 is similar to the FCB system of Fig. 7.

Ninth Illustrative Embodiment Of The FCB System

Fig. 10 shows a ninth illustrative embodiment of the FCB system of the present invention. In this illustrative embodiment, the cathode structure is realized as a belt structure 40 transported between a first pair of cylindrical rollers 41 and 42 driven by drive units 37 and 38 , respectively, in a manner similar to the way shown in Figs. 7 through 9D. The ionically-conductive medium is realized as an ionically-conductive belt 35 transported between transport cylinder 66 and transport cylinder 42 driven by drive units 62 and 38, respectively, in a manner similar as shown in Fig. 6. A supply of metal-fuel tape 13 (13'.13") is transported over the ionically-conductive belt structure 35 between a pair of supply and take-up reels as taught in Applicant's copending Application Serial Nos. 08/944,507 and 09/074,337. The drive units 38, 39, and 62 as well as tape drive units 21 are controlled by a system controller 22 so that the velocity of both the metal-fuel tape 13, ionically-conductive belt structure 35 and the cathode belt structure 40 are maintained at substantially the same velocity at the locus of points at which the ionically-conducing belt structure 35 contacts the metal-fuel tape and the cathode belt structure 40 during system operation. By controlling the relative movement between the metal-fuel tape, ionically-conductive belt structure 35 and cathode belt structure 40, the system controller 22 minimizes the generation of frictional forces therebetween and thus the problems associated therewith.

In general, velocity control can be achieved in various ways in the FCB system of Fig. 10. For example, one way might be to drive the transport cylinders 41, 42 and 66 using a belt structure that is also used to transport the metal-fuel tape 13 (e.g. between supply and take-up reels or hubs within a cassette type-device). Another way might be to drive transport cylinders 41, 42 and 66 with a first set of DC-controlled motors, while driving the supply and take-up hubs of the metal-fuel cassette device using a different set of DC-controlled motors, synchronized with the first set of DC-controlled motors. Other ways of achieving velocity control among the movable components of the FCB system will become apparent to those skilled in the art.

In general, it will be desired in most applications to mount a plurality of pairs of "rotatable" cathode and anode contacting elements about the cathode belt structure of the system of Fig. 10. Such an arrangement will enable maximum current collection from each moving cathode belt structure in the system, at the generated output voltage. For clarity of exposition, however, only a single pair of cathode and anode contacting elements are shown in Fig. 10.

As shown in Fig. 10, an electrically-conductive "cathode-contacting" element 48 is rotatably supported by a pair of brackets 69 so that it is arranged in electrical contact with the exposed nickel mesh fabric on the outer edge portions of the cathode belt structure 40 as the cathode belt structure is transported about transport cylinder 41. Also, an electrically-conductive "anode-contacting" element 50 is rotatably supported by a pair of brackets 70 disposed above the metal-fuel tape and opposite the cathode contacting element 48, so that the anode-contacting element establishes electrical contact with the outerside surface of the metal-fuel tape 13 (13',13"), as shown in Fig. 10. The cathode and anode contacting elements 48 and 50 are connected to electrical conductors (e.g. wiring) which are terminated at an output power controller 29. An electrical load can be connected to the output terminal of the output power controller 29 in order to receive a supply of electrical power generated within the FCB system.

When using the ionically-conductive belt 35 described hereinabove, it will necessary to provide a means for achieving "wetting" between (1) the ionically-conductive belt and the metal-fuel tape 13 (13", 13"), and (2) the ionically-conductive belt 35 and the movable cathode belt 40. One way of achieving wetting would be to continuously or periodically apply a coating of water (H_2O) and/or electrolyte make-up solution to the surface of the metal-fuel tape (and/or ionically-conductive belt) during system operation to enable a sufficient level of ionic transport between the metal-fuel tape and the ionically-conductive belt and also between the movable cathode belt and the ionically-conductive medium. Notably, the thickness of the water coating applied to the metal-fuel tape (and/or the ionically-conductive belt 35) will depend on the transport speed of the metal fuel tape, its water absorption properties, etc. In the illustrative embodiment shown in Fig. 10, wetting of the metal-fuel tape and/or ionically-conductive belt 35 can be carried out using applicator 54 and dispensing mechanism 55 controlled by the system controller 22. It is understood, however, that other methods of wetting the metal-fuel tape 13 (13', 13") and/or ionically-conductive belt 35 may be used with excellent results.

In the event that the cathode belt 40 is employed within a

Metal-Fuel Tape Discharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Discharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 10. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, a portion of the cathode belt structure 40 shown in Fig. 10, along which electrical current is generated, can be enclosed by an oxygen-injection chamber (connected to an air pump or oxygen source), and having one or more pO_2 sensors, one or more temperature sensors, discharging head cooling equipment, and the like, so that system controller 22 can control the $p0_2$ level within this section of the moving cathode belt structure 40, as well as maintain the temperature of the discharging head therealong during discharging operations.

Similarly, in the event that the cathode belt structure 40 is employed within a Metal-Fuel Tape Recharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Recharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 10. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, a portion of the cathode belt structure 40 shown in Fig. 10, along which electrical current is generated, can be enclosed by an oxygen-evacuation chamber (connected to a vacuum pump or like device), and having one or more pO_2 sensors, one or more temperature sensors, recharging head cooling equipment, and the like, so that system controller 22 can control the $p0_2$ level within this section of the moving cathode belt structure 40, as well as maintain the temperature of the recharging head therealong during recharging operations.

As shown in Fig. 10, during tape discharging operations, oxygen-rich air is permitted or forced to flow through the fine perforations 21 formed in the cathode belt structure 40 and reach the interface between the metal-fuel tape and the ionically-conductive belt 35. During tape recharging operations, oxygen liberated from the interface between the metal-fuel tape and the ionically-conductive belt 35 is permitted or forced to flow through the fine perforations 21 formed in the cathode belt structure 40, to the ambient environment.

While the illustrative embodiment shown in Fig. 10 is designed for single-cathode/single-anode type applications, it is understood that this system embodiment can be readily modified to include a plurality of electrically-isolated cathode elements formed along the cathode belt structure 40 for use with multi-track metal-fuel tape, as taught in Applicant's copending Application Serial Nos. 08/944,507 and 09/074,337, supra.

In alternative embodiments of the present invention, the metal-fuel tape used in the FCB System of Fig. 10 can be realized in a variety of different ways. As shown in Fig. 10C, the first type of metal-fuel tape 13 is formed as a thin layer of metal-fuel material (e.g. zinc). The second type of metal-fuel tape 13' shown in Fig. 10D is formed by depositing a metallic (e.g. zinc) powder and binder (e.g. PVC) 31 on a polyester substrate 32. As shown in Fig. 10E, the third type of metal-fuel tape 13" is formed by impregnating metallic powder (e.g. zinc powder) 33 within a substrate material 34 such as PVC. Techniques for fabricating such forms of metal-fuel are described in copending Application Serial Nos. 08/944,507 and 09/074,337.

During discharging operations, the cathode belt structure 40 is transported at a controlled velocity between transport cylinders 41 and 42, while the ionically-conductive belt structure 35 is transported at a controlled velocity between transport cylinders 41 and 42. Therewhile, a continuous supply of metal-fuel tape 13 (13', 13") is transported over the surface of the cathode belt structure 40 at substantially the same velocity at the locus of points at which the ionically-conducing belt structure 35 contacts the metal-fuel tape and the cathode belt structure 40 without slippage.

Alternative Embodiments of The FCB System of The Present Invention

Having described the illustrative embodiments of the present invention, several modifications thereto readily come to mind which would be advantageous in the commercial practice of the present invention.

In order to eliminate the need to separately drive and actively control the velocity of the metal-fuel tape, movable cathode structure and ionically-conductive medium in the system hereof using complex mechanisms, the present invention also contemplates creating a condition of "hydrostatic drag" (i.e. hydrostatic attraction) between the metal-fuel tape and the ionically-conductive medium (e.g. belt or applied gel/solid-state film), and the ionically-conductive medium (e.g. belt or applied gel/solid-state film and the cathode structure (e.g. cylinder or belt). This condition will enable a more efficient transportation of the metal-fuel tape, ionically-conductive medium and movable cathode structure through the FCB system when transporting only one of these three movable system components (e.g. metal-fuel tape, ionically-conductive medium, or movable cathode structure) using a mechanically (e.g. spring-wound), electrically, or pneumatically driven motor. This reduces the complexity of the system as well as the cost of manufacture thereof. Also, it enables the metal-fuel tape, ionically-conductive medium, and cathode structures to be moved within the system without generating significant frictional (e.g. shear) forces, and thus transporting these moving components using torque-control (or current control) techniques regulated by the output power requirements set by electrical loading conditions at any instant in time.

Hydrostatic drag can be created between these system components by maintaining a sufficient level of surface tension between the ionically-conductive medium and the metal-fuel tape, and the ionically-conductive medium and the movable cathode structure during system operation.

When using the ionically-conductive media disclosed hereinabove, sufficient surface tension can be created between the three primary moving components of the FCB system by continuously or periodically applying an even coating of water (H_2O) and/or electrolyte make-up solution to the surface of the metal-fuel tape (and/or ionically-conductive medium) so that, during system, operation "wetting" occurs between (1) the ionically-conductive medium and the metal-fuel tape, and (2) the ionically-conductive medium and the movable cathode structure. Notably, the thickness of the water coating and/or electrolyte make-up solution applied to the metal-fuel tape (and/or the ionically-conductive medium) will depend on the transport speed of the metal fuel tape, its water absorption properties, etc. In each of the illustrative embodiments disclosed herein, wetting of the metal-fuel tape and/or ionically-conductive medium can be carried out using applicator 54 and dispensing mechanism 55 shown in the figure drawings hereof. It is understood, however, that other methods of wetting the metal-fuel tape and/or ionically-conductive medium may be used with excellent results.

For example, in the illustrative embodiment shown in Fig. 4, periodic or continuously wetting of the metal-fuel tape 8 and the ionically-conductive coating 30 on the cathode cylinder 11 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable the cathode cylinder 11 to passively move (i.e. rotate) at the same velocity as the metal-fuel tape in contact therewith while only the metal-fuel tape is being actively driven by its tape transport mechanism 21. In this alternative embodiment of the present invention, the use of cathode cylinder drive unit 17 and velocity equalization by system controller 22 can be eliminated while still achieving the principles of the present invention. This modification would reduces the complexity of the system as well as its cost of manufacture and maintenance.

In the illustrative embodiment shown in Fig. 5, periodic or continuously wetting of the ionically-conductive coating 30 on the metal-fuel tape 8 and the cathode cylinder 11 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable the cathode cylinder 11 to passively move at the same velocity as the metal-fuel tape in contact therewith while only the metal-fuel tape is being actively driven by its tape transport mechanism 21. In this alternative embodiment of the present invention, the use of cathode cylinder drive unit 17 and velocity equalization by system controller 22 can be eliminated while still achieving the principles of the present invention. This modification would reduces the complexity of the system as well as its cost of manufacture and maintenance.

In the illustrative embodiment shown in Fig. 6, periodic or continuously wetting of the metal-fuel tape 13 (13', 13"), ionically-conductive belt 35, and cathode cylinder 11 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable the cathode cylinder 11, belt transport cylinder 36 and ionically-conductive belt 35 to passively rotate at the same velocity as the metal-fuel tape 13 in contact therewith while only the metal-fuel tape 13 is being actively driven by its tape transport mechanism 21. In this alternative embodiment of the present invention, the use of cylinder drive units 38 and 39 and velocity equalization by system controller 22 can be eliminated while still achieving the principles of the present invention. Alternatively, it may be possible in some instances to actively drive the ionically-conductive belt 35 and allow the cathode cylinder 11, and metal fuel tape 13 to passively move at the same velocity as the ionically-conductive belt 35 in contact therewith. In either case, such modifications will reduce the complexity of the system as well as its cost of manufacture and maintenance.

In the illustrative embodiment shown in Fig. 7, periodic or continuously wetting of the metal-fuel tape 13 (13', 13") and the ionically-conductive medium 53 on and cathode belt 40 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable the cathode belt 40, belt transport cylinder 41 and ionically-conductive belt 42 to passively rotate at the same velocity as the metal-fuel tape 13 in contact therewith while only the metal-fuel tape 13 is being actively driven by its tape transport mechanism 21. In this alternative embodiment of the present invention, the use of cylinder drive units 38 and 39 and velocity equalization by system controller 22 can be eliminated while still achieving the principles of the present invention. Alternatively, it may be possible in some instances to actively drive the cathode belt 40 and allow the metal fuel tape 13 to passively move at the same velocity as the ionically-conductive medium 53 in contact therewith. In either case, such modifications will reduce the complexity of the system as well as its cost of manufacture and maintenance.

In the illustrative embodiment shown in Fig. 8, periodic or continuously wetting of the metal-fuel tape 13 (13', 13") and the ionically-conductive medium 53 on and cathode belt 40 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable the cathode belt 40, belt transport cylinder 41 and ionically-conductive belt 42 to passively rotate at the same velocity as the metal-fuel tape 13 in contact therewith while only the metal-fuel tape 13 is being actively driven by its tape transport mechanism 21. In this alternative embodiment of the present invention, the use of cylinder drive units 38 and 39 and velocity equalization by system controller 22 can be eliminated while still achieving the principles of the present invention. Alternatively, it may be possible in some instances to actively drive the cathode belt 40 and allow the metal fuel tape 13 to passively move at the same velocity as the ionically-conductive medium 53 in contact with the cathode belt and metal-fuel tape. In either case, such modifications will reduce the complexity of the system as well as its cost of manufacture and maintenance.

In the illustrative embodiment shown in Fig. 9, periodic or continuously wetting of the cathode belt 40 and the ionically-conductive medium 53 on the metal-fuel tape 13 (13', 13") can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable the cathode belt 40, belt transport cylinder 41 and ionically-conductive belt 42 to passively rotate at the same velocity as the metal-fuel tape 13 in contact therewith while only the metal-fuel tape 13 is being actively driven by its tape transport mechanism 21. In this alternative embodiment of the present invention, the use of cylinder drive units 38 and 39 and velocity equalization by system controller 22 can be eliminated while still achieving the principles of the present invention. Alternatively, it may be possible in some instances to actively drive the cathode belt 40 and allow the ionically-conductive medium 53 (and metal fuel tape 13) to passively move at the same velocity as the cathode belt 40 in contact with the ionically-conductive medium 53. In either case, such modifications will reduce the complexity of the system as well as its cost of manufacture and maintenance.

In the illustrative embodiment shown in Fig. 10, periodic or continuously wetting of the metal-fuel tape 13 (13', 13") and the ionically-conductive belt 35 on and cathode belt 40 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable the cathode belt 40, ionically-conductive belt 35 and belt transport cylinders 41, 42 and 66 to passively move at the same velocity as the metal-fuel tape 13 in contact with ionically-conductive belt 35 while only the metal-fuel tape 13 is being actively driven by its tape transport mechanism 21. In this alternative embodiment of the present invention, the use of cylinder drive units 38, 39 and 67 and velocity equalization by system controller 22 can be eliminated while still achieving the principles of the present invention. Alternatively, it may be possible in some instances to actively drive the cathode belt 40 (or ionically-conductive belt 35) and allow the metal fuel tape 13 to passively move at the same velocity as the ionically-conductive belt 35 in contact therewith. In either case, such modifications will reduce the complexity of the system as well as its cost of manufacture and maintenance.

Configuring System Components To Produce Metal-Air FCB Systems Having Improved Volumetric Power Density

In Figs. 11 through 22, there is disclosed a novel way of improving the volumetric power density (VPD) characteristics of FCB systems by using a plurality of moving cathode structures closely arranged together for transporting metal-fuel tape and ionically-conducting medium at substantially the same velocity as the cathode structures at the locus of points at which the ionically-conductive medium contacts the cathode structures and the metal-fuel tape. The objective to be achieved by this condition of operation is to improve the volumetric power density characteristics of the FCB system, while minimizing the generation of frictional (e.g. shear) forces among the metal-fuel tape, ionically-conducting medium and cathode structures and thus reduce the amount of electrical power required to transport the likelihood of damaging the cathode structures and metal-fuel tape used in the FCB system.

First Illustrative Embodiment Of The FCB System

As shown in Figs. 11 through 12C, the first illustrative embodiment of the FCB system 101 comprises a metal-fuel tape discharging device (i.e. "engine") 102 containing a plurality of cylindrically shaped cathodes 103 rotatably mounted within a compact fixture (i.e. housing) 104. The actual number of cathode cylinders provided for in any particular embodiment of the present invention will depend on the application at hand. Also, while it is understood that the actual physical arrangement of the cathode cylinders within the housing 104 will vary from application to application, it will be advantageous to arrange the cathode cylinders in an array formation (e.g. 3x3, 4x5, or NxM). The guiding principle when arranging a plurality of cylindrical cathodes within the fixture housing to construct a tape discharging engine should be maximize the volumetric power density characteristics of the metal-air FCB system.

In the illustrative embodiment of the present invention shown in Fig. 11, each of the cylindrical cathodes 103 in the engine 102 is realized as a plastic cylindrically-shaped structure having a hollow center 106 with fine perforations formed in the surface thereof. The function of these fine perforations is to permit oxygen transport to the interface formed between the ionically-conductive medium 107 and metal-fuel tape 108 transported over the respective cathode cylinder. In general, each cathode cylinder 103 can be made from plastic, ceramic, composite or other suitable material. The outer diameter of each cathode cylinder can be similar in size, or different in size, depending on factors such as velocity control, power generation capacity, etc.

As shown in Fig. 11, the compact housing 104 comprises a pair of spaced apart panels 104A and 104B having pairs of holes formed therein, within which each cathode cylinder in the array thereof can be rotatably mounted by way of bearings or like structures. Top and bottom panels can be used to maintain the spacing between panels 104A and 104B. Other panels can be used to enclose side openings of the housing. In general, each cathode cylinder 103 is rotated by a suitable drive mechanism which can be realized in a number of different ways, e.g. using an electric or pneumatic motor, gears, drive belts, or like devices known in the tape transport art. In the illustrative embodiment shown in Fig. 11, each of the cathode cylinders 103 is provided with a gear 9 formed at one end thereof which intermeshes with the gear of a neighboring cathode cylinder within the cathode array. A geared motor 110, coupled to the gear 111 meshing with one of the cathode cylinders, can be used to impart torque to a particular cathode cylinder, which in turn is imparted to all other cathode cylinders within the array. With this arrangement, the array of cathode cylinders mounted with the housing 10 cooperate to transport a supply 112 of metal-fuel tape 108 from cartridge 112, along a predetermined tape pathway within the housing of the system. As shown, tape guiding rollers 114A and 114B can be strategically installed within the engine housing 104 to guide the metal-fuel tape along the predetermined tape pathway through the housing. Also, tape guiding deflectors 115 can be strategically located within the housing to self-guide the metal-fuel tape through the housing, as well as assist in automatic (e.g. self) treading of metal-fuel tape being supplied from open-type reels and cartridge devices.

As illustrated in Fig. 12D, a cathode element 116 is mounted over the outer surface of each cathode cylinder 103. Preferably, each cathode element 116 is made from nickel mesh fabric embedded within carbon and catalytic material. Preferably, the metal-fuel tape 108 is transported between a pair of supply and take-up reels 117A and 117B, contained within a cassette or like cartridge, as taught in Applicant's copending Application Serial No. 09/074,337. Also, the metal-fuel tape for use with the FCB system of Fig. 11 can be fabricated using any of the techniques taught in Application Serial No. 09/074,337.

In the event that the cathode-cylinder based engine 102 is employed within a Metal-Fuel Tape Discharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Discharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 11. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, the interior portion of each cylindrical cathode structure 103 in the cathode-cylinder based engine can be equipped with an oxygen-injection chamber (connected to an air pump or oxygen source), one or more pO_2 sensors, one or more temperature sensors, discharging head cooling equipment, and the like, so that system controller 120 can control the $p0_2$ level within the cathode element 116, as well as maintain the temperature of the discharging heads during discharging operations.

Similarly, in the event that the cathode-cylinder based engine 102 is employed within a Metal-Fuel Tape Recharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Recharging Subsystem disclosed in copending Application Serial No.

09/074,337 can be incorporated into the system schematically depicted in Fig. 11. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337, the interior portion of each cathode cylinder 103 can be equipped with an oxygen-evacuation chamber (connected to a vacuum pump or like device), one or more pO_2 sensors, one or more temperature sensors, recharging head cooling equipment, and the like, so that system controller 120 can control the $p0_2$ level within each cathode element 116, as well as maintain the temperature of the recharging head during recharging operations.

As shown in Fig. 11, each cathode cylinder 103 is rotated about its axis of rotation at an angular velocity controlled by gears and drive unit (e.g. motor) driving the cathode cylinder. The metal-fuel tape 108 is transported over the surface of each cylindrical cathode element 116 by a fuel-tape transporter 121 operable during discharging and recharging operations. The cathode cylinder drive unit and the fuel-tape transporter 121 are controlled by system controller 120 so that the metal-fuel tape 108, array of cathode structures 103 and ionically-conductive medium are transported at substantially the same velocity at the locus of points at which the ionically-conducing medium contacts the metal-fuel tape and the cathode structures. By controlling the relative movement between the metal-fuel tape, ionically-conductive medium and the cathode cylinders within the engine housing, the system controller 120 effectively reduces the generation of frictional (e.g. shear) forces thereamong. This condition of operation results in a reduction in the amount of electrical power required to transport the metal-fuel tape, ionically-conductive medium and cathode structures, It also reduces shedding of metal-oxide particles from the metal-fuel tape and becoming embedded with the porus structure of the cathodes. In turn, this decreases likelihood of damage or destruction of the cylindrical cathode elements 116 and metal-fuel tape 108.

In general, velocity control among the cathode structure, ionically-conductive medium and metal-fuel tape can be achieved in various ways in the FCB system of Fig. 11. For example, one way would be to drive the array of cathode cylinders using a set of engaging gears, as shown in Fig. 11. Another way would be to drive the array of cathode cylinders using a belt structure that is also used to transport the metal-fuel tape 108 (e.g. between supply and take-up reels or hubs within a cassette type-device. Yet another way would be to drive the array of cathode cylinders using a first set of DC-controlled motors, while driving the supply and take-up hubs of the fuel cassette device using a second set of DC-controlled motors, synchronized with the first set of DC-controlled motors. Other ways of achieving velocity control will become apparent to those skilled in the art having had the benefit of reading the present disclosure.

In general, it will be desirable in most applications to mount a plurality of pairs of "rotatable" cathode and anode contacting elements 123 about each cathode cylinder shown in Figs. 11 and 11A. Such an arrangement will enable maximum current collection from each rotating cathode cylinder in the FCB system, at the output voltage specified by the cathode and anode materials. Specifically, as shown in Figs. 11 and 11A, an electrically-conductive "cathode-contacting" element 123A is rotatably supported at the ends of each cylindrical cathode structure 103 by a pair of brackets or like structures. When properly mounted, each cathode-contacting element 123A is arranged in electrical contact with its nickel mesh fabric exposed on the outer edge portion thereof and is permitted to rotate about the axis of rotation of the cathode-contacting element as the cylindrical cathode structure is rotated about the axis of rotation of the cylindrical cathode structure.

Also shown in Fig. 11, an electrically-conductive "anode-contacting" element 123B is rotatably supported by a pair of brackets or like structures so that it is arranged in electrical contact with the underside surface of the metal-fuel tape 108, and permitted to rotate about the axis of rotation of the anode-contacting element as the metal-fuel tape is transported over the rotating cathode cylinder with the ionically-conductive medium disposed therebetween. As shown in Fig. 11, the cathode cylinder and anode contacting elements 123A and 123B are electrically connected to electrical conductors (e.g. wiring) 124 which are terminated at an output power controller 125. In turn, the electrical load 26 is connected to the output power controller 125 for receiving a supply of electrical power from the FCB system.

As shown in Figs. 11 and 11A, during discharging operations, oxygen-rich air flows along the hollow central bore 6 formed through each cathode cylinder, and through the ultra fine perforations formed in the cathode structure to reach the interface between ionically-conductive medium (e.g. electrolyte) 107 and the metal-fuel tape 108. During recharging operations, oxygen liberated from reduced metal-fuel tape flows along the hollow central bore 106 formed through each cathode cylinder 3, and through the ultra fine perforations formed in the cathode structure to reaches the ambient environment.

In the illustrative embodiment shown in Fig. 11, the ionically-conductive medium 107 is realized as an ionically-conductive fluid or viscous gel applied in the form of a thin film over the outer surface of each cathode cylinder 103 in the FCB system. The ionically-conductive fluid/gel 107 can be applied to the surface of the cathode element or metal-fuel tape in either a continuous or periodic manner to ensure that ionically-conductive medium is sufficiently replenished during system operation and thus maintain an optimum level of hydroxide ion concentration at the interface between the ionically-conductive medium and metal-fuel tape. Notably, the required thickness of the ionically-conductive film layer will vary from application to application, but typically will depend on a number of factors including, for example, the electrical conductivity of the ionically-conductive medium, the current flow expected to be produced by the FCB system during discharging operations, the surface area of the cathode element, and the like.

Ionically-conductive fluid/gel 107 for use with the FCB system of Fig. 11 can be made using the following formula. One mole of potassium hydroxide (KOH) and one mole of calcium chloride are dissolved in 100 grams of water. The function of KOH is to provide a hydroxide ion source, whereas the function of calcium chloride is as a hygroscopic agent. Thereafter, one-half (0.5) of a mole of polyethylene oxide (PEO) is added to the mixture as an ion carrier. The mixture is then blended for about 10 minutes. Thereafter, 0.1 mole of cellulose methoxycarboxylic acid, a gellant, is added to the blended mixture. This procedure results in the generation of an ionically-conductive gel suitable for application to the surface of each cylindrical cathode element 116 within the FCB system or metal-fuel tape 8 transported through the FCB system.

Alternatively, ionically-conductive medium 107 can be realized as a solid-state ionically-conductive film applied to the outer surface of the cylindrical cathode element 116, or the inner surface of the metal-fuel tape. In this alternative embodiment of the present invention, the solid-state ionically-conductive film can be formed on the cathode element or the metal-fuel tape using either of the following formulas set forth below.

In accordance with the first formula, one mole of KOH, a hydroxide source, and 0.1 mole of calcium chloride, a hygroscopic agent, are dissolved in the mixed solvents of 60 milliliters of water and 40 milliliters of tetrahydrogen furan (THF). Thereafter, one mole of PEO is added to the mixture as an ion carrier. Then, the resulting solution (e.g. mixture) is cast (i.e. coated) as a thick film onto the outer surface of each cylindrical cathode element 116, or as a thick film onto the underside surface of the metal-fuel tape 108, as the case may be. Using the above formulation, ionically-conductive film can be obtained with a thickness in the range of about 0.2 mm to about 0.5 mm. As the mixed solvents (i.e. water and THF) within the applied film coating are allowed to evaporate, an ionically-conductive gel-like (i.e. solid state) film is formed on the outer surface of the cathode element 116, or on the underside surface of the metal-fuel tape 8, as the case may be.

According to the second formula, one mole of KOH and 0.1 mole of calcium chloride are dissolved in the mixed solvents of 60 milliliters of water and 40 milliliters of tetrahydrogen furan (THF). The function of KOH is as an ion source, whereas the function of the calcium chloride is as a hygroscopic agent. Thereafter, one mole of polyvinyl chloride (PVC) is added to the solution in an amount sufficient to produce a gel-like substance. The solution is then cast (coated) as a thick film onto the outer surface of each cathode element 116, or as a thick film onto on the underside surface of the metal-fuel tape, as the case may be. Using the above formulation, ionically-conductive film can be obtained with a thickness in the range of about 0.2 mm to about 0.5 mm. As the mixed solvents (i.e. water and THF) within the applied coating are allowed to evaporate, an ionically-conductive gel-like (i.e. solid state) film forms on the outer surface of each cylindrical cathode element 116, or on the underside surface metal-fuel tape, as the case may be.

When using the ionically-conductive media 107 described hereinabove, it will necessary to provide a means for achieving "wetting" between (1) the ionically-conductive medium 107 and the metal-fuel tape 108, and (2) the ionically-conductive medium 107 and each movable cathode cylinder 3. One way of achieving wetting would be to continuously or periodically apply a coating of water (H_2O) and/or electrolyte make-up solution to the surface of the metal-fuel tape 108 (and/or ionically-conductive medium 107) during system operation to enable a sufficient level of ionic transport between the metal-fuel tape and the ionically-conductive medium and also between the movable cathode cylinder and the ionically-conductive medium. Notably, the thickness of the water and/or electrolyte make-up coating applied to the metal-fuel tape (and/or the ionically-conductive medium) will depend on the transport speed of the metal fuel tape, its water absorption properties, surface temperature of the cathode cylinder etc. In the illustrative embodiment shown in Fig. 11, wetting of the metal-fuel tape and/or ionically-conductive medium can be carried out using applicator 170 and dispensing mechanism 171. It is understood, however, that other methods of wetting the metal-fuel tape, cathode cylinder and ionically-conductive medium may be used with excellent results.

While the illustrative embodiments schematically depicted in Figs. 11 and 11A and described hereinabove are shown for use in single-cathode/single-anode type applications, it is understood that such system embodiments can be readily modified to include a plurality of electrically-isolated cathode elements formed about the cathode support cylinder for use with multi-track metal-fuel tape of the type taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, supra. The primary advantage of such system modifications is that it will be possible to deliver electrical power at various output voltage levels required by particular electrical loads.

As shown in Fig. 12A, the first type of metal-fuel tape 8 is formed as a thin layer of metal-fuel material (e.g. zinc). The second type of metal-fuel tape 108' shown in Fig. 12B is formed by depositing a metallic powder (e.g. zinc powder) and binder (e.g. polyethylene) 127 on a polyester substrate 128. As shown in Fig. 12C, a third type of metal-fuel tape 108" is formed by impregnating metallic powder 129 (e.g. zinc powder) within a substrate material 130 such as polyvinyl chloride (PVC). Techniques for fabricating such forms of metal-fuel are described in copending Application Serial Nos. 08/944,507 and 09/074,337.

Second Illustrative Embodiment Of The FCB System

In Fig. 13, a second illustrative embodiment of the FCB system 131 is shown. This illustrative embodiment is similar to the FCB system shown in Fig. 11, except that in the system of Fig. 13, the ionically-conducting medium is realized as a solid-state ionically-conducting belt 107' which is transported through the predetermined tape pathway within the system housing, and about a belt transport cylinder 135 driven synchronously with the cathode cylinders in the FCB system. All other respects, the FCB system of Fig. 18 is similar to the FCB system of Fig. 17.

As shown in Figs. 13 and 13A, each cathode cylinder 103 is rotated about its axis of rotation at an angular velocity controlled by gears and drive unit (e.g. motor) 110 driving the cathode cylinder. The metal-fuel tape 8 is transported over the surface of each cylindrical cathode element 16 by fuel-tape transport mechanism 121 operable during discharging and recharging operations. The cathode cylinder drive unit 110 and fuel-tape transport mechanism 21 are controlled by system controller 20 so that the metal-fuel tape 108, array of cathode structures 103 and the solid-state, yet-flexible, ionically-conductive belt structure 107' are transported at substantially the same velocity at the locus of points at which the ionically-conducing medium 107' contacts the metal-fuel tape 108 and the cathode structures 116. By controlling the relative movement between the metal-fuel tape, ionically-conductive belt and the cathode cylinders within the engine housing, the system controller 120 effectively minimizes the generation of frictional (e.g. shear) forces thereamong. This reduces the amount of electrical the likelihood of damage to the cylindrical cathode elements 16 and metal-fuel tape 108.

In general, velocity control among the cathode structure, ionically-conductive belt and metal-fuel tape can be achieved in various ways in the FCB system of Figs. 13 and 13A. For example, one way would be to drive the array of cathode cylinders using a set of engaging gears, as shown in Fig. 11. Another way would be to drive the array of cathode cylinders using a belt structure that is also used to transport the metal-fuel tape 108 (e.g. between supply and take-up reels or hubs within a cassette type-device. Yet another way would be to drive the array of cathode cylinders using a first set of DC-controlled motors, while driving the supply and take-up hubs of the fuel cassette device using a second set of DC-controlled motors, synchronized with the first set of DC-controlled motors. Other ways of achieving velocity control will become apparent to those skilled in the art having had the benefit of reading the present disclosure.

In general, it will be desirable in most applications to mount a plurality of pairs of "rotatable" cathode and anode contacting elements about each cathode cylinder as shown in Figs. 13 and 13A, and described hereinabove. As shown in Fig. 13, the cathode and anode contacting elements 123A and 123B are electrically connected to electrical conductors (e.g. wiring) 124 which are terminated at an output power controller 125. In turn, the electrical load is connected to the output power controller for receiving a supply of electrical power from the FCB system.

As shown in Figs. 13 and 13A, during discharging operations, oxygen-rich air flows along the hollow central bore 106 formed through each cathode cylinder, and through the ultrafine perforations formed in the cathode structure to reach the interface between ionically-conductive belt (e.g. electrolyte) 107' and the metal-fuel tape 108. During recharging operations, oxygen liberated from reduced metal-fuel tape flows along the hollow central bore 106 formed through each cathode cylinder 103 and through the ultrafine perforations formed in the cathode structure 116 to reaches the ambient environment.

In the illustrative embodiment shown in Figs. 13 and 13A, the ionically-conductive belt 107' can be realized as flexible belt made from an open-cell polymer material having a porous structure, impregnated with an ionically-conductive material (e.g. KOH) capable of supporting ionic transport between the cathode and anode structures of the FCB system. Ionically-conductive belt 107' , schematically depicted in Fig. 14, can be realized as a solid-state membrane having ionic-conduction characteristics. In general, there will be many ways of making the ionically-conductive belt. For purposes of illustration, two formulas are described below.

In accordance with the first formula, one mole of KOH and 0.1 mole of calcium chloride are dissolved in the mixed solvents of 60 milliliters of water and 40 milliliters of tetrahydrogen furan (THF). The function of KOH is as a hydroxide ion source, whereas calcium chloride is as a hygroscopic agent. Thereafter, one mole of PEO is added to the mixture. Then, the solution is cast (or coated) as a thick film onto substrate made of polyvinyl alcohol (PVA) type plastic material. This material has been found to work well with PEO, although it is expect that other substrate materials having a surface tension higher than the film material should work as well with acceptable results. As the mixed solvents evaporate from the applied coating, an ionically-conductive solid state membrane (i.e. thick film) is formed on the PVA substrate. By peeling the solid state membrane off the PVA substrate, a solid-state ionically-conductive membrane or film is formed. Using the above formulation, it is possible to form ionically-conductive films having a thickness in the range of about 0.2 to about 0.5 millimeters. Then, the solid-state membrane can be cut into a shape required to form a belt-like structure transportable about two or more rotating cylinders. The ends of the shaped membrane can be joined by an adhesive, ultra-sonic welding, appropriate fasteners or the like to form a solid-state ionically-conductive belt structure 107' for use in the FCB systems of the present invention.

In accordance with the second formula, one mole of KOH and 0.1 mole of calcium chloride are dissolved in the mixed solvents of 60 millimeters of water and 40 milliliters of tetrahydrogen furan (THF). The function of KOH is as a hydroxide ion source, whereas calcium chloride is as a hygroscopic agent. Thereafter, one mole of polyvinyl chloride (PVC) is added to the mixture. Then, the resulting solution is cast (or coated) as a thick film onto substrate made of polyvinyl alcohol (PVA) type plastic material. This material has been found to work well with PVC, although it is expect that other substrate materials having a surface tension higher than the film material should work as well with acceptable results. As the mixed solvents evaporate from the applied coating, an ionically-conductive solid state membrane (i.e. thick film) is formed on the PVA substrate. By peeling the solid state membrane off the PVA substrate, a solid-state ionically-conductive membrane is formed. Using the above formulation, it is possible to form ionically-conductive films having a thickness in the range of about 0.2 to about 0.5 millimeters. Then, the solid-state film or membrane can be cut into a shape required to form a belt-like structure transportable about two or more rotating cylinders. The ends of the shaped membrane can be joined by an adhesive, ultra-sonic welding, appropriate fasteners or the like to form a solid-state ionically-conductive belt structure 107' for use in the FCB systems of the present invention.

Metal-fuel tape for use in the FCB System of Fig. 13 can be realized in a variety of different ways. As shown in Fig. 15A, a first type of metal-fuel tape 108 is formed as a thin layer of metal-fuel material (e.g. zinc). A second type of metal-fuel tape 108" is formed by depositing a metallic powder (e.g. zinc powder) and binder (e.g. PVC) 127 on a polyester substrate 128. As shown in Fig. 15C, a third type of metal-fuel tape 8" is formed by impregnating metallic powder 129 (e.g. zinc powder) within a substrate material 130 such as PVC. Techniques for fabricating such forms of metal-fuel are described in copending Application Serial No. 09/074,337.

When using the ionically-conductive belt 107" described hereinabove, it will necessary to provide a means for achieving "wetting" between (1) the ionically-conductive belt 107' and the metal-fuel tape 108, and (2) the ionically-conductive belt 7' and the movable cathode cylinder 103. One way of achieving wetting would be to continuously or periodically apply a coating of water (H_2O) to the surface of the metal-fuel tape (and/or ionically-conductive belt) during system operation to enable a sufficient level of ionic transport between the metal-fuel tape and the ionically-conductive belt and also between the movable cathode cylinder and the ionically-conductive belt. Notably, the thickness of the water coating applied to the metal-fuel tape (and/or the ionically-conductive belt) will depend on the transport speed of the metal fuel tape, its water absorption properties, temperature of the cathode cylinder surface, etc. In the illustrative embodiment shown in Fig. 13, wetting of the metal-fuel tape and/or ionically-conductive belt can be carried out using applicator 170 and dispensing mechanism 171. It is understood, however, that other methods of wetting the metal-fuel tape 108, ionically-conductive belt 7' and cathode cylinder 3 may be used with excellent results.

While the illustrative embodiment shown in Fig. 13 is designed for single-cathode/single-anode type applications, it is understood that this system embodiment can be readily modified to include a plurality of electrically-isolated cathode elements formed about the cathode support cylinder for use with multi-track type metal-fuel tape, as taught in Applicant's copending Application Serial No. 08/944,507, supra.

Third Illustrative Embodiment Of The FCB System

In Figs. 16 and 16A, the third illustrative embodiment of the FCB system of the present invention comprises a metal-fuel tape discharging device (i.e. "engine") 140 containing a plurality of cathode belt structures 141 and a plurality of ionically-conductive belts 107' mounted within a compact fixture (i.e. housing) 142. As shown in Figs. 16 and 16A, each cathode belt structure 41 is rotatably supported between a pair of belt transport cylinders 143 and 144 that are mounted within the system housing and driven at a required angular velocity by a belt drive mechanism. Similarly, each ionically-conductive belt 107' is rotatably supported between a pair of belt transport cylinders 144 and 145 that are mounted within the system housing and driven at a required angular velocity by a belt drive mechanism. Notably, in the illustrative embodiment, one of the belt transport cylinders 44 used to transport the ionically-conductive belt

107' will be the same transport cylinder used to transport the corresponding cathode belt structure 141. Also, a supply 112 of metal-fuel tape 108 is transported over each ionically-conductive belt structure 7' using tape transport drive mechanism 121 that cooperates with a pair of supply and take-up reels 17A and 17B as taught in Applicant's copending Application Serial No. 09/074,337.

The actual number of cathode belts 141 and ionically-conductive belts 171 employed in any particular embodiment of the present invention will depend on the application at hand. In some cases, as depicted in Fig. 16, one ionically-conducting belt is provided for each cathode belt structure employed in the FCB system. It is possible, in other alternative embodiments of the present invention, to use a single (common) ionically-conductive belt structure that is transported over each cathode belt structure in the FCB system, in a manner similar to that illustrated in the FCB system shown in Fig. 13. Also, while it is understood that the actual physical arrangement of the cathode belts within the housing 142 will vary from application to application, it will be advantageous to arrange the cathode belt structures in a stacked linear-array formation (e.g. 1x3, 1x5, or 1xM). The guiding principle when arranging a plurality of cathode belts within the fixture housing to construct a discharging-type engine should be to maximize the volumetric power density characteristics of the metal-air FCB system under design.

While not shown in Figs. 16 and 16A for clarity of exposition, the compact housing 142 could be constructed using a pair of spaced apart panels having pairs of holes formed therein, within which each belt transport cylinder 141 can be rotatably mounted by way of belt transport cylinders 143 and 144 utilizing bearings and/or like structures. Top and bottom panels 142E and 142D can be used to maintain the spacing between panels 142A and 142B. Other panels can be used to enclose side openings of the housing. There are numerous ways to realize a suitable housing for compactly containing the elements of the FCB system.

In general, each cathode belt 141 is transported between its transport cylinders by a suitable drive mechanism which can be realized in a number of different ways, e.g. using an electric or pneumatic motor, gears, drive belts, or like devices known in the tape transport art. Similarly, each ionically-conductive belt 107' is transported between its transport cylinders by a suitable drive mechanism which can be realized in a number of different ways, e.g. using an electric or pneumatic motor, gears, drive belts, or like devices known in the tape transport art. In the illustrative embodiment shown in Fig. 16, each of the belt transport cylinders 143 and 144 can be provided with a gear 146 formed at one end thereof which intermeshes with the gear of a neighboring belt transport cylinder within the system housing. A geared motor 147, coupled to the gear on one of the belt transport cylinders, can be used to impart torque to a particular belt transport cylinder 144, which in turn is imparted to all other belt transport cylinders within the housing 142. With this arrangement, the cathode belt structures 141 and ionically-conductive belt structures 107 installed within the housing cooperate with tape drive mechanism 121 to transport a supply of metal-fuel tape 112 from cartridge 113 along a predetermined tape pathway within the housing of the system schematically depicted in Fig. 16A. The belt drive mechanisms and tape drive mechanism are controlled by system controller 20 so that the velocity of both the metal-fuel tape 118 and corresponding cathode and ionically-conductive belt structures 141 and 107' respectively are maintained at substantially the same velocity at the locus of points which the ionically-conducing belt structure 107 contacts the metal-fuel tape 108 and the corresponding cathode belt structure 141 during system operation. By controlling the relative movement between the metal-fuel tape, the cathode belt structures and ionically-conductive structures within the system, the system controller 120 effectively minimizes the generation of frictional forces therebetween and thus reduces damage to the cathode belt structure and metal-fuel tape.

In order guide the metal-fuel tape along the predetermined tape pathway through the housing, tape guiding rollers 148 can be strategically installed within the engine housing 142, as shown in Fig. 16A. Also, tape guiding deflectors can be strategically located within the housing to self-guide the metal-fuel tape through the housing, as well as assist in automatic (e.g. self) treading of metal-fuel tape being supplied from open-type reels and cartridge devices.

In the event that the cathode-belt based engine of Fig. 16 is employed within a Metal-Fuel Tape Discharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Discharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 16. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, those sections of each cathode belt at which electrical power is being generated can be equipped with an oxygen-injection chamber (connected to an air pump or oxygen source), one or more pO_2

sensors, one or more temperature sensors, discharging head cooling equipment, and the like, so that system controller can control the $p0_2$ level within the cathode belt structure as it is transported between its transport cylinders, as well as maintain the temperature of the discharging heads during discharging operations.

Similarly, in the event that the cathode-belt based engine of Fig. 16 is employed within a Metal-Fuel Tape Recharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Recharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 16. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337, those sections of each cathode belt at which electrical power is being supplied (during recharging operations) can be equipped with an oxygen-evacuation chamber (connected to a vacuum pump or like device), one or more pO_2 sensors, one or more temperature sensors, recharging head cooling equipment, and the like, so that system controller 120 can control the $p0_2$ level within each cathode belt structure as it is transported between its transport cylinders, as well as maintain the temperature of the recharging head during recharging operations.

In general, velocity control among the cathode belts 141, ionically-conductive belts 107' and metal-fuel tape 108 can be achieved in various ways in the FCB system of Fig. 16. For example, one way would be to drive the cathode and ionically-conductive belts using a set of engaging gears, in a manner similar to that shown in Fig. 11. Another way would be to drive the array of cathode belts and ionically-conductive using a belt structure that is also used to transport the metal-fuel tape (e.g. between supply and take-up reels or hubs within a cassette type-device). Yet another way would be to drive the array of cathode belts and ionically-conductive using a first set of DC-controlled motors, while driving the supply and take-up hubs of the fuel cassette device using a second set of DC-controlled motors, synchronized with the first set of DC-controlled motors. Other ways of achieving velocity control will become apparent to those skilled in the art having had the benefit of reading the present disclosure.

In general, it will be desirable in most applications to mount a plurality of pairs of "rotatable" cathode and anode contacting elements 123A and 123B respectively, along the length of each cathode belt structure shown in Figs. 16 and 16A. Such an arrangement will enable maximum current collection from each cathode belt transported within the FCB system, at the output voltage specified by the cathode and anode materials. Specifically, as shown in Fig. 16C, an electrically-conductive "cathode-contacting" element 23B is rotatably supported at the ends of each cathode belt structure 141 by a pair of brackets or like structures 150. When properly mounted, the flange portion 151 on each cathode-contacting element 123B is arranged in electrical contact with the nickel mesh fabric 52 exposed on the outer edge portion of the cathode belt 141 and is permitted to rotate about the axis of rotation of the cathode-contacting element as the cathode belt structure 141 is transported past the cathode-contacting element 123B.

Also shown in Fig. 16C, an electrically-conductive "anode-contacting" element 123A is rotatably supported by a pair of brackets or like structures 153 so that it is arranged in electrical contact with the underside surface of the metal-fuel tape 108, and permitted to rotate about the axis of rotation of the anode-contacting element as the metal-fuel tape is transported over the moving cathode belt structure 141 with the ionically-conductive medium disposed therebetween. As shown in Fig. 16, the cathode and anode contacting elements 123A and 123B are electrically connected to electrical conductors (e.g. wiring) which are terminated at an output power controller 125. In turn, the electrical load 126 is connected to the output power controller 125 for receiving a supply of electrical power from the FCB system.

The cathode belt structure 141 employed in the FCB system of Fig. 16 has ultrafine perforations in the surface thereof to permit oxygen transport to the anodic metal-fuel tape 108 passing thereover. A preferred method of making the flexible cathode structure is to blend black Carbon powder (60%/weight), with a binder material such as Teflon emulsion(T-30 from Dupont) (20%/weight), and catalyst material such as magnesium dioxide MnO_2 (20%/weight) within 100 milliliters of water (solvent) and surfactant (e.g Triton X-10 from Union Carbide) 2.0%/weight in order to make a slurry. Then the slurry is cast or coated onto the Nickel sponge (or mesh fabric material). The slurry-coated nickel mesh fabric is then air dried for about 10 hours. Thereafter, dried article is compressed at 200 [pounds/cm^2] in to form flexible cathodic material having a desired porosity (e.g. 30-70%) and about 0.5-0.6 millimeters. It is understood, however, that the thickness and porosity of the cathode material may vary from application to application. The cathode material is then sintered at about 280 degree C for about 2 hours to remove the solvent (i.e. water) and provide a flexible sheet of cathodic material which can then be cut into the desired dimensions to form a cathode belt structure for the FCB system under design. The ends of belt structure can be joined by soldering, fasteners, or the like to form a virtually seamless cathode surface about closed belt structure. The nickel mesh material 151 can be exposed at the ends of the cathode belt structure 141, as illustrated in Fig. 16C, to allow cathode contacting elements 123A to establish electrical contact therewith during discharging and recharging operations, as discussed above.

In the illustrative embodiment shown in Figs. 16 and 16A, each ionically-conductive belt 107' can be realized as flexible belt made from an open-cell polymer material having a porous structure and impregnated with an ionically-conductive material (e.g. KOH) capable of supporting ionic transport between the cathode and anode structures of the FCB system. Ionically-conductive belt 107' can be realized as a solid-state membrane having ionic-conduction characteristics. In general, there will be many ways of making the ionically-conductive belt. For purposes of illustration, two formulas are described below.

In accordance with the first formula, one mole of KOH and 0.1 mole of calcium chloride are dissolved in the mixed solvents of 60 milliliters of water and 40 milliliters of tetrahydrogen furan (THF). The function of KOH is as a hydroxide ion source, whereas calcium chloride is as a hygroscopic agent. Thereafter, one mole of PEO is added to the mixture. Then, the solution is cast (or coated) as a thick film onto substrate made of polyvinyl alcohol (PVA) type plastic material. This material has been found to work well with PEO, although it is expect that other substrate materials having a surface tension higher than the film material should work as well with acceptable results. As the mixed solvents evaporate from the applied coating, an ionically-conductive solid state membrane (i.e. thick film) is formed on the PVA substrate. By peeling the solid state membrane off the PVA substrate, a solid-state ionically-conductive membrane or film is formed. Using the above formulation, it is possible to form ionically-conductive films having a thickness in the range of about 0.2 to about 0.5 millimeters. Then, the solid-state membrane can be cut into a shape required to form a belt-like structure transportable about two or more rotating cylinders. The ends of the shaped membrane can be joined by an adhesive, ultra-sonic welding, appropriate fasteners or the like to form a solid-state ionically-conductive belt structure 107' for use in the FCB system shown in Fig. 16.

In accordance with the second formula, one mole of KOH and 0.1 mole of calcium chloride are dissolved in the mixed solvents of 60 millimeters of water and 40 milliliters of tetrahydrogen furan (THF). The function of KOH is as a hydroxide ion source, whereas calcium chloride is as a hygroscopic agent. Thereafter, one mole of polyvinyl chloride (PVC) is added to the mixture. Then, the resulting solution is cast (or coated) as a thick film onto substrate made of polyvinyl alcohol (PVA) type plastic material. This material has been found to work well with PVC, although it is expect that other substrate materials having a surface tension higher than the film material should work as well with acceptable results. As the mixed solvents evaporate from the applied coating, an ionically-conductive solid state membrane (i.e. thick film) is formed on the PVA substrate. By peeling the solid state membrane off the PVA substrate, a solid-state ionically-conductive membrane is formed. Using the above formulation, it is possible to form ionically-conductive films having a thickness in the range of about 0.2 to about

0.5 millimeters. Then, the solid-state film or membrane can be cut into a shape required to form a belt-like structure transportable about two or more rotating cylinders. The ends of the shaped membrane can be joined by an adhesive, ultra-sonic welding, appropriate fasteners or the like to form a solid-state ionically-conductive belt structure 107' for use in the FCB systems of the present invention.

When using the ionically-conductive belt 107' disclosed hereinabove, it will necessary to provide a means for achieving "wetting" between (1) the ionically-conductive belt 107' and the metal-fuel tape 108, and (2) the ionically-conductive belt 107' and the movable cathode belt 141. One way of achieving wetting would be to continuously or periodically apply a coating of water (H_2O) and/or electrolyte make-up solution to the surface of the metal-fuel tape 108 (and/or ionically-conductive belt 107') during system operation to enable a sufficient level of ionic transport between the metal-fuel tape and the ionically-conductive belt and also between the movable cathode belt and the ionically-conductive belt. Notably, the thickness of the water and/or electrolyte coating applied to the metal-fuel tape (and/or the ionically-conductive belt) will depend on the transport speed of the metal fuel tape, its water absorption properties, the temperature of the cathode belt, etc. In the illustrative embodiment shown in Fig. 16, wetting of the metal-fuel tape 108, the ionically-conductive belt 107' and the cathode belt 141 can be carried out using applicator 170 and dispensing mechanism 171. It is understood, however, that other methods of wetting the metal-fuel tape, ionically-conductive belt and cathode belt may be used with excellent results.

In general, controlling the velocity of the moving components in the FCB system of Fig. 16 can be achieved in various ways. For example, one way might be to drive belt transport cylinders 143 and 144 and 145 with a common belt structure that is also used to transport the metal-fuel tape (e.g. between supply and take-up reels or hubs 117A and 117B within a cassette type-device 113). Another way might be to drive transport cylinders 143, 144 and 145 with a first set of DC-controlled motors, while driving the supply and take-up hubs 117A and 117B of the metal-fuel cassette device 113 using a second set of DC-controlled motors, synchronized with the first and second DC speed-controlled motors. Other ways of achieving velocity control will become apparent to those skilled in the art.

In the event that the cathode-belt based engine 140 is employed within a Metal-Fuel Tape Discharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Discharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 16. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, those sections of the cathode belt structure 141 along which electrical current is generated can be enclosed by an oxygen-injection chamber (connected to an air pump or oxygen source), and having one or more pO_2 sensors, one or more temperature sensors, discharging head cooling equipment, and the like, so that system controller 122 can control the pO_2 level within this section of the moving cathode-belt structure 141, as well as maintain the temperature of the discharging head therealong during discharging operations.

Similarly, in the event that the cathode-belt based engine 140 is employed within a Metal-Fuel Tape Recharging Subsystem, then each of the subsystems contained within the Metal-Fuel Tape Recharging Subsystem disclosed in copending Application Serial No. 09/074,337 can be incorporated into the system schematically depicted in Fig. 16. Thus, as taught in Applicant's copending Application Serial Nos. 09/074,337 and 08/944,507, those sections of the cathode belt structure 141 along which electrical current is generated can be enclosed by an oxygen-evacuation chamber (connected to a vacuum pump or like device), and having one or more pO_2 sensors, one or more temperature sensors, recharging head cooling equipment, and the like, so that system controller 120 can control the pO_2 level within these sections of the moving cathode belt structure 141, as well as maintain the temperature of the recharging head therealong during recharging operations.

As shown in Fig. 16, during tape discharging operations, oxygen-rich air flows through the ultra fine perforations formed in the cathode belt structure 141 and reaches the interface between the metal-fuel tape 108 and the corresponding ionically-conductive belt structure 107. During tape recharging operations, oxygen liberated from the interface between the metal-fuel tape 108 and the ionically-conductive belt structure 107 flows through the fine perforations formed in the cathode belt structure 141, to the ambient environment.

The FCB system of Fig. 16 can be readily modified in various ways. For example, the ionically-conductive belt structures 107' can be removed from the system, and in lieu thereof, a thin film of ionically-conductive gel 7 applied to the cathode belt structure 141 or metal-fuel tape 108 during system operation. This can be achieved using an electrolyte applicator, disposed beneath the metal-fuel tape 108, and fed by a dispenser governed by system controller 120. During operation, a thin layer of ionically-conductive gel 107 is dispensed from applicator over the surface of the metal-fuel tape contacting the cathode belt 141. Notably, the required thickness of the ionically-conductive film layer 107 will vary from application to application, but typically will depend on a number of factors including, for example, the electrical conductivity of the ionically-conductive medium, the current flow expected to be produced by the FCB system during discharging operations, the surface area of the cathode element, and the like.

Alternatively, the ionically-conductive belt structures 107' can be removed from the system shown in Fig. 16, and in lieu thereof, a solid-state ionically-conductive film layer 107" applied to the cathode belt structure 141 or metal-fuel tape 108 during manufacture thereof. In such modified systems, the required thickness of the ionically-conductive film layer 107" will also vary from application to application, but typically will depend on a number of factors including, for example, the electrical conductivity of the ionically-conductive medium, the current flow expected to be produced by the FCB system during discharging operations, the surface area of the cathode element, and the like.

In alternative embodiments of the present invention, the metal-fuel tape used with the FCB System of Fig. 16 can be realized in a variety of different ways. As shown in Fig. 17A, the first type of metal-fuel tape 152 is formed as a thin layer of metal-fuel material (e.g. zinc) 108 on which a thin layer of ionically-conductive solid-state film material 107" is deposited. The second type of metal-fuel tape 152' shown in Fig. 17B is formed by depositing a metallic powder (e.g. zinc powder) and binder (e.g. polyethylene) on a polyester substrate to form metal-fuel tape 108', and thereafter, depositing a thin layer of ionically-conductive solid-state film material 107" thereon. As shown in Fig. 17C, a third type of metal-fuel tape 52 is formed by impregnating metallic powder (e.g. zinc powder) within a substrate material such as polyvinyl chloride PVC to form metal-fuel tape 108", and thereafter, depositing a thin layer of ionically-conductive solid-state film material 107" thereon. Techniques for fabricating such forms of metal-fuel tape are described in copending Application Serial Nos. 08/944,507 and 09/074,337.

In Fig. 18, there is shown an alternative embodiment of cathode belt structure is shown for use in the FCB system of Fig. 16. This cathode belt structure can be made by either applying a thin layer of solid-state ionically-conductive film onto each cathode belt structure shown in the FCB system during manufacture of the cathode belt structures, or by applying a thin layer of ionically conducting gel onto each belt structure during system operation. Various techniques can be used to apply the ionically-conductive film layer to the cathode belt structure.

While the illustrative embodiment shown in Fig. 16 is designed for single-cathode/single-anode type applications, it is understood that this system embodiment can be readily modified to include a plurality of electrically-isolated cathode elements (tracks) formed along the flexible cathode belt structures for use with multi-track metal-fuel tape, as taught in Applicant's copending Application Serial Nos. 08/944,507, supra.

Fourth Illustrative Embodiment Of The FCB System

In Figs. 19 and 19A, the fourth illustrative embodiment of the

FCB system is shown. This FCB system 155 is similar to the FCB system 40 shown in Fig. 16, expect that it is modified to use double-sided metal-fuel tape 155 to further improve the volumetric power density characteristics of the FCB system. The primary difference between these two systems is that in Figs. 19 and 19A, the tape path configuration in FCB system 155 is designed so that metal-fuel tape transported through system 155 is discharged from both sides, thus achieving more efficient utilization of the metal-fuel tape. Notably, metal-fuel tape 108 and 108" are double-sided and thus adapted for use in FCB system 155. Metal-fuel tape 108' and 108" can be readily justified so that both sides of its substrate carry metal-fuel material. In all other respects, the FCB system of Figs. 19 and 19A is similar to the FCB system of Fig. 16.

As shown in Figs. 19 and 19A, the double-sided metal-fuel tape 108, 108" is discharged along its lower (i.e. inner) surface 156 as it is transported over the first set of cathode and ionically-conductive belts (141 and 171), and after routing about path-directing roller 114A is discharged along its upper (i.e. outer) surface 157 as it is transported over the second first set of cathode and ionically-conductive belts. As shown, after being routed about roller 148A, the double-sided metal fuel tape 108 is discharged once again along its lower (i.e. inner) surface 156 as it is transported over the third set of cathode and ionically-conductive belts, and after routing about path-directing roller 148B is discharged along its upper (i.e. outer) surface once again as it is transported over the fourth set of cathode and ionically-conductive belts. As shown in Figs. 19 and 19A, a plurality of cathode and anode contacting elements 123A and 123B are rotatably mounted along each of the sets of cathode and ionically-conductive belts within the FCB system. In Fig. 19B, a pair of cathode and anode contacting elements 123A and 123B are shown in greater detail. As shown, metal-fuel tape 108 (108"), a section of ionically-conductive belt 107' and a section of cathode belt 141 (moving at the same velocity) are disposed between the cathode and anode contacting rollers 123A and 123B, wherebetween electrical power is electrochemically generated during discharging operations.

While the illustrative embodiment shown in Figs. 19 and 19A is designed for single-cathode/single-anode type applications, it is understood that this system embodiment can be readily modified to include a plurality of electrically-isolated cathode elements (tracks) formed along the flexible cathode belt structures for use with multi-track metal-fuel tape, as taught in Applicant's copending Application Serial Nos. 08/944,507, supra.

Fifth Illustrative Embodiment Of The FCB System

In Fig. 20, the fifth illustrative embodiment of the FCB system is shown. This embodiment of the FCB system is similar to the FCB system shown in Figs. 19 and 19A in which double-sided metal-fuel tape is used. The primary difference between these two systems is that in Figs. 19 and 19A, the ionically-conductive medium is realized as an ionically-conductive film layer 107 applied over the outer surface of each cathode belt structure. In all other respects, the FCB system of Fig. 20 is similar to the FCB system of Figs. 19 and 19A.

In Fig. 20B, a pair of cathode and anode contacting elements 123A and 123B employed in FCB system of Fig. 20 are shown in greater detail. As shown in this figure, metal-fuel tape 108 (108"), a section of ionically-conductive belt 107' and a section of cathode belt 141 (moving at the same velocity) are disposed between the cathode and anode contacting rollers 142 and 143, wherebetween electrical power is electrochemically generated during discharging operations.

While the illustrative embodiment shown in Fig. 20 is designed for single-cathode/single-anode type applications, it is understood that this system embodiment can be readily modified to include a plurality of electrically-isolated cathode elements (tracks) formed along the flexible cathode belt structures for use with multi-track metal-fuel tape, as taught in Applicant's copending Application Serial Nos. 08/944,507, supra.

Sixth Illustrative Embodiment Of The FCB System

In Fig. 21, the sixth illustrative embodiment of the FCB system is shown. This embodiment of the FCB system is similar to the FCB system shown in Figs. 20 and 20A in which double-sided metal-fuel tape 108 (108") is used. The primary difference between these two systems is that in Figs. 20 and 20A, adjacent pairs of cathode belts 141A and 141B, 141B and 141C and 141C and 141D are mounted closely together. As shown in Fig. 20A, the double-sided metal-fuel tape can be discharged from both its upper and lower sides in order to improve the volumetric power density of the FCB system. This modification requires the use of a cathode and anode contacting mechanism of the type illustrated in Fig. 21A. As shown therein, a pair of neighboring cathode belts 141A and 141B are contacted by a pair of cathode contacting elements 123A1 and 123A2 , respectively, rotatably mounted from the system housing, while metal-fuel tape transported through the mechanism is contacted by a common anode contacting element 62 rotatably mounted from the system housing. This arrangement enables both sides of double-sided metal-fuel tape 108 (108”) to be simultaneously discharged. In all other respects, the FCB system of Fig. 21 is similar to the FCB system of Figs. 20 and 20A.

Alternatively, the FCB system of Fig. 21 can be modified in a variety of ways. One way is to remove the ionically-conductive layer from the cathode belt structures, and in lieu thereof, form an ionically-conductive solid-state (or gel) film 107” onto each side of the metal-fuel tape 108 (108”) being transported through the discharging engine.

While the illustrative embodiment shown in Fig. 21 is designed for single-cathode/single-anode type applications, it is understood that this system embodiment can be readily modified to include a plurality of electrically-isolated cathode elements (tracks) formed along the flexible cathode belt structures for use with multi-track metal-fuel tape, as taught in Applicant's copending Application Serial Nos. 08/944,507, supra.

Seventh Illustrative Embodiment Of The FCB System

In Fig. 22, the seventh illustrative embodiment of the FCB system is shown. This embodiment of the FCB system is similar to the FCB system shown in Figs. 20 and 20A. The primary difference between these two systems is that in Fig. 22, the plural streams of metal-fuel tape 8A, 8B and 108C (108’A, 108’B, 108’C), (108’’A, 108’’B, 108””C) are supplied from the supply reel 17A, transported about a plurality of cathode belt structures 411 (and ionically-conductive belts

107'), and then taken-up by a take-up reel 118B associated with a tape cartridge 113 or like device, as taught in Applicant's copending Application Serial Nos. 08/944,507, supra. This arrangement enables a significant reduction in the bending radius of the metal-fuel tape as it is transported between the supply and take-up reels of the tape cartridge device or like device employed in the FCB system.

Alternative Embodiments of The FCB System of The Present Invention

Having described the illustrative embodiments of the present invention in great detail above, several modifications thereto readily come to mind which would be advantageous in the practice of the present invention.

In order to eliminate the need to separately drive and actively control the velocity of the metal-fuel tape, the movable cathode structures and ionically-conductive medium in the FCB system hereof using complex mechanisms, the present invention also contemplates creating a condition of "hydrostatic drag" between the metal-fuel tape and the ionically-conductive medium (e.g. belt or applied gel/solid-state film), and the ionically-conductive medium (e.g. belt or applied gel/solid-state film and the cathode structure (e.g. cylinder or belt). By virtue of the hydrostatic drag, the metal-fuel tape, ionically-conductive medium and movable cathode structure can be moved at substantially the same velocity (at points of contact therebetween) by transporting only one of these movable system components (e.g. metal-fuel tape, ionically-conductive medium, or movable cathode structure) using, for example, a motor or like device driven by mechanical (e.g. spring-wound), electrical, or pneumatic forces. This method of transport and velocity equalization significantly reduces the complexity of the FCB system as well as the cost of manufacture and maintenance thereof. Also, it enables the metal-fuel tape, ionically-conductive medium, and cathode structures to be moved within the system without generating significant frictional (e.g. shear) forces, and thus transporting these moving components using torque-control (or current control) techniques regulated by the output power requirements set by electrical loading conditions at any instant in time.

Hydrostatic drag can be created between these moving system components by maintaining a sufficient level of surface tension between the ionically-conductive medium and the metal-fuel tape, and the ionically-conductive medium and the movable cathode structure during system operation. When using the ionically-conductive media disclosed hereinabove, sufficient surface tension can be created between the three primary moving components of the FCB system by continuously or periodically applying an even coating of water (H_2O) and/or electrolyte make-up solution to the surface of the metal-fuel tape (and/or ionically-conductive medium) so that, during system, operation "wetting" occurs between (1) the ionically-conductive medium and the metal-fuel tape, and (2) the ionically-conductive medium and the movable cathode structure. Notably, the thickness of the water coating and/or electrolyte make-up solution applied to the metal-fuel tape (and/or the ionically-conductive medium) will depend on the transport speed of the metal fuel tape, its water absorption properties, etc. In each of the illustrative embodiments disclosed herein, wetting of the metal-fuel tape and/or ionically-conductive medium can be carried out using applicator 170 and dispensing mechanism 171 shown in the figure drawings hereof. It is understood, however, that other methods of wetting the metal-fuel tape and/or ionically-conductive medium may be used with excellent results.

For example, in the illustrative embodiment shown in Fig. 11, periodic or continuous wetting of the metal-fuel tape 108 and the ionically-conductive coating 107 on each cathode cylinder 103 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable each cathode cylinder within the system to passively move (i.e. rotate) at the same velocity as the metal-fuel tape in contact therewith while only the metal-fuel tape 108 is being actively driven by its tape transport mechanism 121. In this alternative embodiment of the present invention, the use of cathode cylinder drive unit 110 and velocity equalization by system controller 120 can be eliminated while still achieving the principles of the present invention. This modification would reduces the complexity of the system as well as its cost of manufacture and maintenance.

In the illustrative embodiment shown in Fig. 13, periodic or continuous wetting of the ionically-conductive belt 107', the metal-fuel tape 108 and each cathode cylinder 103 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable each cathode cylinder 103 within the system to passively move at the same velocity as the metal-fuel tape in contact therewith while only the metal-fuel tape 108 is being actively driven by its tape transport mechanism 121. In this alternative embodiment of the present invention, the use of cathode cylinder drive unit 110 and velocity equalization by system controller 120 can be eliminated while still achieving the principles of the present invention. This modification would reduces the complexity of the system as well as its cost of manufacture and maintenance.

In the illustrative embodiment shown in Fig. 16, periodic or continuous wetting of the metal-fuel tape 108, ionically-conductive belt 107', and cathode belt 141 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable each cathode belt 141, belt transport cylinders 143 and 144, ionically-conductive belt 107' and belt cylinder 145 to passively rotate at the same velocity as the metal-fuel tape 108 in contact therewith while only the metal-fuel tape is being actively driven by its tape transport mechanism 121. In this alternative embodiment of the present invention, the use of cylinder drive units 147 and velocity equalization by system controller 122 can be eliminated while still achieving the principles of the present invention. Alternatively, it may be possible in some instances to actively drive one ionically-conductive belt 107' and/or corresponding cathode belt 141 and allow the other cathode belts 141, ionically-conductive belts 107' and metal fuel tape 108 to passively move at the same velocity as the actively-driven cathode belt with minimal slippage. In either case, such modifications will reduce the complexity of the system as well as its cost of manufacture and maintenance.

In the illustrative embodiment shown in Fig. 19, periodic or continuous wetting of the metal-fuel tape 108, ionically-conductive belt 107', and cathode belt 41 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable each cathode belt 141, belt transport cylinders 143 and 144, ionically-conductive belt 107' and belt cylinder 145 to passively rotate at the same velocity as the metal-fuel tape 108 in contact therewith while only the metal-fuel tape is being actively driven by its tape transport mechanism 121. In this alternative embodiment of the present invention, the use of cylinder drive units 147 and velocity equalization by system controller 122 can be eliminated while still achieving the principles of the present invention. Alternatively, it may be possible in some instances to actively drive one ionically-conductive belt 107' and/or corresponding cathode belt 141 and allow the other cathode belts 141, ionically-conductive belts 107' and metal fuel tape 108 to passively move at the same velocity as actively-driven cathode belt with minimal slippage. In either case, such modifications will reduce the complexity of the system as well as its cost of manufacture and maintenance.

In the illustrative embodiment shown in Fig. 20, periodic or continuous wetting of the metal-fuel tape 108 and the ionically-conductive film coating 107 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable each cathode belt 141 and belt transport cylinders 143 and 144 to passively rotate at the same velocity as the metal-fuel tape 108 in contact therewith while only the metal-fuel tape is being actively driven by its tape transport mechanism 121. In this alternative embodiment of the present invention, the use of cylinder drive units 147 and velocity equalization by system controller 122 can be eliminated while still achieving the principles of the present invention. Alternatively, it may be possible in some instances to actively drive one cathode belt 141 and allow the other cathode belts and metal fuel tape 108 to passively move at the same velocity as the actively driven cathode belt 141 with minimal slippage. In either case, such modifications will reduce the complexity of the system as well as its cost of manufacture and maintenance.

In the illustrative embodiment shown in Fig. 21, periodic or continuous wetting of the metal-fuel tape 108 and the ionically-conductive film coating 107 can create sufficient surface tension therebetween, and thus sufficient hydrostatic drag, to enable each cathode belt 141 and belt transport cylinders 143 and 144 to passively rotate at the same velocity as the metal-fuel tape 108 in contact therewith while only the metal-fuel tape is being actively driven by its tape transport mechanism 121. In this alternative embodiment of the present invention, the use of cylinder drive units 147 and velocity equalization by system controller 122 can be eliminated while still achieving the principles of the present invention. Alternatively, it may be possible in some instances to actively drive one cathode belt 141 and allow the other cathode belts and metal fuel tape 108 to passively move at the same velocity as the actively-driven cathode belt with minimal slippage. In either case, such modifications will reduce the complexity of the system as well as its cost of manufacture and maintenance.

In addition, a plurality of cathode cylinders (or cathode belts) of the general type disclosed hereinabove can be rotatably mounted within an array-like support structure as disclosed in Applicant's copending Application No. 09/110,761 entitled "Metal-Air Fuel Cell Battery System Employing a Plurality of Moving Cathode Structures for Improved Volumetric Power Density" filed on the same date herewith, and incorporated herein by reference in its entirety. The cathode support tube of each such cylindrical cathode structure can be driven by a supply of metal-fuel tape transported over the surfaces thereof in accordance with a predefined tape pathway. Transport of the metal-fuel tape can be carried out using a tape transport mechanism similar to that disclosed in Applicant's copending Application Serial No. 09/074,337. The ionically-conductive medium can be realized as a solid-state film or layer applied to either the outer surface of each cylindrical cathode structure or the surface of the metal-fuel tape, as described in the various illustrative embodiments described herein. Alternatively, the ionically-conductive medium can be realized as an ionically-conductive belt structure that is transported through the cylindrical cathode array, while disposed between the metal-fuel tape and the surface of the cathode cylinders. Using this system design, it is possible to generate very high electrical power output from physical structures occupying relatively small volumes of space, thereby providing numerous advantages over prior art FCB systems.

Applications of Metal-Air FCB Systems of Present Invention

In general, any of the metal-air FCB systems described above can be integrated together, with other subsystems, in order to provide an electrical power generation system (or plant), wherein real-time management of metal-fuel within the system is used to satisfy peak power requirements of AC and/or DC type electrical loads without sacrificing reliability or operating efficiency.

For purposes of illustration, the electrical power generation system of the present invention 700 is shown in Fig. 23A as embedded within an electrically-powered transportation system or vehicle 701 realizable in the form of an electrically-powered automobile, train, truck, motorcycle, or any other type of vehicle employing one or more AC and/or DC powered loads (e.g. motors) well known in the art. In Fig. 23B, the electrical power generation system 700 is shown realized as a stationary power plant. Each arrangement, the power generation system 700 is shown having auxiliary and hybrid power sources connected 702,703 and 704 thereto. In general, the electrical power generation system 700 can be configured to produce DC power for supply to one or more DC-type electrical loads 702 as shown in Fig. 23A, or AC power for supply to one or more AC-type electrical loads as shown in Fig. 23B. Each of these system embodiments will be described in detail below.

As shown in Fig. 24A, the first illustrative embodiment of the electric power generation system 700 comprises: an output DC power bus structure 706 for supplying DC electrical power to a plurality of electrical loads 707A-707D connected thereto; a network of metal-air FCB (sub)systems 708A through 708H, each operably connected to the DC power bus structure 706 by way of its output power control subsystem, so as to enable a supply of DC electrical power to the DC power bus structure; an output voltage control subsystem 709 operably connected to the DC power bus structure 706, for controlling (i.e. regulating) the output voltage therealong; loading sensing circuitry 710 operably connected to the output DC power bus structure 706 for sensing real-time loading conditions along the DC power bus and generating input signals indicative of the loading conditions along the DC power bus structure; a network control subsystem (e.g. microcomputer with RAM/ROM/EPROM) 711 for controlling the operation of each FCB subsystem within the network (e.g. by way of controlling discharging/recharging parameters during discharging/recharging modes of operation, respectively, and collecting metal-fuel and metal-oxide indicative data from the particular FCB subsystems on a real-time basis); a FCB subsystem control bus structure 712 to which each FCB subsystem 708A through 708H is operably connected by way of its input/output subsystem, and for enabling the transfer of metal-fuel indicative data from the FCB subsystems to the network control subsystem 711, and the transfer of control signals from the network control subsystem 711 to the FCB subsystems during power generation operations; and a network-based metal-fuel management subsystem (e.g. a relational database management system) 713 operably connected to the network control subsystem 711, for storing information representative of the amount of metal-fuel (and metal-oxide) present along each zone of each metal-fuel track within each FCB subsystem connected between bus structures 706 and 712 in the system; an input DC power bus structure 714 for supplying DC power to each of the FCB subsystems 707A-707H during recharging operations, produced from auxiliary and hybrid power sources 702, 703, 704 and 704'; and an input voltage control subsystem 715 for controlling the input voltage along input DC power bus structure 714.

In general, any one of the FCB subsystems disclosed herein can be embedded within the electrical power supply network described above. Embedding each FCB subsystem is simply achieved by connecting its input/output subsystem to the FCB subsystem control bus structure 712, and connecting its output power control subsystem to the DC power bus structure 706. Also, each FCB subsystem includes a metal-fuel recharging subsystem for recharging metal-fuel tracks under the global control of the network control subsystem 711.

In Fig. 24B, an alternative embodiment of the electric power generation system of the present invention is shown. In this alternative embodiment of the present invention, a DC-AC power conversion subsystem 716 is provided between the output DC power bus structure 706 and an output AC power bus structure 717, to which a plurality of AC-type electrical loads 707A and 707D are connected in an operable manner. In such an alternative embodiment of the present invention, DC power supplied to the DC power bus structure 706 is converted to an AC power supply that is applied to the AC power bus structure 717. Output voltage control unit 709 is provided for the purpose of controlling the output voltage along the AC power bus structure 717. AC power delivered to the AC bus structure 717 is supplied to the AC electrical loads (e.g. AC motors) connected thereto.

In the preferred embodiment, the metal-fuel management subsystem 713 comprises a relational-database management system comprising means for maintaining a plurality of data tables containing information representative of the amount of metal-fuel available (and metal-oxide present) along each zone of each metal-fuel track within each FCB subsystem in the electrical power generation system. In Fig. 24C, such data tables are schematically depicted. As electrical power is being generated from the individual FCB subsystems, metal-fuel indicative data is automatically generated within each subsystem during discharging modes, while metal-oxide presence data is generated during recharging modes of operation. As shown in Figs. 24A and 24B, locally generated metal-fuel indicative data and metal-oxide indicative data is transferred to the network-based metal-fuel/metal-oxide management subsystem 713 by way of the control bus structure 712 and network control subsystem 711.

In many applications it will be desirable to manage the consumption of metal-fuel in each FCB subsystem 707A through 707D so that each such FCB subsystem has substantially the same amount of metal-fuel available at each instant in time. This metal-fuel equalization principle is achieved by the network control subsystem 711 carrying out the following functions: (1) enabling the sensing of actual loading conditions along the DC power bus structure by the load sensing subsystem 710; (2) enabling particular FCB subsystems (708A-708B) to generate and supply electrical power to the output DC power bus structure 706 in response to such sensed loading conditions; (3) managing the availability of metal-fuel and the presence of metal-oxide within the FCB subsystems using the network-based metal-fuel management (database) subsystem 713; and (4) enabling selective discharging of metal-fuel tracks within selected FCB subsystems (and optionally, the selective recharging of metal-oxide therealong) so that the metal-fuel availability within each FCB subsystems is substantially equalized on a time-average basis. This method can be achieved in a straightforward manner programming technologies well known the computing arts.

The advantages derived from having the network control subsystem 711 carry out “metal-fuel equalization” across each of the FCB subsystems can be best appreciated by way of example, referring to Fig. 25.

In general, the amount of electrical power that is produced by the electrical power system hereof depends on the amount of electrical power required by the electrical load(s) connected to the system. In accordance with the present invention, an increase in electrical power output from the system is achieved by enabling additional metal-air FCB subsystems to generate and supply electrical power to the output power bus, structure 706 (or 717 in the case of AC loads) under the control of a programmed network control subsystem 711. For example, consider the case of an electrical power system having eight FCB subsystems connected between its DC power bus structure 706 and FCB subsystem control bus structure 712. In such an example, it might be helpful to metaphorically view each FCB subsystem 707A through 708D as a "power cylinder" within an engine capable of doing work. Thus, consider the case of an electrical power generation system (or plant) in accordance with the present invention, wherein eight FCB subsystems (i.e. power cylinders) which are configured together and embodied within the structure of an electrically-powered automobile or like vehicle, as shown in Fig. 23A. In such a case, the number of FCB subsystems (i.e. power cylinders) that are enabled to generate electrical power at any instant in time will depend on the electrical load presented to the electrical power generation plant aboard the automobile 701. Thus, when the automobile is travelling along a flat horizontal road surface or cruising downhill, it is conceivable that only one or a few FCB subsystems (i.e. power cylinders) will be enabled, by network control subsystem 711, whereas when travelling uphill or passing another automobile, more or all FCB subsystems (i.e. power cylinders) are enabled by subsystem 711 in order to meet the power requirements demanded by such operating conditions. Regardless of the loading conditions imposed on the electrical power generation system aboard the vehicle, the average rate of consumption of metal-fuel within each of the metal-air FCB subsystems 708A through 708H will be substantially equal on a time-average basis, in accordance with the metal-fuel equalization principle described above, so that, on a time-average basis, the amount of metal-fuel available for discharging in each FCB subsystem 708A through 708H is maintained substantially equal by network control subsystem 711.

In the illustrative embodiment, the network control subsystem 711 carries out a control process (i.e. algorithm) which is designed to receive various input parameters and produce various output parameters so that the control processes of the present invention are carried out in an automated manner. The input parameters in the control process include, for example, data relating to: (i) load conditions sensed by load sensing subsystem 710 and other sensors aboard the electrically-powered vehicle (e.g. RPM of the electric motors, speed of the vehicle, etc.); (ii) the amount of metal-fuel available along each zone of metal-fuel within each metal-air FCB subsystem; (iii) the amount of metal-oxide present along each zone of metal-fuel within each metal-air FCB subsystem; (iv) discharging parameters associated with each of the metal-air FCB subsystems; and (v) recharging parameters associated with each of the metal-air FCB subsystems (when recharging mode is provided therewithin). The output parameters in the control process include, for example, control data for controlling: (i) which set of metal-air FCB subsystems should be enabled at any instant in time for discharging operations; (ii) which metal-fuel zones should be discharged within an enabled metal-air FCB subsystem at any instant in time; (iii) how should the discharging parameters be controlled within each enabled metal-air FCB subsystem at any instant in time; (iv) which set of metal-air FCB subsystems should be enabled at any instant in time for recharging operations; (v) which metal-fuel zones should be recharged within an enabled metal-air FCB subsystem at any instant in time; and (vi) how should the recharging parameters be controlled within each enabled metal-air FCB subsystem at any instant in time. The network control subsystem 711 can be realized using a microcomputer programmed to carry out the above-described functions in a straightforward manner. The network control subsystem can be embedded within the host system (e.g. vehicle 701) in a simple manner.

Notably, in the illustrative embodiment shown in Figs. 23A through 24C, each metal-air FCB subsystem 708A through 708H has a discharging mode of operation and a recharging mode of operation. Consequently, the electrical power generation system (i.e. plant) of the present invention is capable of recharging selected zones of metal fuel (tape) when the corresponding metal-air FCB subsystem is not enabled in its discharging (power-generating) mode of operation. By virtue of this aspect of the present invention, it is possible for auxiliary power generators (e.g. alternators, electrical power supply from a stationary source, etc.) 702, 703 and/or hybrid-types of electrical power generators (e.g. photo-voltaic cells, thermo-electric devices, etc.) 704, 704' shown in Figs. 23A and 23B to be used to produce electrical power for supply to the input DC power bus structure 714 of the system shown in Fig. 23A. Notably, during recharging operations within enabled FCB subsystems, the input DC power bus structure 714 is designed to receive DC electrical power from auxiliary and hybrid-type power generation sources 702, 703, 704 and 704' for supply to metal-fuel recharging subsystems embodied within metal-air FCB subsystems 708A through 708H enabled for discharging operation while the host vehicle (e.g. automobile) 701 is in motion or at rest, as the case may be. When recharging metal-fuel while the vehicle is stationary, electrical power from a stationary source (e.g. power receptacle) can be provided as input to the input DC power bus structure 714 for recharging metal-fuel within enabled FCB subsystems.

The above-described FCB systems of the present invention can be used to power various types of electrical circuits, systems and devices, including, but not limited to, power tools, consumer appliances, stand-alone portable generators, vehicular systems, and the like.

Having described in detail the various aspects of the present invention described above, it is understood that modifications to the illustrative embodiments will readily occur to persons with ordinary skill in the art having had the benefit of the present disclosure. All such modifications and variations are deemed to be within the scope and spirit of the present invention as defined by the accompanying Claims to Invention.

CLAIMS TO INVENTION

1. A metal-air fuel cell battery (FCB) system for generating electrical power, comprising:

a movable cathode structure;

a supply of metal-fuel tape transportable relative to said movable cathode structure;

an ionically-conducing medium disposed between said movable cathode and said metal-fuel tape, for contacting said movable cathode structure and said metal-fuel tape and supporting ionic conduction therebetween during system operation; and

a transport mechanism for transporting said movable cathode structure and said metal-fuel tape relative to each other, at substantially the same velocity at the locus of points at which the ionically-conductive medium contacts said metal-fuel tape and said movable cathode structure during system operation,

whereby damage to said movable cathode structure and metal-fuel tape is substantially reduced.

2. The metal-air fuel cell battery system of claim 1, wherein said movable cathode structure is cylindrically shaped and has a hollow center permitting air flow therethrough.

3. The metal-air fuel cell battery system of claim 2, wherein said ionically-conductive medium is a film integrated with said movable cathode structure.

4. The metal-air fuel cell battery system of claim 2, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

5. The metal-air fuel cell battery system of claim 2, wherein said ionically-conductive medium is an ionically-conductive belt structure transported between said movable cathode structure and at least a portion of said metal-fuel tape.

6. The metal-air fuel cell battery system of claim 3, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure; and

second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape during system operation.

7. The metal-air fuel cell battery system of claim 6, wherein said first means comprises one or more electric motors for rotating said movable cathode structure, and said second means comprises one or more electric motors for transporting said metal-fuel tape relative to said moving cathode structure.

8. The metal-air fuel cell battery system of claim 4, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure; and second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape during system operation.

9. The metal-air fuel cell battery system of claim 5, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure;

second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal-fuel tape during system operation; and

third means for transporting said ionically-conductive belt structure between said movable cathode structure and said metal-fuel tape during system operation, at substantially the same velocity as said metal-fuel tape during system operation.

10. The metal-air fuel cell battery system of claim 2, wherein said transport mechanism comprises a common belt structure for transporting said movable cathode structure and said metal-fuel tape relative to each other at substantially the same velocity at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape.

11. The metal-air fuel cell battery system of claim 5, wherein said transport mechanism comprises a common belt structure for transporting said movable cathode structure, said ionically-conducing belt structure and said metal-fuel tape relative to each other at

substantially the same velocity at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape.

12. The metal-air fuel cell battery system of claim 1, wherein said movable cathode structure is a cathode belt structure.

13. The metal-air fuel cell battery system of claim 12, wherein said ionically-conductive medium is a film integrated with said cathode belt structure.

14. The metal-air fuel cell battery system of claim 12, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

15. The metal-air fuel cell battery system of claim 12, wherein said ionically-conductive medium is a belt structure disposed between at least a portion of said cathode belt structure and said metal-fuel tape.

16. The metal-air fuel cell battery system of claim 13, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure; and

second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation.

17. The metal-air fuel cell battery system of claim 16, wherein said first means comprises one or more motors for rotating said movable cathode structure, and said second means comprises one or more motors for transporting said metal-fuel tape relative to said moving cathode structure.

18. The metal-air fuel cell battery system of claim 14, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure; and

second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation.

19. The metal-air fuel cell battery system of claim 18, wherein said first means comprises one or more electric motors for rotating said movable cathode structure, and said second means comprises one or more motors for transporting said metal-fuel tape relative to said moving cathode structure.

20. The metal-air fuel cell battery system of claim 15, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure;

second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation; and

third means for transporting said ionically-conductive belt structure between said movable cathode structure and said metal-fuel tape during system operation, at substantially the same velocity as said metal-fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation.

21. The metal-air fuel cell battery system of claim 20, wherein said first means comprises one or more motors for rotating said movable cathode structure, and said second means comprises one or more motors for transporting said metal-fuel tape relative to said moving cathode structure.

22. The metal-air fuel cell battery system of claim 12, wherein said transport mechanism comprises a common belt structure for transporting said cathode belt structure and said metal-fuel tape.

23. The metal-air fuel cell battery system of claim 1, wherein said ionically-conductive medium is an ionically-conductive belt structure transported between said movable cathode structure and at least a portion of said metal-fuel tape.

24. The metal-air fuel cell battery system of claim 23, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure;

second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation; and

third means for transporting said ionically-conductive belt structure between said movable cathode structure and said metal-fuel tape during system operation, at substantially the same velocity said metal-fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation.

25. The metal-air fuel cell battery system of claim 24, wherein said first means comprises one or more motors for rotating said movable cathode structure, and said second means comprises one or more motors for transporting said metal-fuel tape relative to said moving cathode structure.

26. The metal-air fuel cell battery system of claim 23, wherein said transport mechanism comprises a common belt structure for transporting said movable cathode structure, said ionically-conductive belt structure and said metal-fuel tape relative to each other at

substantially the same velocity at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape.

27. A method of producing electrical power from a metal-air fuel cell battery (FCB) system having a movable cathode structure, a supply of an ionically-conducing medium, and an source of ionically-conductive medium for supporting ion transport between said movable cathode structure and said metal-fuel tape during system operation, said method comprising the steps of:

(a) arranging said moving cathode structure and said supply of metal-fuel tape so that said ionically-conducing medium is disposed in physical contact with said movable cathode structure and said metal-fuel tape; and

(b) moving said movable cathode structure and said metal-fuel tape relative to each other during operation of said system.

28. The method of claim 27, where during step (b), said movable cathode structure is moved at substantially the same velocity at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape.

29. The method of claim 27, wherein said movable cathode structure is cylindrically shaped and has a hollow center permitting air flow therethrough.

30. The method of claim 27, wherein said movable cathode structure is

a cathode belt structure.

31. The method of claim 27, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

32. The method of claim 27, wherein said ionically-conductive medium is a film integrated with said movable cathode structure.

33. The method of claim 27, wherein said ionically-conductive medium is an ionically-conductive belt structure disposed between at least a portion of said movable cathode structure and said metal-fuel tape.

34. The method of claim 27, wherein step (b) comprises using one or more electric motors to move said movable cathode structure and said metal-fuel tape.

35. The method of claim 27, wherein step (b) comprises using a common belt structure to move said cathode belt structure and said metal-fuel tape.

36. A metal-air fuel cell battery (FCB) system for generating electrical power, comprising:

a movable cathode structure;

a supply of metal-fuel tape transportable relative to said movable cathode structure during operation of said system;

an ionically-conductive medium disposed between said movable cathode structure and said metal-fuel tape, for contacting said movable cathode structure and said metal-fuel tape and supporting ionic conduction therebetween during operation of said system; and

a transport mechanism for transporting said movable cathode structure and said metal-fuel tape relative to each other during operation of said system.

37. The metal-fuel cell battery system of claim 36, wherein said transport mechanism comprises means for transporting said movable cathode structure and said metal-fuel tape relative to each other, at substantially the same velocity at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape.

38. The metal-air fuel cell battery system of claim 36, wherein said movable cathode structure is cylindrically shaped and has a hollow center permitting air flow therethrough.

39. The metal-air fuel cell battery system of claim 38, wherein said ionically-conductive medium is a film integrated with said movable cathode structure.

40. The metal-air fuel cell battery system of claim 38, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

41. The metal-air fuel cell battery system of claim 38, wherein said ionically-conductive medium is an ionically-conductive belt structure

transported between said movable cathode structure and at least a portion of said metal-fuel tape.

42. The metal-air fuel cell battery system of claim 39, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure; and

second means for moving said movable cathode structure relative to said metal fuel tape during system operation.

43. The metal-air fuel cell battery system of claim 42, wherein said first means comprises one or more motors for rotating said movable cathode structure, and said second means comprises one or more motors for transporting said metal-fuel tape relative to said moving cathode structure.

44. The metal-air fuel cell battery system of claim 39, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure; and

second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation.

45. The metal-air fuel cell battery system of claim 44, wherein said

first means comprises one or more motors for rotating said movable cathode structure, and said second means comprises one or more motors for transporting said metal-fuel tape relative to said moving cathode structure.

46. The metal-air fuel cell battery system of claim 41, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure;

second means for moving said movable cathode structure relative to said metal fuel tape during system operation; and

third means for transporting said ionically-conductive belt structure between said movable cathode structure and said metal-fuel tape during system operation.

47. The metal-air fuel cell battery system of claim 36, wherein said transport mechanism comprises a common belt structure for transporting said movable cathode structure and said metal-fuel tape relative to each other during system operation.

48. The metal-air fuel cell battery system of claim 41, wherein said transport mechanism comprises a common belt structure for transporting said movable cathode structure, said ionically-conducing belt structure and said metal-fuel tape relative to each other during system operation.

49. The metal-air fuel cell battery system of claim 36, wherein said

movable cathode structure is a cathode belt structure.

50. The metal-air fuel cell battery system of claim 49, wherein said ionically-conductive medium is a film integrated with said cathode belt structure.

51. The metal-air fuel cell battery system of claim 49, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

52. The metal-air fuel cell battery system of claim 49, wherein said ionically-conductive medium is a belt structure disposed between at least a portion of said cathode belt structure and said metal-fuel tape.

53. The metal-air fuel cell battery system of claim 51, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure; and

second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation.

54. The metal-air fuel cell battery system of claim 53, wherein said first means comprises one or more motors for rotating said movable cathode structure, and said second means comprises one or more motors for

transporting said metal-fuel tape relative to said moving cathode structure.

55. The metal-air fuel cell battery system of claim 54, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure; and

second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation.

56. The metal-air fuel cell battery system of claim 55, wherein said first means comprises one or more motors for rotating said movable cathode structure, and said second means comprises one or more motors for transporting said metal-fuel tape relative to said moving cathode structure.

57. The metal-air fuel cell battery system of claim 52, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure;

second means for moving said movable cathode structure relative to said metal fuel tape during system operation; and

third means for transporting said ionically-conductive belt structure between said movable cathode structure and said metal-fuel tape during system operation.

58. The metal-air fuel cell battery system of claim 57, wherein said first means comprises one or more motors for rotating said movable cathode structure, and said second means comprises one or more motors for transporting said metal-fuel tape relative to said moving cathode structure.

59. The metal-air fuel cell battery system of claim 49, wherein said transport mechanism comprises a common belt structure for transporting said cathode belt structure and said metal-fuel tape.

60. The metal-air fuel cell battery system of claim 49, wherein said ionically-conductive medium is an ionically-conductive belt structure transported between said movable cathode structure and at least a portion of said metal-fuel tape.

61. The metal-air fuel cell battery system of claim 60, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure;

second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation; and

third means for transporting said ionically-conductive belt structure between said movable cathode structure and said metal-fuel tape during system operation, at substantially the same velocity said metal-fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation.

62. The metal-air fuel cell battery system of claim 61, wherein said first means comprises one or more motors for rotating said movable cathode structure, and said second means comprises one or more motors for transporting said metal-fuel tape relative to said moving cathode structure.

63. The metal-air fuel cell battery system of claim 60, wherein said transport mechanism comprises a common belt structure for transporting said movable cathode structure, said ionically-conductive belt structure and said metal-fuel tape relative to each other at substantially the same velocity at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape

64. A metal-air fuel cell battery (FCB) system for generating electrical power, comprising:

a cathode structure;

a supply of metal-fuel tape transportable relative to said movable cathode structure during operation of said system; and

an ionically-conductive belt disposed between said cathode structure and said metal-fuel tape, for contacting said cathode structure and said metal-fuel tape and supporting ionic conduction therebetween during operation of said system; and

a transport mechanism for transporting said ionically-conductive belt relative to said metal-fuel tape and said cathode structure during operation of said system.

65. A metal-air fuel cell battery system for generating electrical power, comprising:

a movable cathode structure;

a supply of metal-fuel tape transportable relative to said movable cathode structure during operation of said system; and

an ionically-conductive medium disposed between said movable cathode structure and said metal-fuel tape, for contacting said movable cathode structure and said metal-fuel tape and supporting ionic conduction therebetween during operation of said system.

66. The metal-air fuel cell battery system of claim 65, which further comprises a transport mechanism for transporting said movable cathode structure and said metal-fuel tape relative to each other during operation of said system.

67. A metal-air fuel cell battery (FCB) system for generating electrical power, comprising:

a plurality of movable cathode structures, each mounted within a housing to enable movement about a closed path;

a supply of metal-fuel tape transportable relative to said movable cathode structures, along a predetermined tape path extending within said housing;

an ionically-conducing medium disposed between said plurality of movable cathodes and said metal-fuel tape during system operation, for contacting each said movable cathode structure and said metal-fuel tape being transported thereover, and supporting ionic conduction between said movable cathode structure and said metal-fuel tape during system operation; and

a transport mechanism for transporting said plurality of movable cathode structures, said metal-fuel tape and said ionically-conductive medium relative to said housing.

68. The metal-air fuel cell battery system of claim 67, wherein each said movable cathode structure is cylindrically shaped and has a hollow center permitting air flow therethrough.

69. The metal-air fuel cell battery system of claim 68, wherein said ionically-conductive medium is a film integrated with each said movable cathode structure.

70. The metal-air fuel cell battery system of claim 68, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

71. The metal-air fuel cell battery system of claim 68, wherein said ionically-conductive medium is an ionically-conductive belt structure transported between each said movable cathode structure and at least a portion of said metal-fuel tape.

72. The metal-air fuel cell battery system of claim 69, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to each said movable cathode structure within said housing; and

second means for moving each said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape during system operation.

73. The metal-air fuel cell battery system of claim 72, wherein said first means comprises one or more electric motors for rotating each said movable cathode structure, and said second means comprises one or more electric motors for transporting said metal-fuel tape relative to said each movable cathode structure.

74. The metal-air fuel cell battery system of claim 70, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to said moving cathode structure; and

second means for moving said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape during system operation.

75. The metal-air fuel cell battery system of claim 69, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to each said movable cathode structure;

second means for moving each said movable cathode structure relative to and at substantially the same velocity as said metal-fuel tape during system operation; and

third means for transporting said ionically-conductive belt structure between each said movable cathode structure and said metal-fuel tape during system operation, at substantially the same velocity as said metal-fuel tape during system operation.

76. The metal-air fuel cell battery system of claim 68, wherein said transport mechanism comprises a common belt structure for transporting each said movable cathode structure and said metal-fuel tape relative to each other at substantially the same velocity at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape.

77. The metal-air fuel cell battery system of claim 71, wherein said transport mechanism comprises a common belt structure for transporting said movable cathode structure, said ionically-conducing belt structure and said metal-fuel tape relative to each other at substantially the same velocity at the locus of points at which said ionically-conductive medium contacts each said movable cathode structure and said metal-fuel tape.

78. The metal-air fuel cell battery system of claim 67, wherein each said movable cathode structure is a cathode belt structure.

79. The metal-air fuel cell battery system of claim 78, wherein said

ionically-conductive medium is a film integrated with each said cathode belt structure.

80. The metal-air fuel cell battery system of claim 78, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

81. The metal-air fuel cell battery system of claim 78, wherein said ionically-conductive medium is a belt structure disposed between at least a portion of each said cathode belt structure and said metal-fuel tape.

82. The metal-air fuel cell battery system of claim 81, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to each said movable cathode structure; and

second means for moving each said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts each said movable cathode structure and said metal-fuel tape during system operation.

83. The metal-air fuel cell battery system of claim 82, wherein said first means comprises one or more electric motors for rotating each said movable cathode structure, and said second means comprises one or more electric motors for transporting said metal-fuel tape relative to each said movable cathode structure.

84. The metal-air fuel cell battery system of claim 80, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to each said movable cathode structure; and

second means for moving each said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts each said movable cathode structure and said metal-fuel tape during system operation.

85. The metal-air fuel cell battery system of claim 84, wherein said first means comprises one or more electric motors for rotating each said movable cathode structure, and said second means comprises one or more electric motors for transporting said metal-fuel tape relative to each said movable cathode structure.

86. The metal-air fuel cell battery system of claim 81, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to each said movable cathode structure;

second means for moving each said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation; and

third means for transporting said ionically-conductive belt structure between each said movable cathode structure and said metal-fuel tape during system operation, at substantially the same velocity as said metal-fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation.

87. The metal-air fuel cell battery system of claim 86, wherein said first means comprises one or more electric motors for rotating each said movable cathode structure, and said second means comprises one or more electric motors for transporting said metal-fuel tape relative to each said moving cathode structure.

88. The metal-air fuel cell battery system of claim 78, wherein said transport mechanism comprises a common belt structure for transporting said cathode belt structure and said metal-fuel tape.

89. The metal-air fuel cell battery system of claim 67, wherein said ionically-conductive medium is an ionically-conductive belt structure transported between each said movable cathode structure and at least a portion of said metal-fuel tape.

90. The metal-air fuel cell battery system of claim 89, wherein said transport mechanism comprises:

first means for transporting said supply of metal-fuel tape relative to each said movable cathode structure;

second means for moving each said movable cathode structure relative to and at substantially the same velocity as said metal fuel tape at the locus of points at which said ionically-conductive medium contacts each said movable cathode structure and said metal-fuel tape during system operation; and

third means for transporting said ionically-conductive belt structure between each said movable cathode structure and said metal-fuel tape during system operation, at substantially the same velocity said metal-fuel tape at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape during system operation.

91. The metal-air fuel cell battery system of claim 90, wherein said first means comprises one or more electric motors for rotating each said movable cathode structure, and said second means comprises one or more electric motors for transporting said metal-fuel tape relative to each said movable cathode structure.

92. The metal-air fuel cell battery system of claim 89, wherein said transport mechanism comprises a common belt structure for transporting each said movable cathode structure, said ionically-conductive belt structure and said metal-fuel tape relative to each other at substantially the same velocity at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape.

93. A method of producing electrical power from a metal-air fuel cell battery (FCB) system having a housing, a plurality of movable cathode structures, a supply of an ionically-conducing medium, and an source of

ionically-conductive medium for supporting ion transport between each said movable cathode structure and said metal-fuel tape during system operation, said method comprising the steps of:

(a) arranging said plurality of moving cathode structures and said supply of metal-fuel tape within said housing so that said ionically-conducing medium is disposed in physical contact with each said movable cathode structure and said metal-fuel tape; and

(b) moving each said movable cathode structure, said metal-fuel tape and said ionically-conductive medium relative to said housing during operation of said system.

94. The method of claim 93, where during step (b), said each movable cathode structure is moved at substantially the same velocity at the locus of points at which said ionically-conductive medium contacts said movable cathode structure and said metal-fuel tape.

95. The method of claim 93, wherein each said movable cathode structure is cylindrically shaped and has a hollow center permitting air flow therethrough.

96. The method of claim 93, wherein each said movable cathode structure is a cathode belt structure.

97. The method of claim 93, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

98. The method of claim 93, wherein said ionically-conductive medium

is a film integrated with each said movable cathode structure.

99. The method of claim 93, wherein said ionically-conductive medium is an ionically-conductive belt structure disposed between at least a portion of said movable cathode structure and said metal-fuel tape.

100. The method of claim 93, wherein step (b) comprises using one or more electric motors to move each said movable cathode structure and said metal-fuel tape.

101. The method of claim 93, wherein step (b) comprises using a common belt structure to move each said cathode belt structure and said metal-fuel tape.

102. A metal-air fuel cell battery (FCB) system for generating electrical power, comprising:

a plurality of movable cathode structures, each mounted within a housing to enable movement about a closed path;

a supply of metal-fuel tape transportable relative to said movable cathode structures, along a predetermined tape path extending within said housing; and

an ionically-conducing medium disposed between said plurality of movable cathodes and said metal-fuel tape during system operation, for contacting each said movable cathode structure and said metal-fuel tape being transported thereover, and supporting ionic conduction between said movable cathode structure and said metal-fuel tape during system operation.

103. The metal-air fuel cell battery (FCB) system of claim 102, which further comprises

a transport mechanism for transporting said plurality of movable cathode structures, said metal-fuel tape and said ionically-conductive medium relative to said housing.

104. A metal-air fuel cell battery system for generating electrical power, comprising:

a plurality of movable cathode structures mounted within a housing; and

a supply of metal-fuel tape transportable relative to said plurality of movable cathode structures during operation of said system,

wherein each said movable cathode structure has an ionically-conductive coating on the outer surface thereof, disposed between said movable cathode structure and said metal-fuel tape, for contacting said movable cathode structure and said metal-fuel tape and supporting ionic conduction therebetween during operation of said system.

105. The metal-air fuel cell battery system of claim 104, which further comprises

a transport mechanism for transporting said metal-fuel tape relative to said plurality of movable cathode structures during operation of said system.

106. A metal-air fuel cell battery system for generating electrical power, comprising:

a plurality of cathode structures mounted within a housing;

a supply of metal-fuel tape transportable relative to said plurality of cathode structures during operation of said system; and

an ionically-conductive belt disposed between each said cathode structure and said metal-fuel tape, for contacting each said cathode structure and said metal-fuel tape and supporting ionic conduction therebetween during operation of said system.

107. The metal-air fuel cell battery system of claim 106, which further comprises

a transport mechanism for transporting said ionically-conductive belt relative to said metal-fuel tape and said plurality of cathode structures during operation of said system.

108. A metal-air fuel cell battery system for generating electrical power, comprising:

a movable cathode structure mounted within a housing to enable movement about a closed path;

a supply of metal-fuel tape transportable relative to said movable cathode structure;

an ionically-conductive medium disposed between said movable cathode structure and said metal-fuel tape during system operation, for contacting said movable cathode structure and said metal-fuel tape being transported over said ionically-conductive medium, and supporting ionic conduction between said movable cathode structure and said metal-fuel tape during system operation;

a transport mechanism for actively transporting at least one of said movable cathode structure, said metal-fuel tape and said ionically-conductive medium relative to said housing; and

a surface tension maintenance mechanism for maintaining a sufficient level of surface tension between (i) said ionically-conductive medium and said metal-fuel tape and/or (ii) said ionically-conductive medium and said movable cathode structure during system operation so that said metal-fuel tape, said ionically-conductive medium and said movable cathode structure are moved at substantially the same velocity at points of contact therebetween, by hydrostatic forces created by said maintained level of surface tension, as at least one of said movable cathode structure, said metal-fuel tape and said ionically-conductive medium are actively transported relative to said housing during system operation.

109. The metal-air fuel cell battery system of claim 108, wherein said surface tension maintenance means comprises:

wetting means for applying a coating of water (H_2O) and/or an electrolyte make-up solution to the surface of said metal-fuel tape and/or said ionically-conductive medium during system operation so that, during system operation, wetting occurs between (i) said ionically-conductive medium and said metal-fuel tape, and (ii) said ionically-conductive medium and said movable cathode structure.

110. The metal-air fuel cell battery system of claim 109, wherein the thickness of said coating of water and/or said electrolyte make-up solution depends on the speed and water absorption properties of said metal fuel tape.

111. The metal-air fuel cell battery system of claim 109, wherein said wetting means comprises a mechanism for dispensing and applying said coating of water and/or said electrolyte make-up solution to the surface of said metal-fuel tape and/or said ionically-conductive medium.

112. The metal-air fuel cell battery system of claim 108, wherein said transport mechanism comprises a motor driven by either mechanical, electrical, or pneumatic forces.

113. The metal-air fuel cell battery system of claim 108, wherein said motor is driven by a spring mechanism.

114. The metal-air fuel cell battery system of claim 108, wherein said movable cathode structure is cylindrically shaped and has a hollow center permitting air flow therethrough.

115. The metal-air fuel cell battery system of claim 114, wherein said ionically-conductive medium is a film integrated with said movable cathode structure.

116. The metal-air fuel cell battery system of claim 112, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

117. The metal-air fuel cell battery system of claim 108, wherein said ionically-conductive medium is an ionically-conductive belt structure

transported between said movable cathode structure and at least a portion of said metal-fuel tape.

118. The metal-air fuel cell battery system of claim 108, wherein said movable cathode structure is a cathode belt structure.

119. The metal-air fuel cell battery system of claim 118, wherein said ionically-conductive medium is a film integrated with said cathode belt structure.

120. The metal-air fuel cell battery system of claim 118, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

121. The metal-air fuel cell battery system of claim 108, wherein said movable cathode structure is a cathode belt structure, and said ionically-conductive medium is an ionically-conductive belt structure disposed between at least a portion of said cathode belt structure and said metal-fuel tape.

122. The metal-air fuel cell battery system of claim 108, wherein only one of said movable cathode structure and said metal-fuel tape is actively transported relative to said housing during system operation.

123. A method of producing electrical power from a metal-air fuel cell battery system having a housing, a movable cathode structure, a supply of a metal-fuel tape, and an source of ionically-conductive medium for

supporting ion transport between said movable cathode structure and said metal-fuel tape during system operation, said method comprising the steps of:

(a) arranging said moving cathode structure and said supply of metal-fuel tape within said housing so that said ionically-conductive medium is disposed in physical contact with said movable cathode structure and said metal-fuel tape; and

(b) actively transporting at least one of said movable cathode structure, said metal-fuel tape and said ionically-conductive medium relative to said housing, while maintaining a sufficient level of surface tension between said ionically-conductive medium and the metal-fuel tape and said ionically-conductive medium and said movable cathode structure during system operation so that said metal-fuel tape, said ionically-conductive medium and said movable cathode structure are moved at substantially the same velocity at points of contact therebetween by hydrostatic forces created by said maintained level of surface tension.

124. The method of claim 123, wherein said movable cathode structure is cylindrically shaped and has a hollow center permitting air flow therethrough.

125. The method of claim 123, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

126. The method of claim 123, wherein said ionically-conductive medium is a film integrated with said movable cathode structure.

127. The method of claim 123, wherein said movable cathode structure is a cathode belt structure.

128. The method of claim 127, wherein said ionically-conductive medium is a film integrated with said metal-fuel tape.

129. The method of claim 127, wherein said ionically-conductive medium is a film integrated with said cathode belt structure.

130. The method of claim 123, wherein said movable cathode structure is a cathode belt structure, and said ionically-conductive medium is an ionically-conductive belt structure disposed between at least a portion of said cathode belt structure and said metal-fuel tape.

131. The method of claim 123, where during step (a) only one of said movable cathode structure and said metal-fuel tape is actively transported relative to said housing during system operation.

132. An ionically-conductive belt structure for use in a metal-air fuel cell battery (FCB) system, comprising:

a flexible belt portion for contacting a movable cathode structure and a length of metal-fuel tape transportable relative to said flexible belt portion during operation of said metal-air fuel cell battery system; and

an ionically-conducing medium embodied within said flexible belt portion, for supporting ionic conduction between said cathode structure and said metal-fuel tape during operation of said system.

133. The ionically-conductive belt structure of claim 132, wherein said flexible belt portion is made from a polymer material, and said ionically-conducting medium is a source of hydroxide ions.

134. The ionically-conductive belt structure of claim 133, wherein said polymer material is polyethylene oxide (POE).

135. The ionically-conductive belt structure of claim 133, wherein said source of hydroxide ions is potassium hydroxide (KOH).

136. The ionically-conductive belt structure of claim 132, which further comprises a hygroscopic agent.

137. The ionically-conductive belt structure of claim 136, wherein said hygroscopic agent is calcium chloride.

138. The ionically-conductive belt structure of claim 132, wherein the thickness of said flexible belt portion is the range of about 0.2 to about 0.5 millimeters.

139. A method of fabricating an ionically-conductive belt structure for use in a metal-air fuel cell battery system, said method comprising:

(a) dissolving a hydroxide ion source and a hygroscopic agent, into a solvent comprising water;

(b) adding a polymer material to the mixture of step (a) to produce a coating material;

(c) applying a thick film of said coating material onto a substrate having a surface tension higher than said thick film applied in step (b);

(d) evaporating said mixed solvent from said applied thick film coating so as to form a solid-state ionically-conductive solid state membrane on said substrate;

(e) removing said solid-state ionically-conductive membrane from said substrate;

(f) cutting said solid-state ionically-conductive membrane into a shape membrane; and

(g) joining the ends of said shaped membrane by an adhesive, ultrasonic welding, or appropriate fasteners to form said solid-state ionically-conductive belt structure.

140. The method of claim 139, wherein said polymer material is polyethylene oxide (POE).

141. The method of claim 140, wherein said substrate comprises polyvinyl alcohol (PVA) plastic material.

142. The method of claim 140, wherein said hydroxide ion source is potassium chloride (KOH).

143. The method of claim 142, wherein said hygroscopic agent is calcium chloride.

144. The method of claim 140, wherein said mixed solvent further comprises tetrahydrogen furan (THF).

145. The method of claim 139, wherein said polymer material is polyvinyl chloride (PVC).

146. The method of claim 145, wherein said hydroxide ion source is potassium chloride (KOH).

147. The method of claim 146, wherein said hygroscopic agent is calcium chloride.

148. The method of claim 145, wherein said substrate comprises polyvinyl alcohol (PVA) plastic material.

149. The method of claim 145, wherein said mixed solvent further comprises tetrahydrogen furan (THF).

150. A cathode cylinder for use in a metal-air fuel cell battery system, comprising:

a cathode structure of cylindrical geometry having a hollow central core, an outer surface, and a constitution allowing oxygen to flow through said outer surface along a substantial portion of said cathode structure towards an ionically-conductive medium in contact with said outer surface during operation of said metal-air fuel cell battery system;

said cathode structure being rotatable about an axis of rotation during operation of said metal-air fuel cell battery system, and further embodying

a catalytic material for supporting a catalytic reaction at the interface formed between said ionically-conductive medium and said outer surface as said metal-fuel material is transported over said ionically-conductive medium in contact with said outer surface during operation of said metal-air fuel cell battery system, and

a current-collecting material for collecting electrical current produced as said metal-fuel material is transported over said ionically-conductive medium in contact with said outer surface during operation of said metal-air fuel cell battery system.

151. The cathode cylinder of claim 150, wherein said ionically-conductive medium comprises a solid-state film having ionically-conductive properties, applied to said outer surface of said cathode structure.

152. The cathode cylinder of claim 151, wherein said solid-state film comprises a gel-like film.

153. The cathode cylinder of claim 150, which further comprises

a cylindrical support structure for supporting said cathode structure during rotation about said axis of rotation.

154. The cathode cylinder of claim 153, wherein said cylindrical support structure has a hollow central core and fine perforations formed therein for enabling the passage of oxygen during operation of said metal-air fuel cell battery system.

155. The cathode cylinder of claim 150, wherein said current collecting material comprises a nickel mesh fabric or sponge material embedded with said catalytic material, carbon and binder material.

156. The cathode cylinder of claim 150, wherein said catalytic material comprises platinum.

157. A method of fabricating a cathode cylinder for use in a metal-air fuel cell battery system, said method comprising:

(a) forming a cathode structure having a cylindrical geometry, an outer surface, and an oxygen-permeable constitution, and further embodying a catalytic material and a current-collecting material; and

(b) applying an ionically-conductive film on said outer surface of said cathode structure.

158. The method of claim 157, wherein step (a) comprises forming said cathode structure about a rotatable support cylinder.

159. A cathode belt structure for use in a metal-air fuel cell battery system, comprising:

a flexible belt portion transportable between two or more support rollers during operation of said metal-air fuel cell battery system, said flexible belt portion further having an outer surface and a constitution allowing oxygen to flow through said outer surface along a substantial portion of said flexible belt portion towards an ionically-conductive medium in contact with said outer surface during operation of said metal-air fuel cell battery system;

a catalytic medium embodied within said flexible belt portion, for supporting a catalytic reaction at the interface formed between said ionically-conductive medium and said outer surface as said metal-fuel material is transported over said ionically-conductive medium in contact with said outer surface during operation of said metal-air fuel cell battery system; and

a current-collecting medium embodied within said flexible belt portion, for collecting electrical current produced as said metal-fuel material is transported over said ionically-conductive medium in contact with said outer surface during operation of said metal-air fuel cell battery system.

160. The cathode belt structure of claim 159, wherein said ionically-conductive medium comprises a solid-state film having ionically-conductive properties, applied to said outer surface of said flexible belt portion.

161. The cathode belt structure of claim 160, wherein said solid-state film comprises a gel-like film.

162. The cathode belt structure of claim 159, wherein said current collecting medium comprises a nickel mesh fabric or sponge material embedded with said catalytic material, carbon and binder material.

163. The cathode belt structure of claim 162, wherein said catalytic material comprises magnesium dioxide.

164. The cathode belt structure of claim 162, wherein said binder material is Teflon.

165. The cathode belt structure of claim 159, wherein the porosity of said flexible belt portion is the range from about 30 to about 70%, and thickness of said flexible belt portion is in the range from about 0.2 to about 0.6

millimeters.

166. A method of fabricating a cathode belt structure for use in a metal-air fuel cell battery system, said method comprising:

(a) blending sinterable powder with a binder material and catalyst material in a solvent including water and surfactant in order to provide a slurry mixture;

(b) applying a coating of said slurry mixture onto a current collecting material to produce a slurry coated material;

(c) drying said slurry coated material to produce a dried article;

(d) compressing said dried article to form a sheet of flexible material having a desired porosity and thickness;

(e) sintering said sheet of flexible material for a time period sufficient to remove said solvent therefrom and form a sheet of flexible cathode material;

(f) cutting said sheet of flexible cathode material into desired dimensions to form a cathode belt structure having a pair of end portions; and

(g) joining the end portions of said cathode belt structure to form a virtually seamless cathode surface about a closed belt structure.

167. The method of claim 166, where in step (b) said current collecting material comprises nickel mesh or sponge material.

168. The method of claim 166, where in step (a) said binder material is a Teflon emulsion.

169. The method of claim 166, wherein said sinterable powder comprises

black carbon powder.

170. The method of claim 166, where in step (c) said catalyst material is magnesium dioxide (MnO_2).

171. The method of claim 166, where during step (d) said dried article is compressed so that said sheet of flexible material has a porosity in the range from about 30 to about 70%, and thickness in the range from about 0.2 to about 0.6 millimeters.

172. The method of claim 166, which further comprises:

forming said ionically conducting medium on said sheet of flexible cathode material after step (e); or

forming said ionically-conductive medium on said cathode belt structure after step (f).

173. The method of claim 162, where after step (e) or step (f), said ionically-conducting medium comprises a solid-state film having ionically-conductive properties.

174. The method of claim 163, where after step (e) or step (f), said solid-state film comprises a gel-like film.

175. A metal-air fuel cell battery system having a discharging mode of operation, comprising:

metal-fuel supply means for supplying metal-fuel material for generating electrical power during said discharging mode of operation, wherein said metal-fuel material has a plurality of zones or subsections demarcated along said metal-fuel material and each said zone is indexed with a code;

code reading means for reading said digital code along each said zone of said metal-fuel material during the discharging of said zone during said discharging mode of operation;

parameter detecting means for detecting a set of discharge parameters during the discharging of each said zone of metal-fuel material during said discharging mode of operation;

parameter processing means for processing said set of discharge parameters detected at each said zone of metal-fuel material, and generating control data signals for controlling one or more discharging parameters while said zone is being discharged.

176. The metal-air fuel cell battery system of claim 175, wherein said set of detected discharge parameters are recorded in memory and read out therefrom for processing during said discharging mode of operation.

177. The metal-air fuel cell battery system of claim 175, wherein said code is a digital code.

178. The metal-air fuel cell battery system of claim 175, wherein said digital code is detected optically.

179. The metal-air fuel cell battery system of claim 178, wherein said digital code is a bar code symbol.

180. The metal-air fuel cell battery system of claim 177, wherein said digital code is detected magnetically.

181. The metal-air fuel cell battery system of claim 175, wherein each said zone of metal-fuel material has a plurality of metal-fuel tracks;

wherein said parameter detecting means detects a set of discharge parameters for each metal-fuel track along each said zone of metal-fuel material during said discharging mode of operation; and

wherein said code reading means reads said digital code along each said zone during the discharging of said zone of metal-fuel material during said discharging mode of operation.

182. The metal-air fuel cell battery system of claim 175, wherein said metal-fuel material is realized in the form of metal-fuel tape.

183. The metal-air fuel cell battery system of claim 175, wherein said metal-fuel material is realized in the form of metal-fuel cards or sheets.

184. The metal-air fuel cell battery system of claim 175, wherein said parameter processing means processes said set of discharge parameters detected at each said zone of metal-fuel material, and generates control data signals for controlling one or more discharging parameters while said zone is being discharged in order to discharge said zone of metal-fuel in a time and/or energy efficient manner.

185. A metal-air fuel cell battery system having a recharging mode of operation, comprising:

metal-fuel supply means for supplying metal-fuel material for recharging during said recharging mode of operation, wherein said metal-fuel material has a plurality of zones or subsections demarcated along said metal-fuel material and each said zone is indexed with a code;

code reading means for reading said digital code along each said zone of said metal-fuel material during the recharging of said zone during said recharging mode of operation;

parameter detecting means for detecting a set of recharge parameters during the recharging of each said zone of metal-fuel material during said recharging mode of operation;

parameter processing means for processing said set of recharge parameters detected at each said zone of metal-fuel material, and generating control data signals for controlling one or more recharging parameters while said zone is being recharged.

186. The metal-air fuel cell battery system of claim 185, wherein said set of detected recharge parameters are recorded in memory and read out therefrom for processing during said recharging mode of operation.

187. The metal-air fuel cell battery system of claim 185, wherein said code is a digital code.

188. The metal-air fuel cell battery system of claim 187, wherein said digital code is detected optically.

189. The metal-air fuel cell battery system of claim 185, wherein said digital code is a bar code symbol.

190. The metal-air fuel cell battery system of claim 185, wherein said digital code is detected magnetically.

191. The metal-air fuel cell battery system of claim 185, wherein each said zone of metal-fuel material has a plurality of metal-fuel tracks;

wherein said parameter detecting means detects a set of recharge parameters for each metal-fuel track along each said zone of metal-fuel material during said recharging mode of operation; and

wherein said code reading means reads said digital code along each said zone during the recharging of said zone of metal-fuel material during said recharging mode of operation.

192. The metal-air fuel cell battery system of claim 185, wherein said metal-fuel material is realized in the form of metal-fuel tape.

193. The metal-air fuel cell battery system of claim 185, wherein said metal-fuel material is realized in the form of metal-fuel cards or sheets.

194. The metal-air fuel cell battery system of claim 185, wherein said parameter processing means processes said set of recharge parameters detected at each said zone of metal-fuel material, and generates control data signals for controlling one or more recharging parameters while said zone is being recharged in order to recharge said zone of metal-fuel in a time and/or energy efficient manner.

195. A metal-air fuel cell battery system having a discharging mode of

operation and a recharging mode of operation, comprising:

metal-fuel supply means for supplying metal-fuel material for use in generating electrical power during said discharging mode of operation and for recharging during said recharging mode of operation, wherein said metal-fuel material has a plurality of zones or subsections demarcated along the length of said metal-fuel material and each said zone is indexed with a code;

discharge parameter detecting means for detecting a set of discharge parameters during the discharging of each said zone of metal-fuel material during said discharging mode of operation;

code reading means for reading said digital code along each said zone of said metal-fuel material during the discharging of said zone during said discharging mode of operation, as well as during the recharging of said zone of metal-fuel during said recharging mode of operation;

discharge parameter recording means for recording said set of discharge parameters detected at each said zone of metal-fuel material, wherein said recorded set of discharge parameters are indexed with said code indexed to said zone;

discharge parameter reading means for reading said recorded discharge parameters;

discharge parameter processing means for processing said recorded set of discharge parameters read from said discharge parameter recording means in order to generate a first set of control data signals for use in controlling said recharging parameters during said recharging mode of operation so that discharged metal-fuel material can be recharged in a time and/or energy efficient manner;

recharge parameter detecting means for detecting a set of recharge parameters during the recharging of each said zone of metal-fuel material during said recharging mode of operation;

recharge parameter recording means for recording said set of recharge parameters detected at each said zone of metal-fuel material, wherein each said recorded set of recharge parameters is indexed with said code indexed to said zone;

recharge parameter reading means for reading said recorded set of recharge parameters; and

recharge parameter processing means for processing said recorded set of recharge parameters from said recharge parameter recording means in order to generate a second set of control data signals for use in controlling said discharging parameters during said discharging mode of operation so that (re)charged metal-fuel material can be discharged in a time and/or energy efficient manner.

196. The metal-air fuel cell battery system of claim 195, wherein said discharge parameter recording means and said recharge parameter recording each comprise a memory device.

197. The metal-air fuel cell battery system of claim 195, wherein said code is a digital code.

198. The metal-air fuel cell battery system of claim 197, wherein said digital code is detected optically.

199. The metal-air fuel cell battery system of claim 197, wherein said digital code is a bar code symbol.

200. The metal-air fuel cell battery system of claim 197, wherein said digital code is detected magnetically.

201. The metal-air fuel cell battery system of claim 197, wherein said discharge parameter processing means processes said recorded set of discharge parameters related to each zone of metal-fuel material so as to determine an amount of electrical power to be delivered to said zone when recharging said zone, and said amount of electrical power being used to generate said control data signals during said recharging mode of operation.

202. The metal-air fuel cell battery system of claim 195, wherein each said zone of metal-fuel material has a plurality of metal-fuel tracks;

wherein said discharge parameter detecting means detects a set of discharge parameters for each metal-fuel track along each said zone of metal-fuel material during said discharging mode of operation;

wherein said code reading means reads said digital code along each said zone during the discharging of said zone of said metal-fuel material during said discharging mode of operation, as well as during the recharging of said zone of said metal-fuel material during said recharging mode of operation;

wherein said discharge parameter recording means records said set of discharge parameters detected at each metal-fuel track along each said zone of metal-fuel material, and wherein said recorded set of discharge parameters are indexed with said code indexed to said metal-fuel track along said zone; and

wherein said discharge parameter reading means reads discharge parameters recorded within said parameter recording means.

203. The metal-air fuel cell battery system of claim 195, wherein said recharge parameter processing means processes said recorded set of recharge parameters related to each zone of metal-fuel material so as to determine the amount of metal-fuel present at each said zone during discharging of each said zone of metal-fuel material, and said amount of metal-fuel present is used to generate said control data signals during said discharging mode of operation.

204. The metal-air fuel cell battery system of claim 195, wherein each said zone of metal-fuel material has a plurality of metal-fuel tracks;

wherein said recharge parameter detecting means detects a set of recharge parameters for each metal-fuel track along each said zone of metal-fuel material during said recharging mode of operation;

wherein said code reading means reads said digital code along each said zone during the recharging of said zone of said metal-fuel material during said recharging mode of operation, as well as during the discharging of said zone of said metal-fuel material during said discharging mode of operation;

wherein said recharge parameter recording means records said set of recharge parameters detected at each metal-fuel track along each said zone of metal-fuel material, and wherein said recorded set of recharge parameters are indexed with said code indexed to said metal-fuel track along said zone; and

wherein said recharge parameter reading means reads recharge parameters recorded within said parameter recording means.

205. The metal-air fuel cell battery system of claim 195, wherein said metal-fuel material is realized in the form of metal-fuel tape.

206. The metal-air fuel cell battery system of claim 195, wherein said metal-

fuel material is realized in the form of metal-fuel cards or sheets.

207. A metal-air fuel cell battery system having a discharging mode of operation and a recharging mode of operation, comprising:

a first plurality of subsystems which cooperate in order to enable detection, storage and processing of discharge parameters during said discharging mode of operation and using said discharge parameters to generate control data signals for controlling recharging parameters during said recharging mode of operation; and

a second plurality of subsystems which cooperate in order to enable detection, storage and processing of recharge parameters during said recharging mode of operation and using said recharge parameters to generate control data signals for controlling discharging parameters during said discharging mode of operation.

208. A metal-air fuel cell battery system having a recharging mode of operation and a discharging mode of operation, said metal-air fuel cell battery system comprising:

a metal-fuel discharging mechanism for discharging metal-fuel material during said discharging mode of operation;

a discharge parameter detecting mechanism for detecting discharge parameters while discharging said metal-fuel material during said discharging mode of operation;

a discharge parameter processing mechanism for processing detected discharge parameters in order to generate a first set of control data signals for controlling recharging parameters during said recharging mode of operation;

a metal-fuel recharging mechanism for recharging said metal-fuel material during said recharging mode of operation;

a recharge parameter detecting mechanism for detecting recharge parameters while recharging said metal-fuel material during said recharging mode of operation; and

a recharge parameter processing mechanism for processing detected recharge parameters in order to generate a second set of control data signals for controlling discharging parameters during said discharging mode of operation.

209. The metal-air fuel cell battery system of claim 208, wherein said discharge parameters are elements selected from the group consisting of cathode-anode voltage and current levels, partial pressure of oxygen within the discharging cathode, relative humidity at the cathode-electrolyte interface, and where applicable, the speed of said metal-fuel material.

210. The metal-air fuel cell battery system of claim 208, wherein said recharge parameters are elements selected from the group consisting of cathode-anode voltage and current levels, partial pressure of oxygen within there recharging cathode, relative humidity at the cathode-electrolyte interface, and where applicable, the speed of said metal-fuel material.

211. The metal-air fuel cell battery system of claim 208, wherein each said first set of control data signals is used to control said recharge parameters so that said zone of metal-fuel material is recharged in an energy efficient manner.

212. The metal-air fuel cell battery system of claim 208, wherein each said

second set of control data signals is used to control said recharge parameters so that said zone of metal-fuel material is recharged in an energy efficient manner.

213. The metal-air fuel cell battery system of claim 208, wherein said metal-fuel material to be recharged is used with stationary and/or moving cathode structures employed in said metal-air fuel cell battery system.

214. The metal-air fuel cell battery system of claim 208, wherein said metal-fuel material is realized in the form of metal-fuel tape.

215. The metal-air fuel cell battery system of claim 209, wherein said metal-fuel tape is contained within a cassette-type storage device.

216. The metal-air fuel cell battery system of claim 208, wherein said metal-fuel material is realized in the form of metal-fuel cards or sheets.

217. The metal-air fuel cell battery system of claim 208, wherein said metal-fuel cards or sheets are contained within a cassette-type storage device.

218. A metal-air fuel cell battery system having a discharging mode of operation, comprising:

metal-fuel supply means for supplying metal-fuel material for use in generating electrical power during said discharging mode of operation, wherein said metal-fuel material has a plurality of zones or subsections demarcated along said metal-fuel material and each said zone is indexed with a code;

parameter detecting means for detecting a set of discharge parameters during the discharging of each said zone of metal-fuel material during said discharging mode of operation;

code reading means for reading said code along each said zone of said metal-fuel material during the discharging of said zone during said discharging mode of operation;

parameter recording means for recording said set of discharge parameters detected at each said zone of metal-fuel material, wherein said recorded set of discharge parameters are indexed with said code indexed to said zone;

parameter reading means for reading said recorded discharge parameters; and

parameter processing means for processing said recorded set of discharge parameters read from said parameter recording means.

219. The metal-air fuel cell battery system of claim 218, wherein said set of processed discharge parameters are used during said discharging mode of operation.

220. The metal-air fuel cell battery system of claim 218, which further comprises a recharging mode of operation, and wherein said set of processed discharge parameters are used during said recharging mode of operation.

221. The metal-air fuel cell battery system of claim 218, wherein said parameter recording means comprising a memory device associated with said system.

222. The metal-air fuel cell battery system of claim 218, wherein said code is a digital code.

223. The metal-air fuel cell battery system of claim 222, wherein said digital code is detected optically.

224. The metal-air fuel cell battery system of claim 222, wherein said digital code is a bar code symbol.

225. The metal-air fuel cell battery system of claim 222, wherein said digital code is detected magnetically.

226. The metal-air fuel cell battery system of claim 218, wherein said parameter processing means processes said recorded set of discharge parameters related to each zone of metal-fuel material so as to determine an amount of electrical power to be delivered to said zone when recharging said zone.

227. The metal-air fuel cell battery system of claim 218, wherein each said zone of metal-fuel material has a plurality of metal-fuel tracks;

wherein said parameter detecting means detects a set of discharge parameters for each metal-fuel track along each said zone of metal-fuel material during said discharging mode of operation;

wherein said code reading means reads said digital code along each said zone during the discharging of said zone of said metal-fuel material during said discharging mode of operation;

wherein said parameter recording means records said set of discharge parameters detected at each metal-fuel track along each said zone of metal-fuel material, and wherein said recorded set of discharge parameters are indexed with said digital code indexed to said metal-fuel track along said zone; and

wherein said parameter reading means reads discharge parameters recorded within said parameter recording means.

228. The metal-air fuel cell battery system of claim 218, wherein said metal-fuel material is realized in the form of metal-fuel tape.

229. The metal-air fuel cell battery system of claim 218, wherein said metal-fuel material is realized in the form of metal-fuel cards or sheets.

230. A metal-air fuel cell battery system having a recharging mode of operation, comprising:

metal-fuel supply means for supplying metal-fuel material for recharging during said recharging mode of operation, wherein said metal-fuel material has a plurality of zones or subsections demarcated along said metal-fuel material and each said zone is indexed with a code;

parameter detecting means for detecting a set of recharge parameters during the recharging of each said zone of metal-fuel material during said recharging mode of operation;

code reading means for reading said code indexed on each said zone of said metal-fuel material during said recharging mode of operation;

parameter recording means for recording said set of recharge parameters detected at each said zone of metal-fuel material, wherein each said recorded set of recharge parameters is indexed with said code indexed to said zone;

parameter reading means for reading said recorded set of recharge parameters; and

parameter processing means for processing said recorded set of discharge parameters read from said parameter recording means.

231. The metal-air fuel cell battery system of claim 230, wherein said set of processed recharge parameters are used during said recharging mode of operation.

232. The metal-air fuel cell battery system of claim 230, which further comprises a discharging mode of operation, and wherein said set of processed recharge parameters are used during said discharging mode of operation.

233. The metal-air fuel cell battery system of claim 230, wherein each said set of detected discharge parameters are recorded in a memory device associated with said system.

234. The metal-air fuel cell battery system of claim 230, wherein said code is a digital code.

235. The metal-air fuel cell battery system of claim 234, wherein said digital code is detected optically.

236. The metal-air fuel cell battery system of claim 234, wherein said digital code is a bar code symbol.

237. The metal-air fuel cell battery system of claim 234, wherein said digital code is detected magnetically.

238. The metal-air fuel cell battery system of claim 230, wherein said parameter processing means processes said recorded set of recharge parameters related to each zone of metal-fuel material so as to determine the amount of electrical power producible from said zone when discharging said zone.

239. The metal-air fuel cell battery system of claim 230, wherein each said zone of metal-fuel material has a plurality of metal-fuel tracks;

wherein said parameter detecting means detects a set of recharge parameters for each metal-fuel track along each said zone of metal-fuel material during said recharging mode of operation;

wherein said code reading means reads said digital code along each said zone during the recharging of said zone of said metal-fuel material during said recharging mode of operation;

wherein said parameter recording means records said set of recharge parameters detected at each metal-fuel track along each said zone of metal-fuel material, and wherein said recorded set of recharge parameters are indexed with said digital code indexed to said metal-fuel track along said zone; and

wherein said parameter reading means reads recharge parameters recorded within said parameter recording means.

240. The metal-air fuel cell battery system of claim 230, wherein said metal-fuel material is realized in the form of metal-fuel tape.

241. The metal-air fuel cell battery system of claim 230, wherein said metal-fuel material is realized in the form of metal-fuel cards or sheets.

242. A metal-air fuel cell battery system having a discharging mode of operation and a recharging mode of operation, comprising:

metal-fuel supply means for supplying metal-fuel material for generating electrical power during said discharging mode of operation and for recharging during said recharging mode of operation, wherein said metal-fuel material has a plurality of zones or subsections demarcated along the length of said metal-fuel material and each said zone is indexed with a code;

discharge parameter detecting means for detecting a set of discharge parameters during the discharging of each said zone of metal-fuel material during said discharging mode of operation;

code reading means for reading said code along each said zone of said metal-fuel material during the discharging of said zone during said discharging mode of operation, as well as during the recharging of said zone of metal-fuel during said recharging mode of operation;

discharge parameter recording means for recording said set of discharge parameters detected at each said zone of metal-fuel material, wherein said recorded set of discharge parameters are indexed with said code indexed to said zone;

discharge parameter reading means for reading said recorded discharge parameters;

discharge parameter processing means for processing said recorded set of discharge parameters read from said discharge parameter recording means;

recharge parameter detecting means for detecting a set of recharge parameters during the recharging of each said zone of metal-fuel material during said recharging mode of operation;

recharge parameter recording means for recording said set of recharge parameters detected at each said zone of metal-fuel material, wherein each said recorded set of recharge parameters is indexed with said code indexed to said zone;

recharge parameter reading means for reading said recorded set of recharge parameters; and

recharge parameter processing means for processing said recorded set of recharge parameters from said recharge parameter recording means.

243. The metal-air fuel cell battery system of claim 242, wherein said set of processed discharge parameters are used during said discharging mode of operation.

244. The metal-air fuel cell battery system of claim 242, wherein said set of processed discharge parameters are used during said recharging mode of operation.

245. The metal-air fuel cell battery system of claim 242, wherein said set of processed recharge parameters are used during said recharging mode of operation.

246. The metal-air fuel cell battery system of claim 242, wherein said set of processed recharge parameters are used during said discharging mode of operation.

247. The metal-air fuel cell battery system of claim 242, wherein said discharge parameter recording means and said recharge parameter recording each comprise a memory device.

248. The metal-air fuel cell battery system of claim 242, wherein said code is a digital code.

249. The metal-air fuel cell battery system of claim 248, wherein said digital code is detected optically.

250. The metal-air fuel cell battery system of claim 248, wherein said digital code is a bar code symbol.

251. The metal-air fuel cell battery system of claim 248, wherein said digital code is detected magnetically.

252. The metal-air fuel cell battery system of claim 252, wherein said discharge parameter processing means processes said recorded set of discharge parameters related to each zone of metal-fuel material so as to determine an amount of electrical power to be delivered to said zone when recharging said zone.

253. The metal-air fuel cell battery system of claim 252, wherein each said zone of metal-fuel material has a plurality of metal-fuel tracks;

wherein said discharge parameter detecting means detects a set of discharge parameters for each metal-fuel track along each said zone of metal-fuel material during said discharging mode of operation;

wherein said code reading means reads said code along each said zone during the discharging of said zone of said metal-fuel material during said discharging mode of operation, as well as during the recharging of said zone of said metal-fuel material during said recharging mode of operation;

wherein said discharge parameter recording means records said set of discharge parameters detected at each metal-fuel track along each said zone of metal-fuel material, and wherein said recorded set of discharge parameters are indexed with said code indexed to said metal-fuel track along said zone; and

wherein said discharge parameter reading means reads discharge parameters recorded within said parameter recording means.

254. The metal-air fuel cell battery system of claim 250, wherein said recharge parameter processing means processes said recorded set of recharge parameters related to each zone of metal-fuel material so as to determine the amount of metal-fuel present at each said zone during discharging of each said zone of metal-fuel material.

255. The metal-air fuel cell battery system of claim 252, wherein each said zone of metal-fuel material has a plurality of metal-fuel tracks;

wherein said recharge parameter detecting means detects a set of recharge parameters for each metal-fuel track along each said zone of metal-fuel material during said recharging mode of operation;

wherein said code reading means reads said code along each said zone during the recharging of said zone of said metal-fuel material during said recharging mode of operation, as well as during the discharging of said zone of said metal-fuel material during said discharging mode of operation;

wherein said recharge parameter recording means records said set of recharge parameters detected at each metal-fuel track along each said zone of metal-fuel material, and wherein said recorded set of recharge parameters are indexed with said code indexed to said metal-fuel track along said zone; and

wherein said recharge parameter reading means reads recharge parameters recorded within said parameter recording means.

256. The metal-air fuel cell battery system of claim 252, wherein said metal-fuel material is realized in the form of metal-fuel tape.

257. The metal-air fuel cell battery system of claim 252, wherein said metal-fuel material is realized in the form of metal-fuel cards or sheets.

258. A metal-air fuel cell battery system comprising:

a plurality of subsystems which cooperate in order to enable data detection, storage and processing of discharge and recharge parameters for use during discharging and recharging modes of operation.

259. A metal-air fuel cell battery system having a recharging mode of operation and a discharging mode of operation, said metal-air fuel cell battery system comprising:

a metal-fuel discharging mechanism for discharging metal-fuel material during said discharging mode of operation;

a discharge parameter detecting mechanism for detecting discharge parameters while discharging said metal-fuel material during said discharging mode of operation;

a metal-fuel recharging mechanism for recharging said metal-fuel material during said recharging mode of operation; and

a recharge parameter detecting mechanism for detecting recharge parameters while recharging said metal-fuel material during said recharging mode of operation.

260. The metal-air fuel cell battery system of claim 259, wherein said discharge parameters are elements selected from the group consisting of cathode-anode voltage and current levels, partial pressure of oxygen within the discharging cathode, relative humidity at the cathode-electrolyte interface, and where applicable, the speed of said metal-fuel material.

261. The metal-air fuel cell battery system of claim 259, wherein said recharge parameters are elements selected from the group consisting of cathode-anode voltage and current levels, partial pressure of oxygen within there recharging cathode, relative humidity at the cathode-electrolyte interface, and where applicable, the speed of said metal-fuel material.

262. The metal-air fuel cell battery system of claim 259, wherein discharge parameters are automatically detected recorded during the discharging mode of operation, and automatically read and processed during the recharging mode of operation in order to recharge said metal-fuel material in an energy efficient manner.

263. The metal-air fuel cell battery system of claim 259, wherein discharge parameters are automatically detected, recorded and processed during the discharging mode of operation in order to discharge said metal-fuel material in

an energy efficient manner.

264. The metal-air fuel cell battery system of claim 259, wherein said metal-fuel material to be recharged is used with stationary and/or moving cathode structures employed in said metal-air fuel cell battery system.

265. The metal-air fuel cell battery system of claim 255, wherein said metal-fuel material is realized in the form of metal-fuel tape.

266. The metal-air fuel cell battery system of claim 265, wherein said metal-fuel tape is contained within a cassette-type storage device.

267. The metal-air fuel cell battery system of claim 258, wherein said metal-fuel material is realized in the form of metal-fuel cards or sheets.

268. The metal-air fuel cell battery system of claim 267, wherein said metal-fuel cards or sheets are contained within a cassette-type storage device.

269. An electrical power generation system comprising:

a power bus structure to which one or more electrical loads are connected;

a plurality of metal-air fuel cell battery (FCB) subsystems connected to said power bus structure, each having a supply of metal fuel, and capable of producing and delivering electrical power to said power bus structure; and

a control subsystem for controlling the operation of said plurality of metal-air FCB subsystems so that electrical power is supplied to said power bus structure in sufficient amounts to satisfy the requirements of said electrical loads independent of the total amount of metal-fuel remaining within the electrical power generation system.

270. An electrical power generation system comprising:

a network of metal-air FCB subsystems connected to a power bus structure and controlled by a network control subsystem associated with a network-based metal-fuel management subsystem.

271. The electrical power generation system, wherein the electrical power output produced from said power bus structure is controlled by enabling a selected set of said metal-air FCB subsystems to supply electrical power to said power bus structure.

272. An electrical power generation system comprising:

a network of metal-air FCB subsystems connected to a power bus structure and controlled by a network control subsystem associated with a network-based metal-fuel management subsystem;

wherein the metal-fuel within each of said FCB subsystems is managed by said network control subsystem so that, on the average, each such FCB subsystem has substantially the same amount of metal-fuel available for power production at any instant in time.

273. A method of operating a network of metal-air FCB subsystems comprising the steps of:

managed the discharging of metal-fuel available within each said metal-air FCB subsystem according to a metal-fuel equalization principle whereby, on the average, the amount of metal-fuel available for discharge at any instant of time is substantially equal in each said meta-air FCB subsystem.

274. An electrical power generation system realized in the form of electrical power plant that can be installed in virtually any system, device or environment in which there is a need to satisfy the peak power demand of an electrical load (e.g. motor, appliance, machinery, tools, etc.) independent of the total amount of unconsumed metal-fuel remaining within the electrical power generation system.

275. An electrically-powered vehicle comprising:

a network of metal-air FCB subsystems connected to a power bus structure and controlled by a network control subsystem associated with a network-based metal-fuel management subsystem;

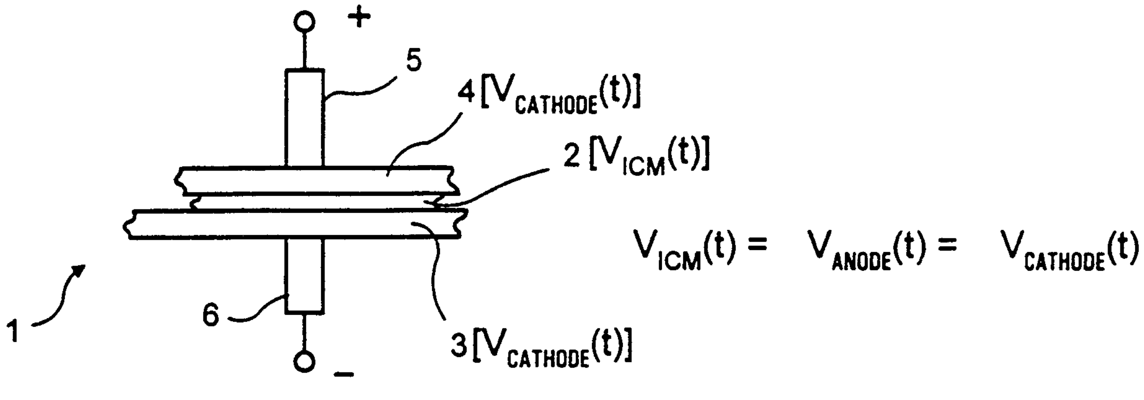
wherein only one or a few of said metal-air FCB subsystems are enabled into discharging operation when said vehicle is travelling along flat land or downhill, and many or all of said metal-air FCB subsystems are enabled into discharging operation when said vehicle is attempting to pass another vehicle or is travelling uphill.

276. An electrical power generation system comprising:

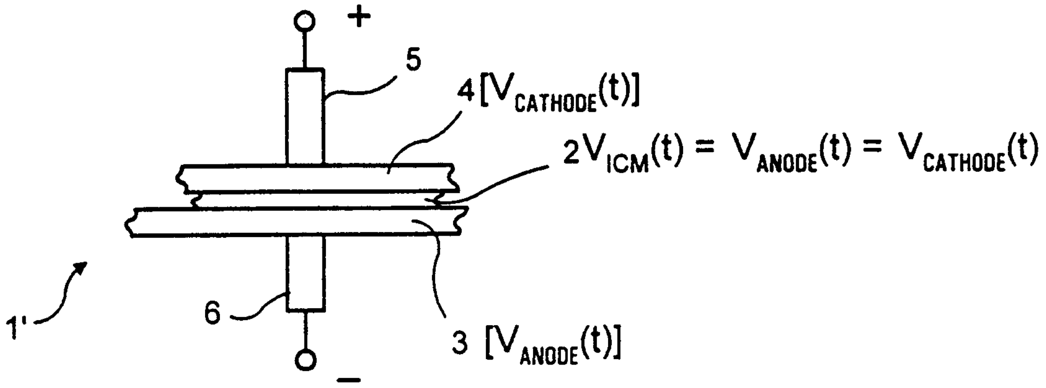
a power bus structure to which an electrical load is connected;

a plurality of metal-air FCB subsystems operably connected to said power bus structure; and

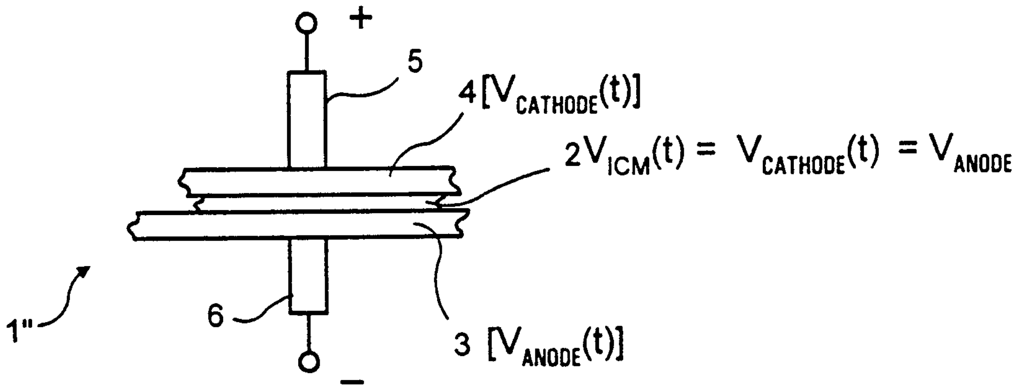
a computer-based metal-fuel management subsystem for managing the amount of metal fuel available in each said metal-air FCB subsystem for use in discharging operations so that on a time-average basis, each said metal-air FCB subsystem has substantially the same amount of metal fuel available for discharging and producing electrical power for supply to said power bus structure.



F I G.1A



F I G.1B



F I G.1C

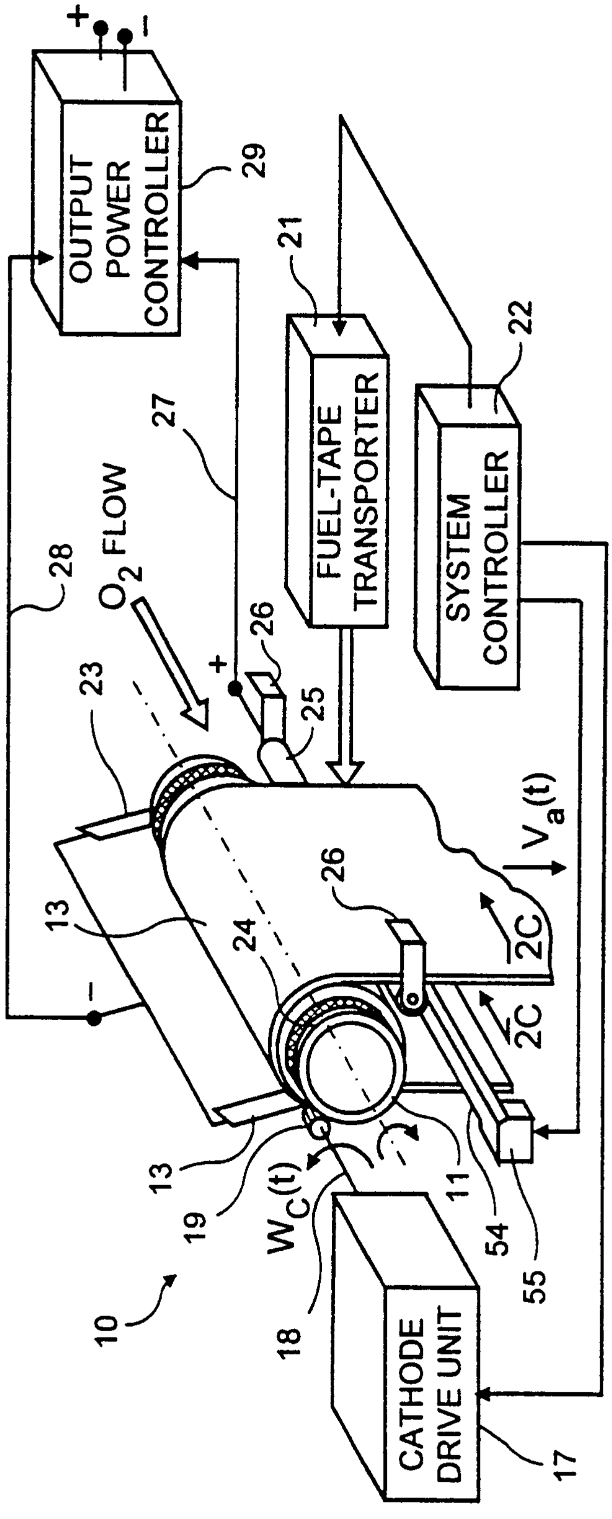


FIG. 2

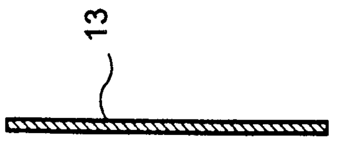


FIG. 2C

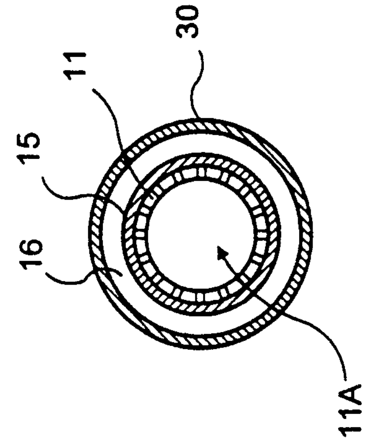


FIG. 2B

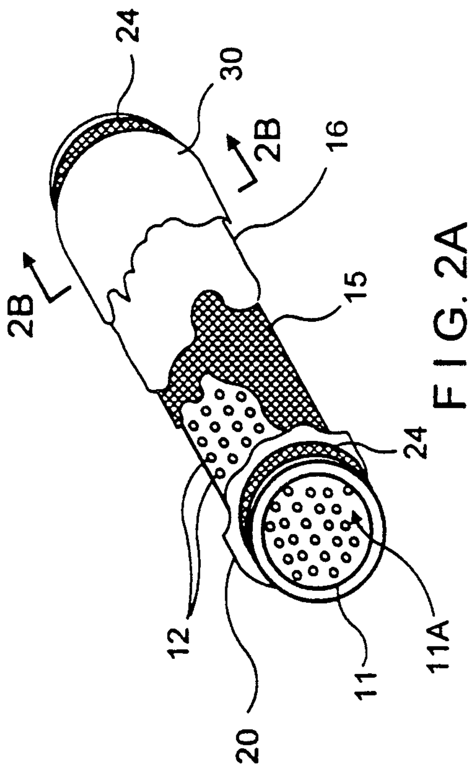
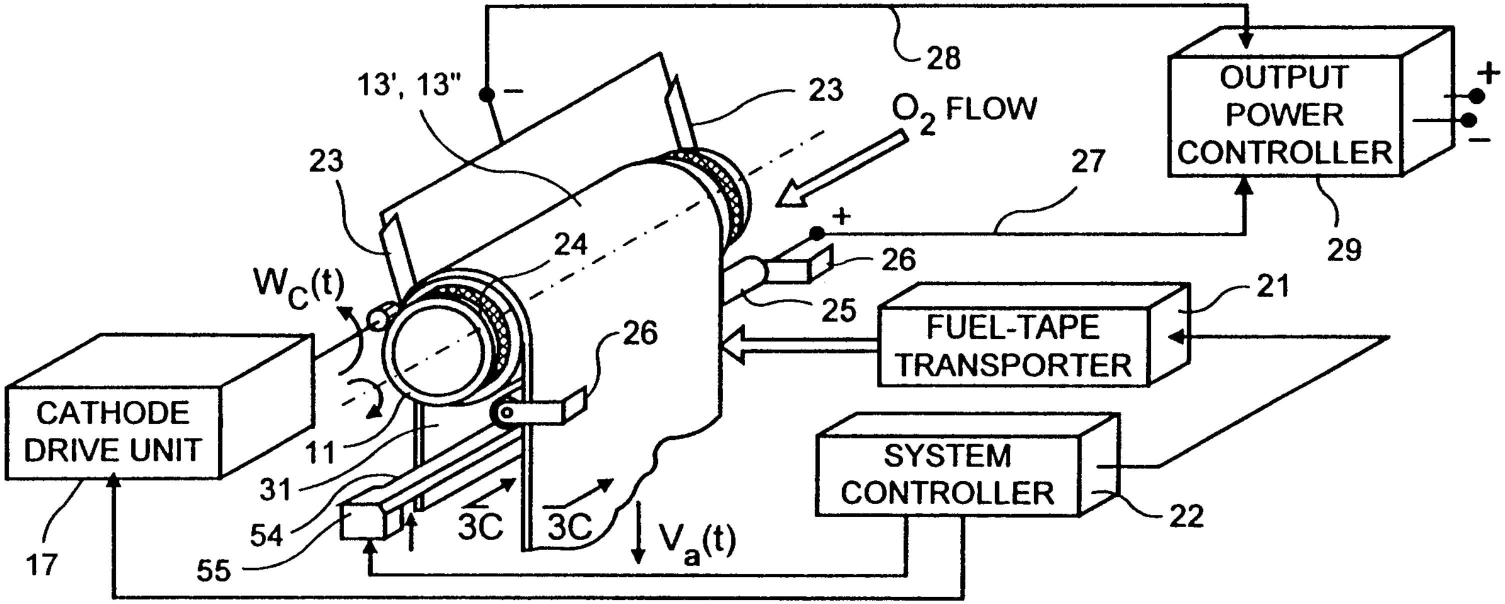
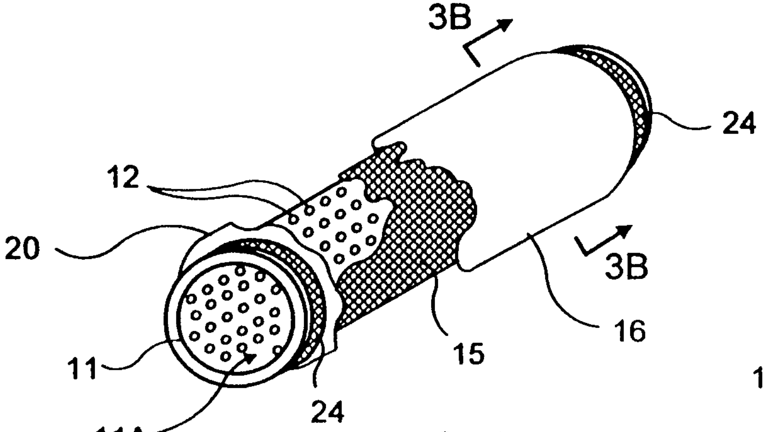


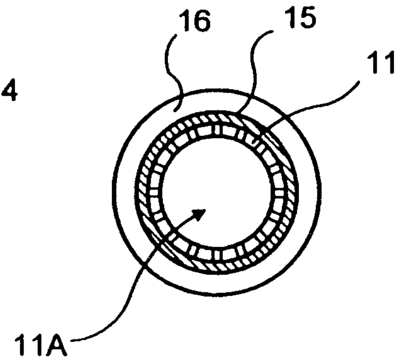
FIG. 2A



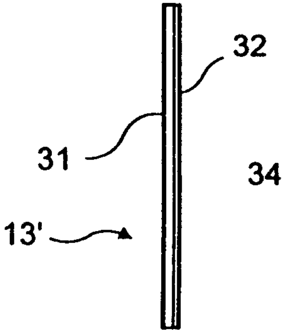
F I G. 3



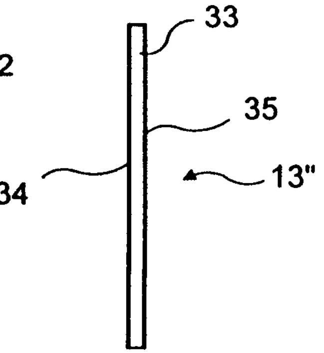
F I G. 3A



F I G. 3B



F I G. 3C1



F I G. 3C2

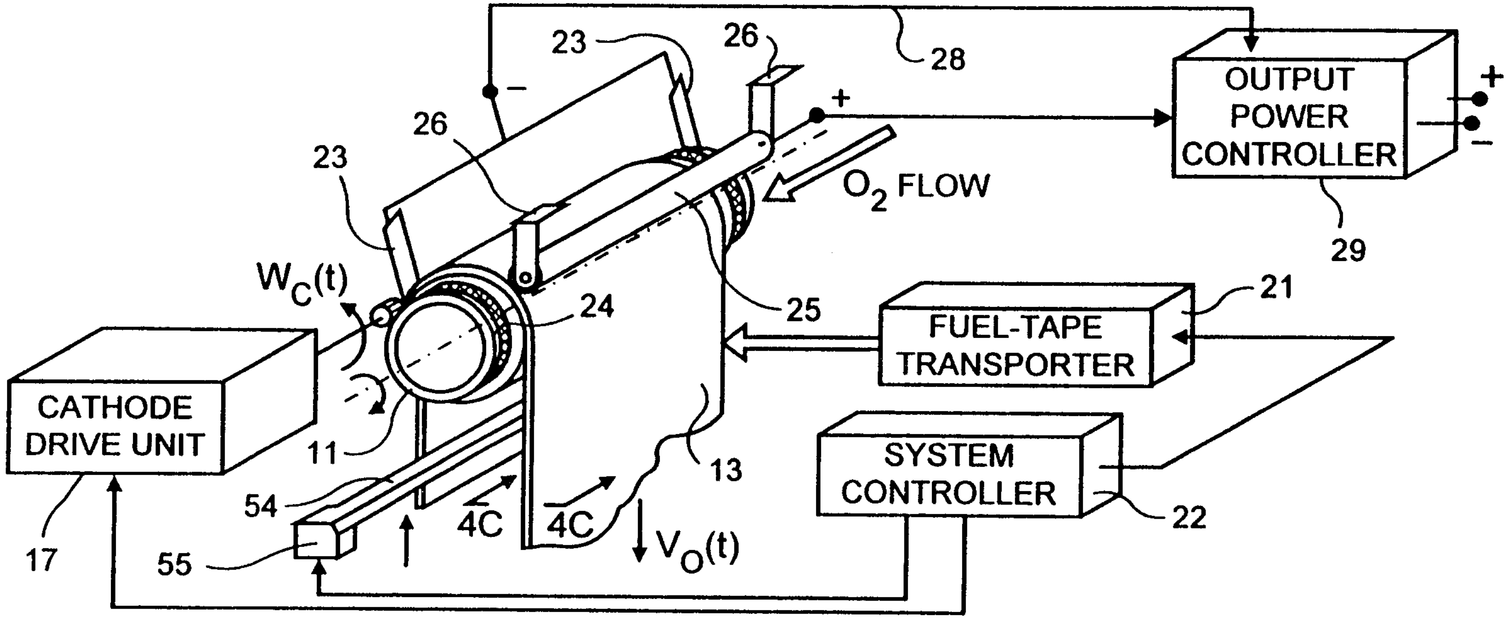


FIG. 4

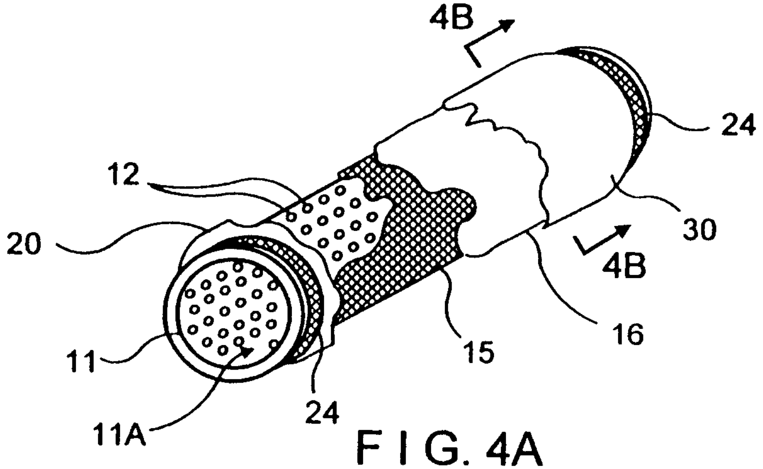


FIG. 4A

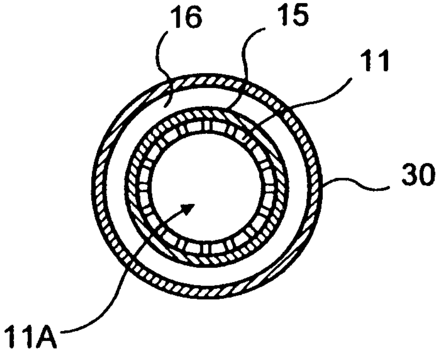


FIG. 4B

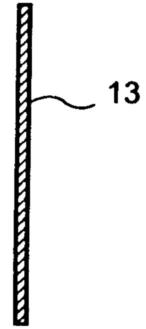
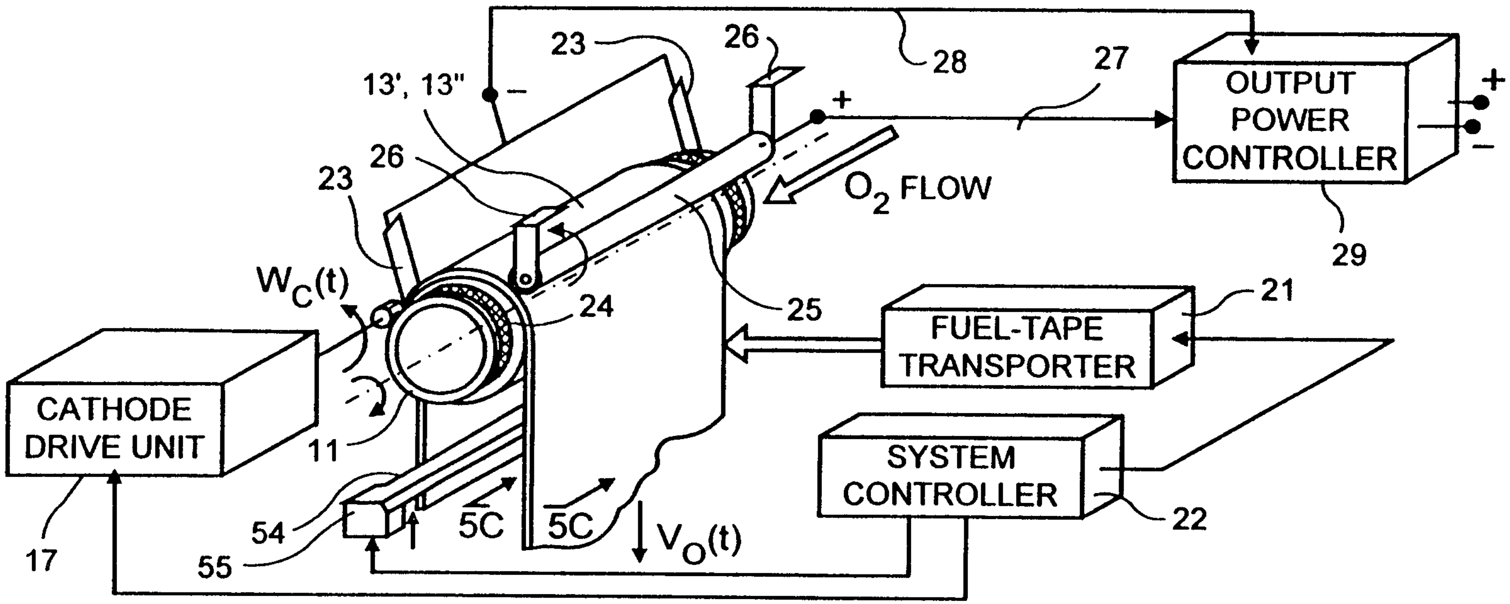
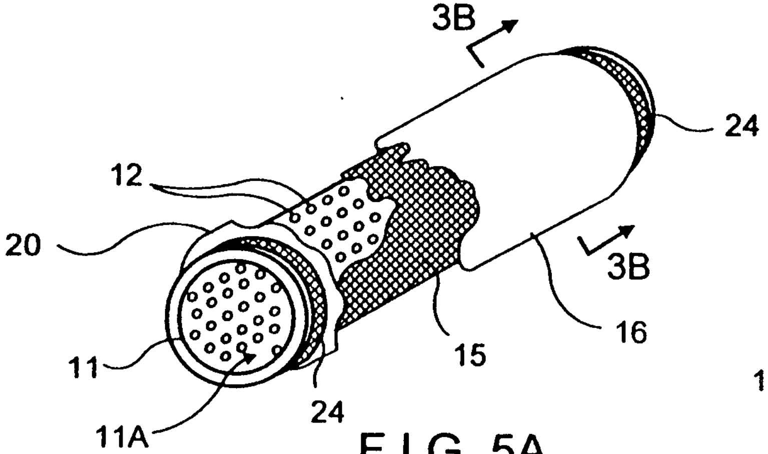


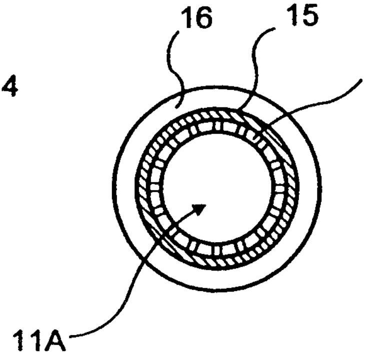
FIG. 4C

F I G. 5

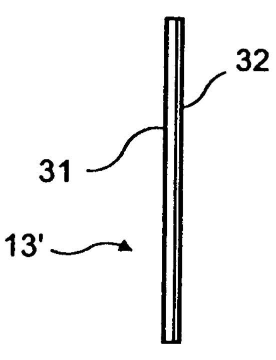




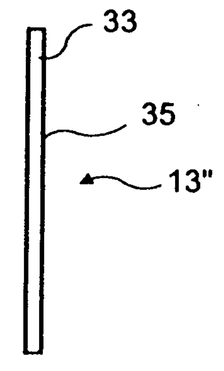
F I G. 5A



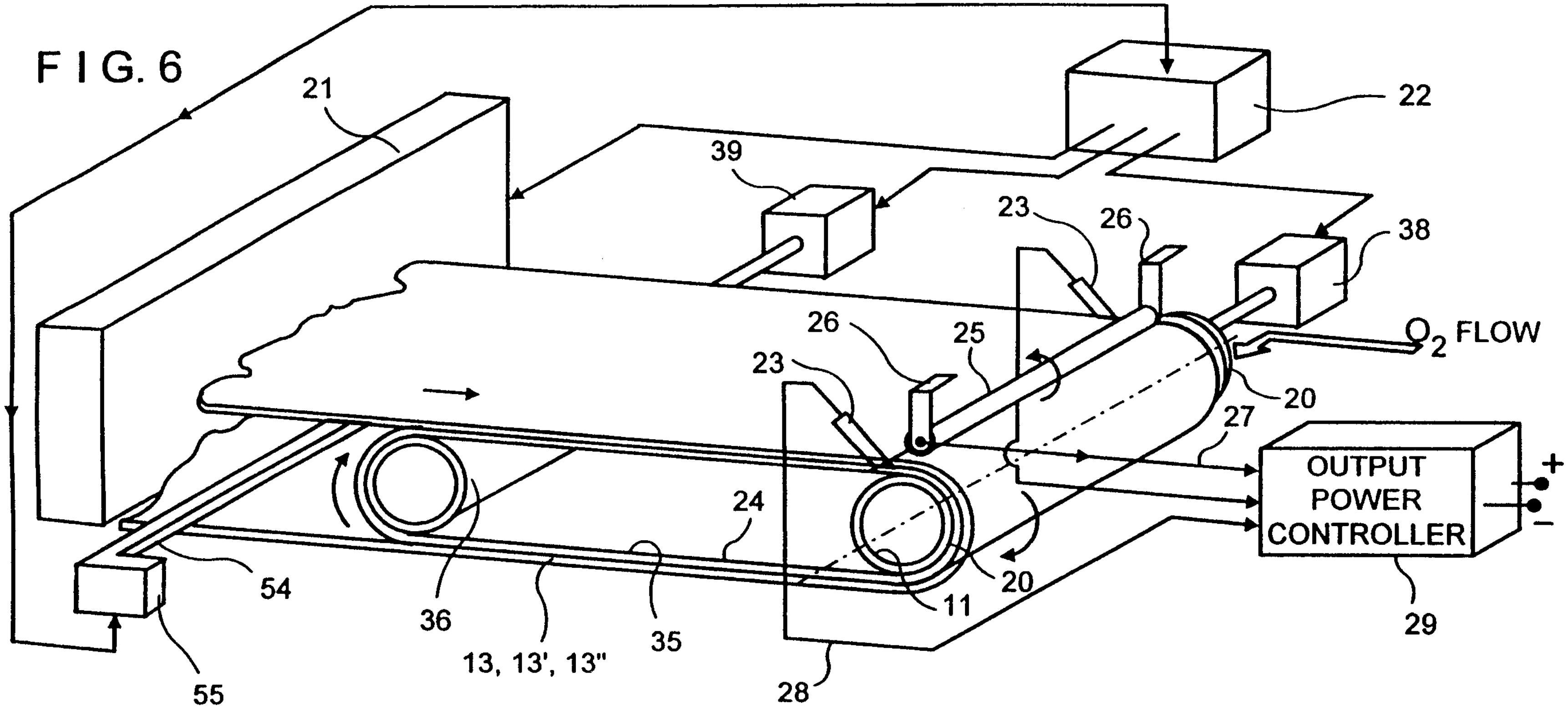
F I G. 5B



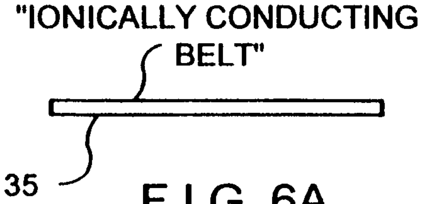
F I G. 5C1



F I G. 5C2

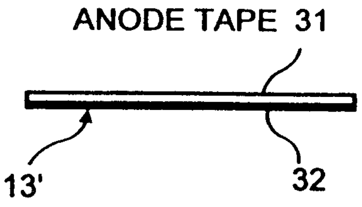


F I G. 6

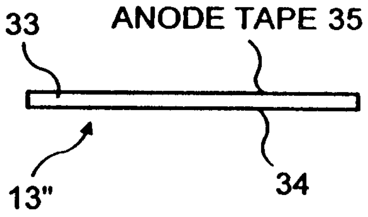


F I G. 6A

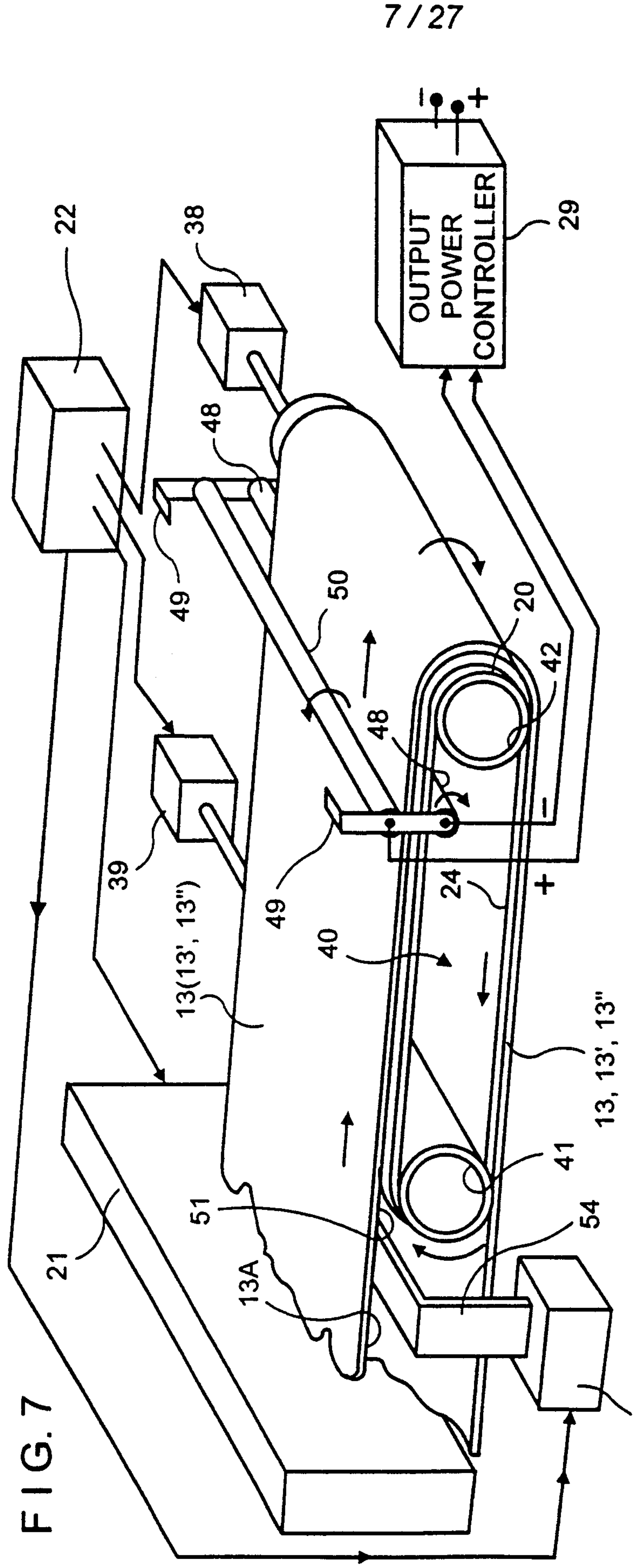
F I G. 6B



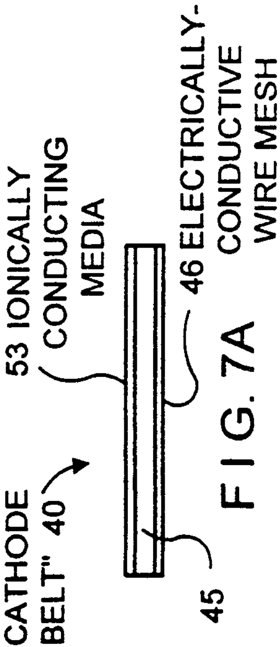
F I G. 6C



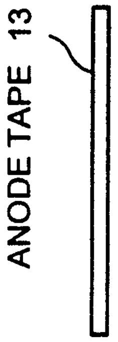
F I G. 6D



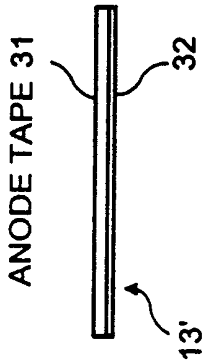
F I G. 7



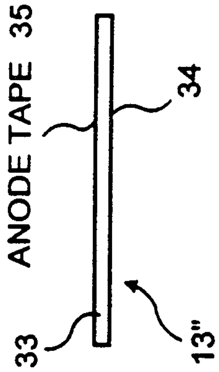
F I G. 7A



F I G. 7B



F I G. 7C



F I G. 7D

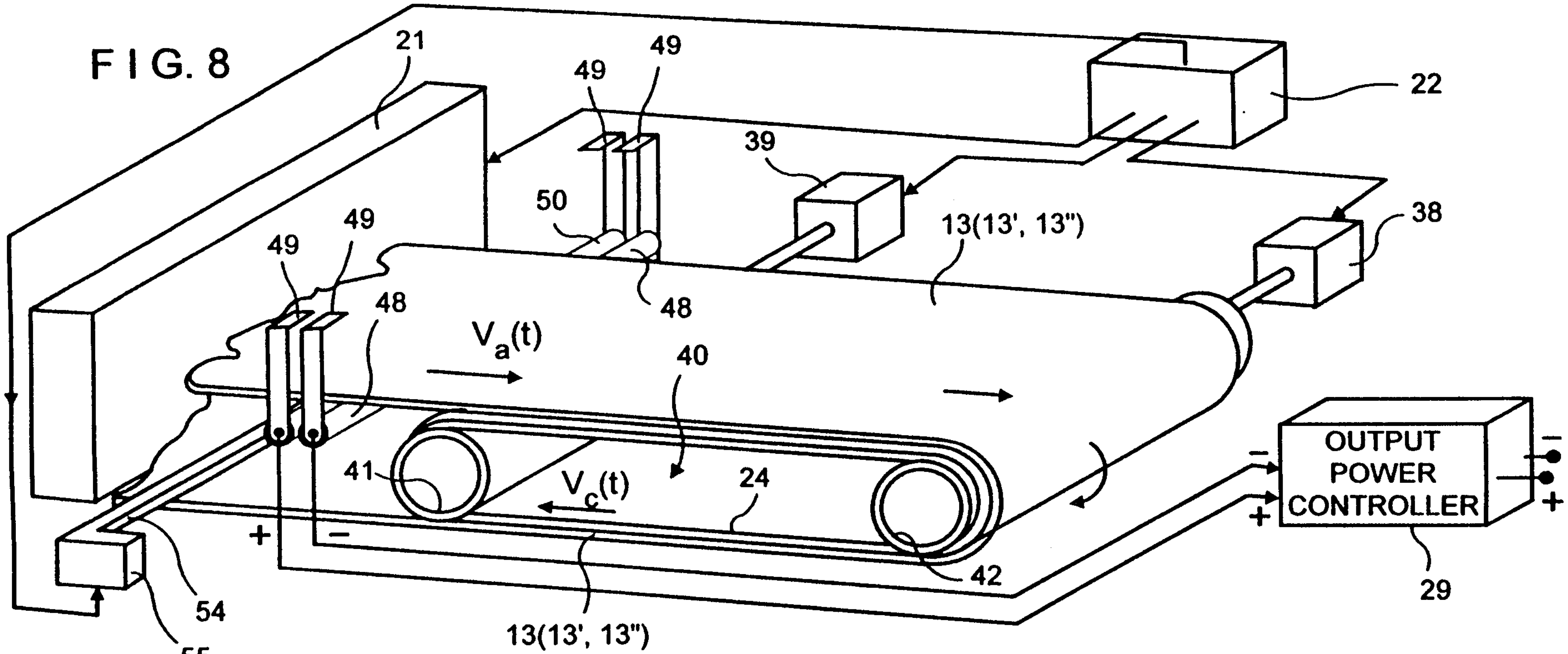


FIG. 8

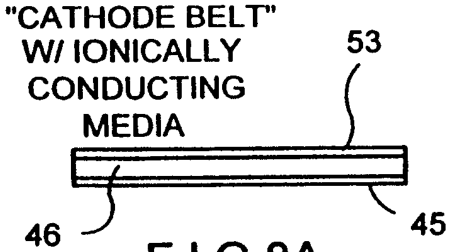


FIG.8A

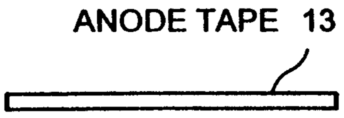


FIG. 8B

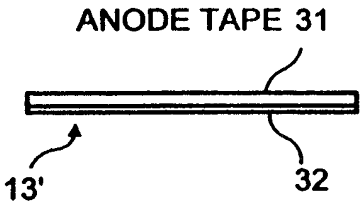


FIG. 8C

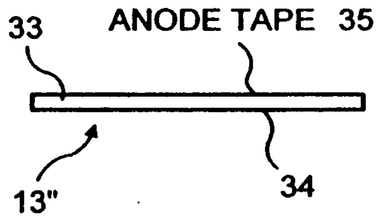
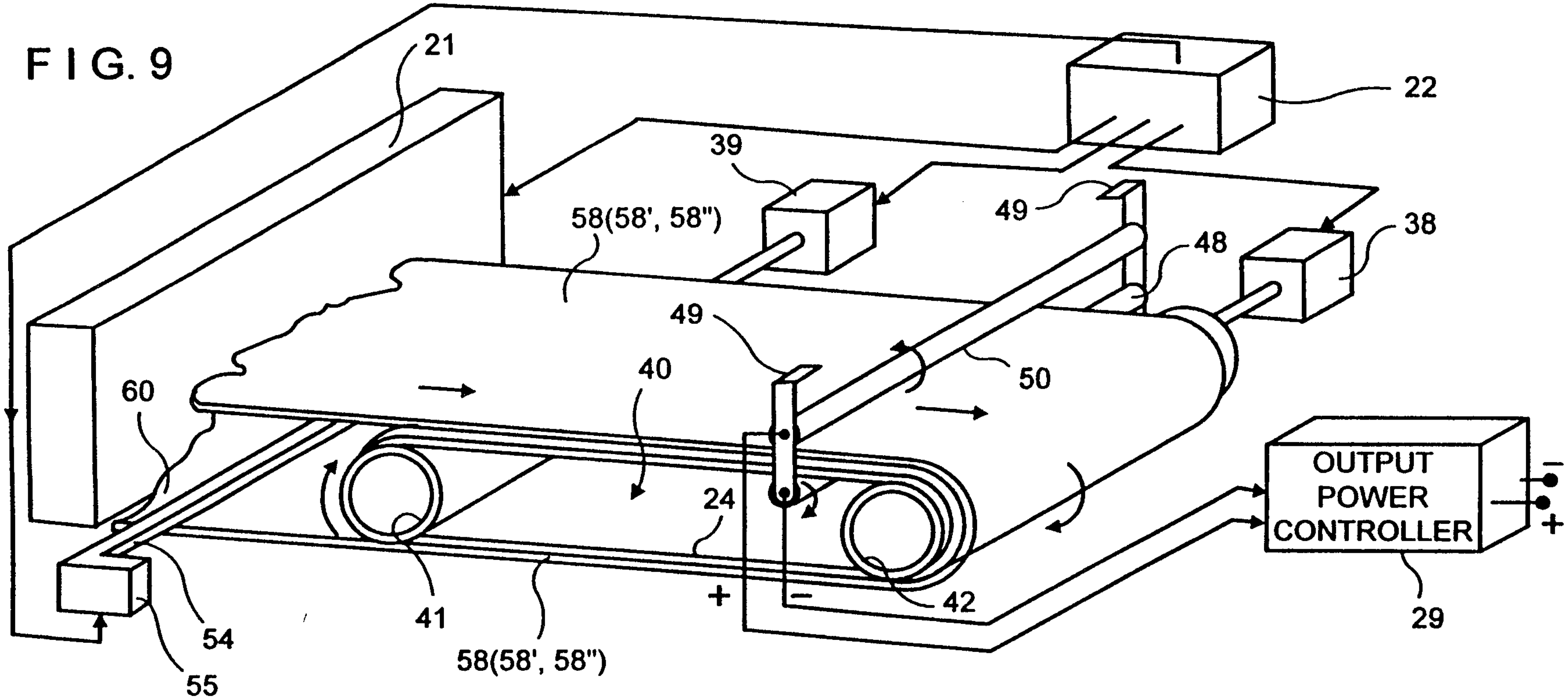
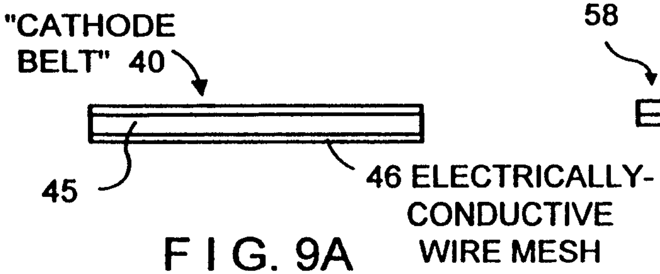


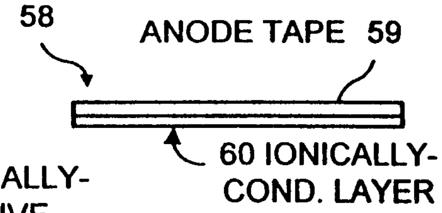
FIG. 8D



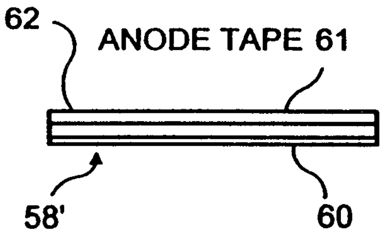
F I G. 9



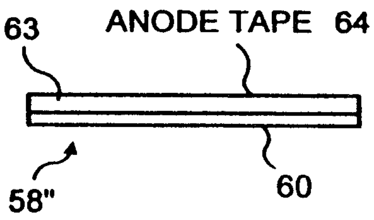
F I G. 9A



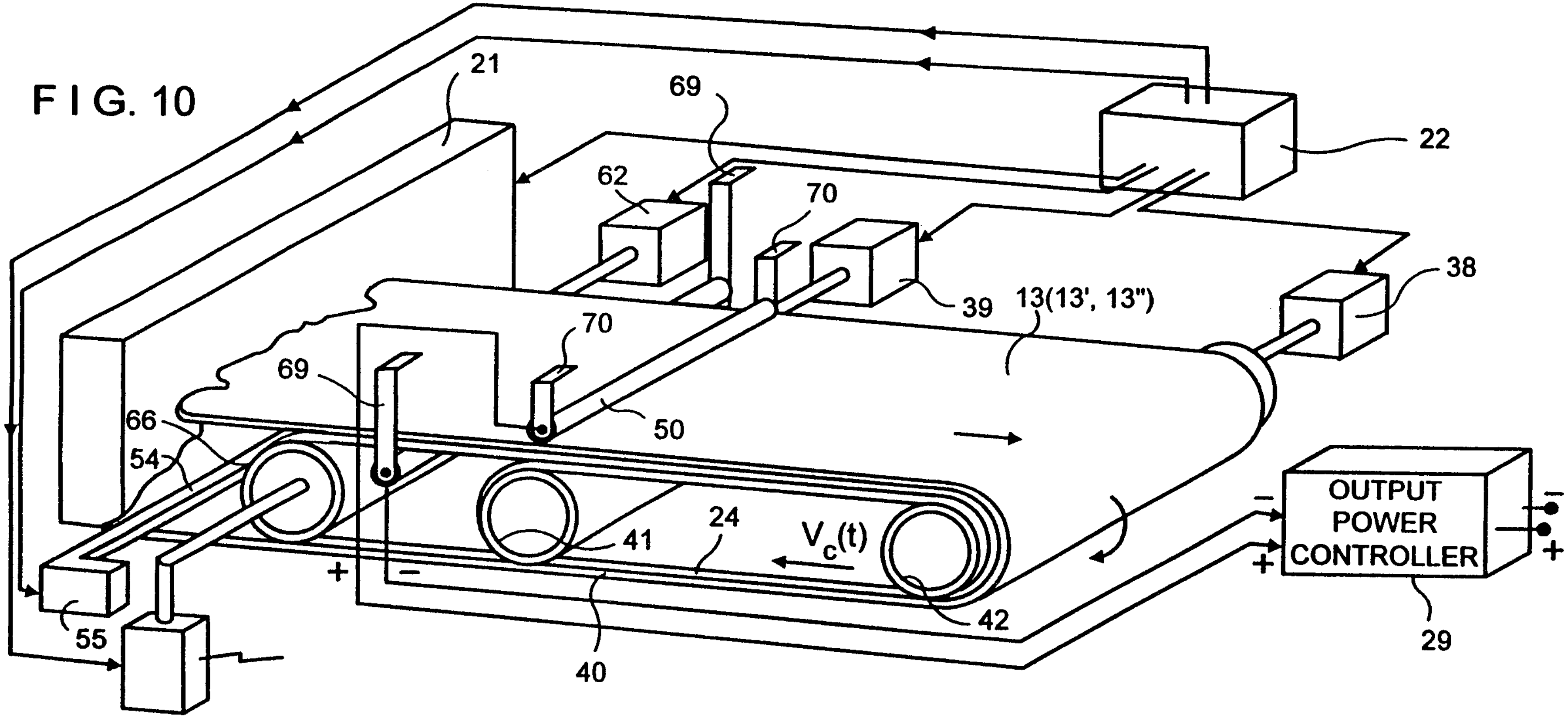
F I G. 9B



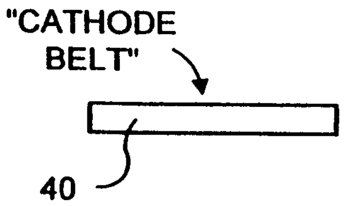
F I G. 9C



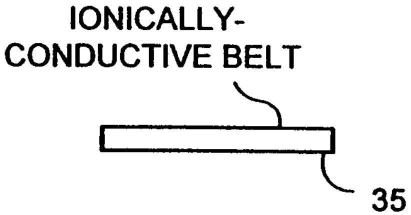
F I G. 9D



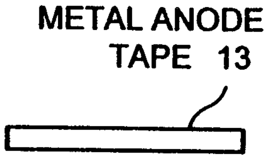
F I G. 10



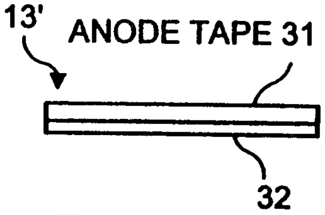
F I G. 10A



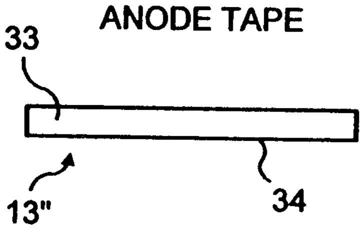
F I G. 10B



F I G. 10C



F I G. 10D



F I G. 10E

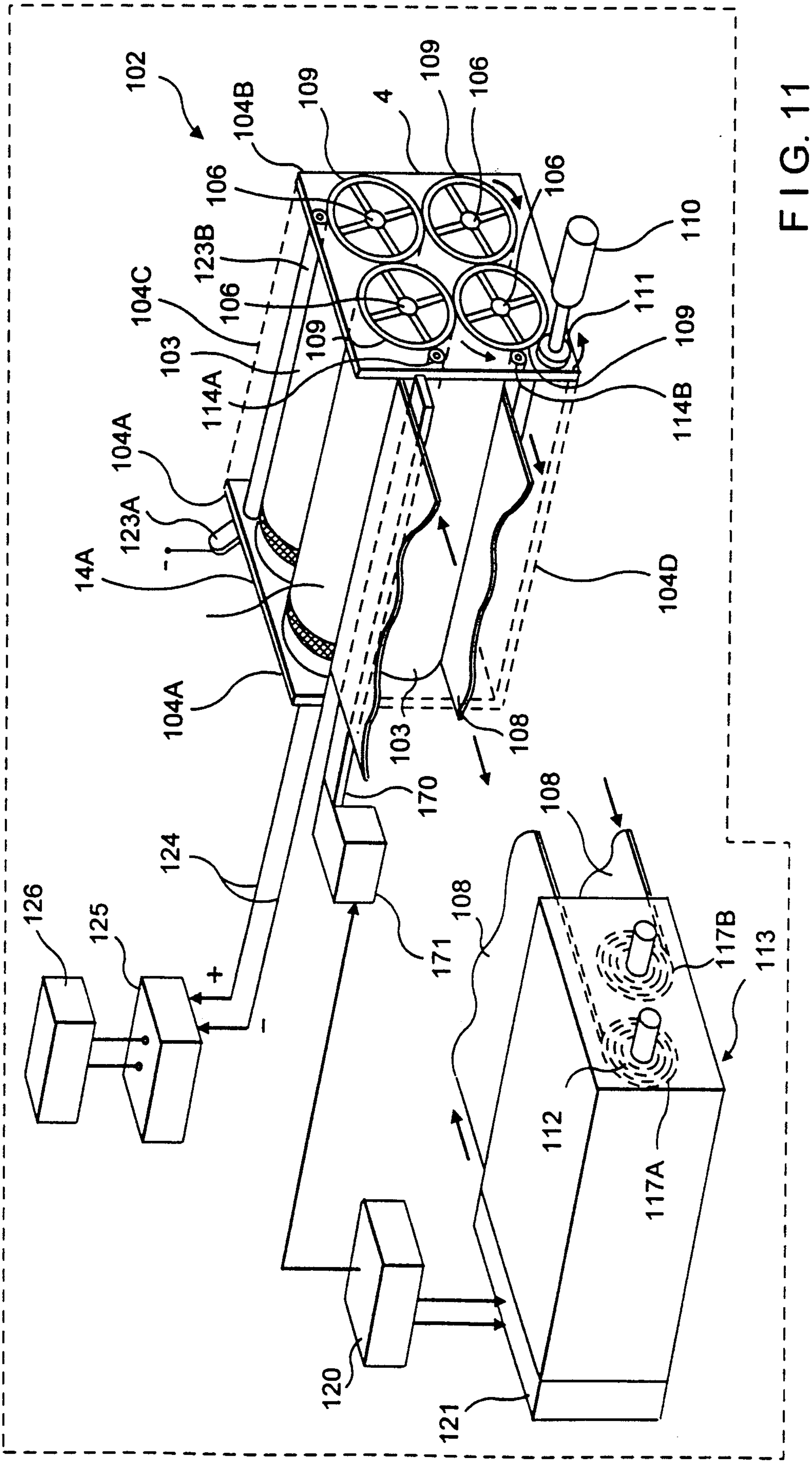

101
102
104B
109
4
109
106
106
106
106
123B
104C
109
103
114A
104A
123A
-
14A
104A
103
108
170
124
126
125
+
-
171
108
108
110
111
109
114B
104D
117B
113
112
117A
120
121

FIG. 11

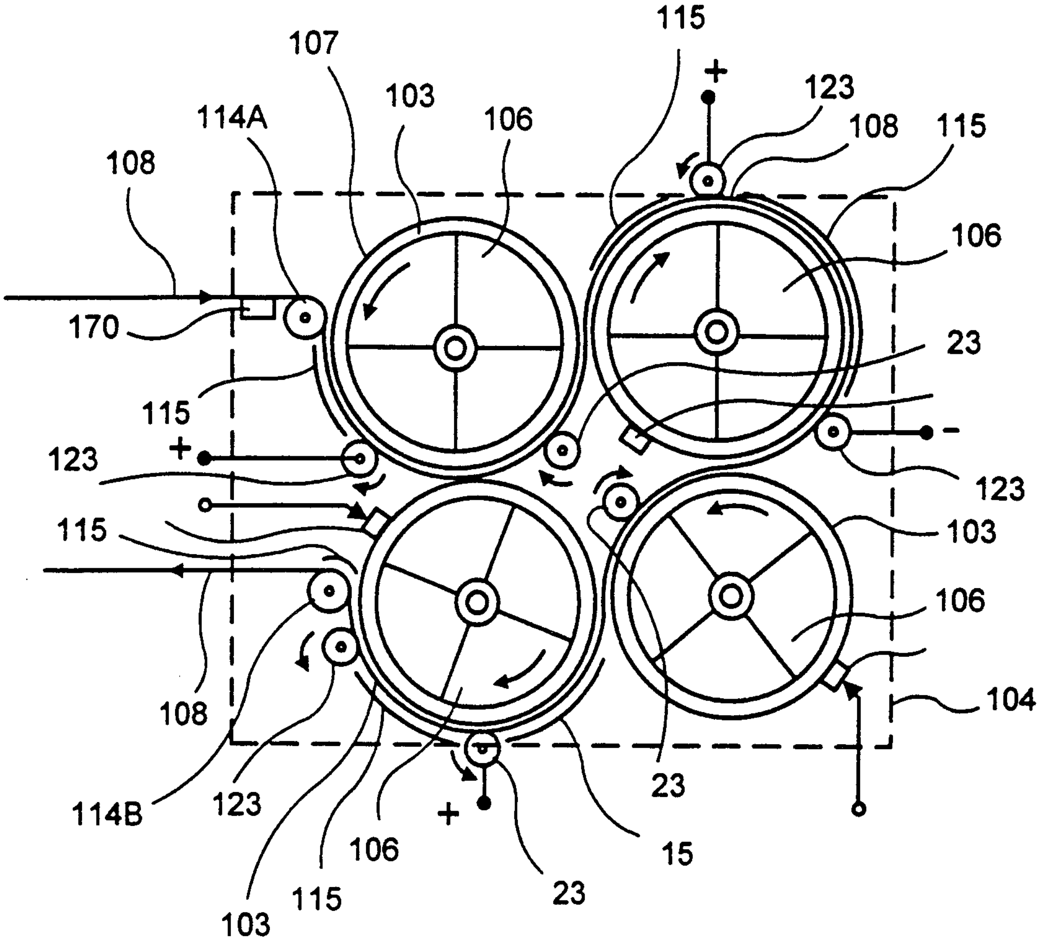


FIG. 11A

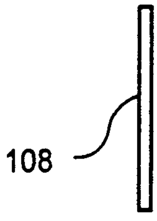


FIG. 12A

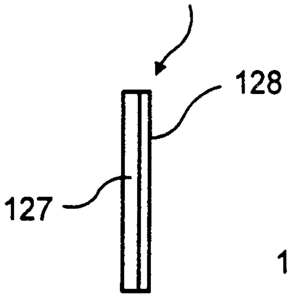


FIG. 12B

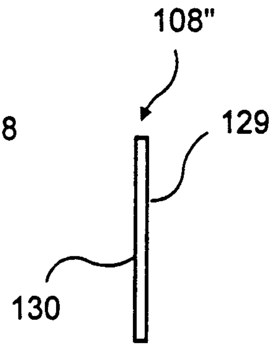


FIG. 12C

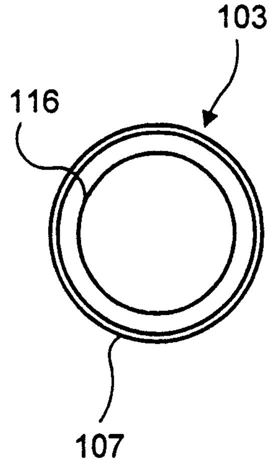


FIG. 12D

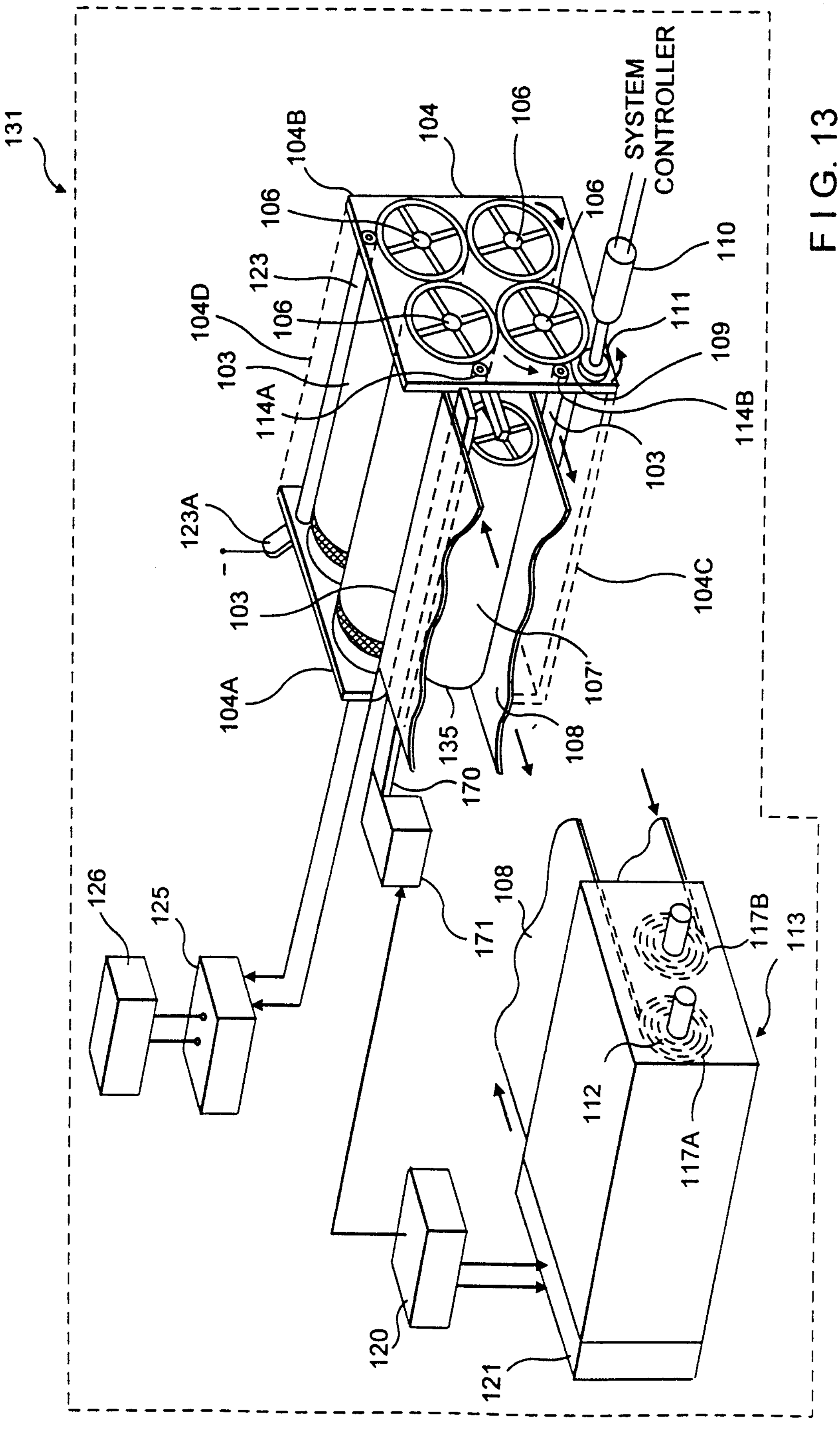
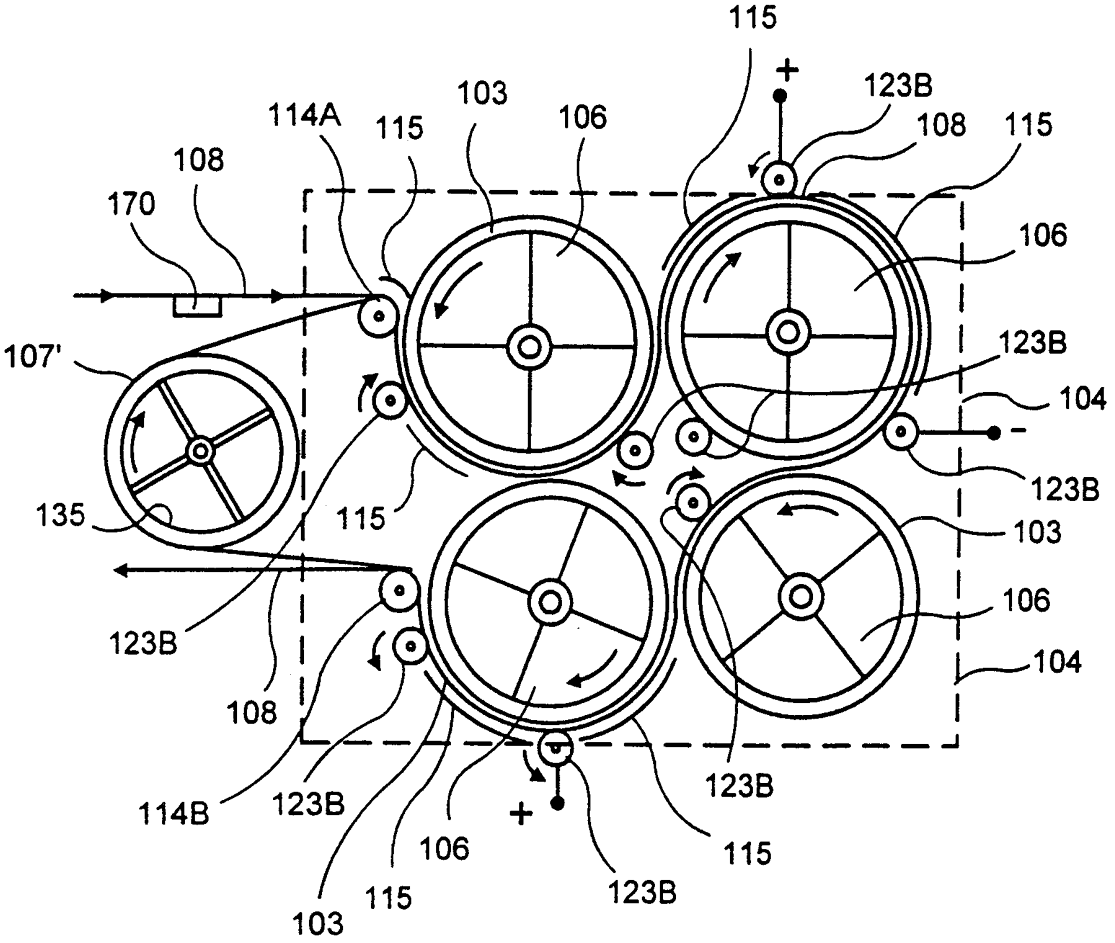
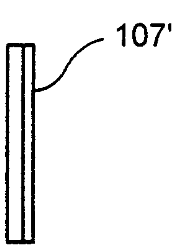

131
104B
104
106
106
106
106
SYSTEM
CONTROLLER
110
111
109
114B
103
123
104D
103
114A
123A
103
104A
135
170
108
107'
104C
171
108
126
125
112
117A
117B
113
120
121

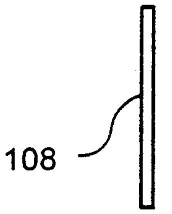
FIG. 13



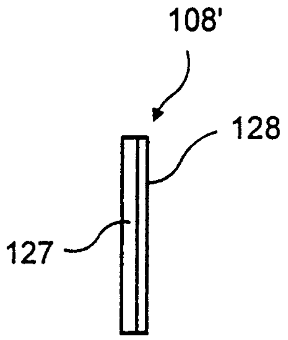
F I G. 13A



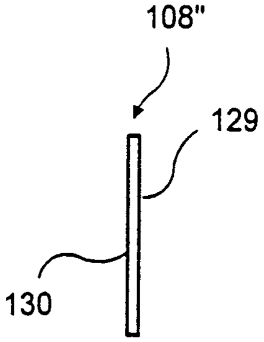
F I G. 14



F I G. 15A



F I G. 15B



F I G. 15C

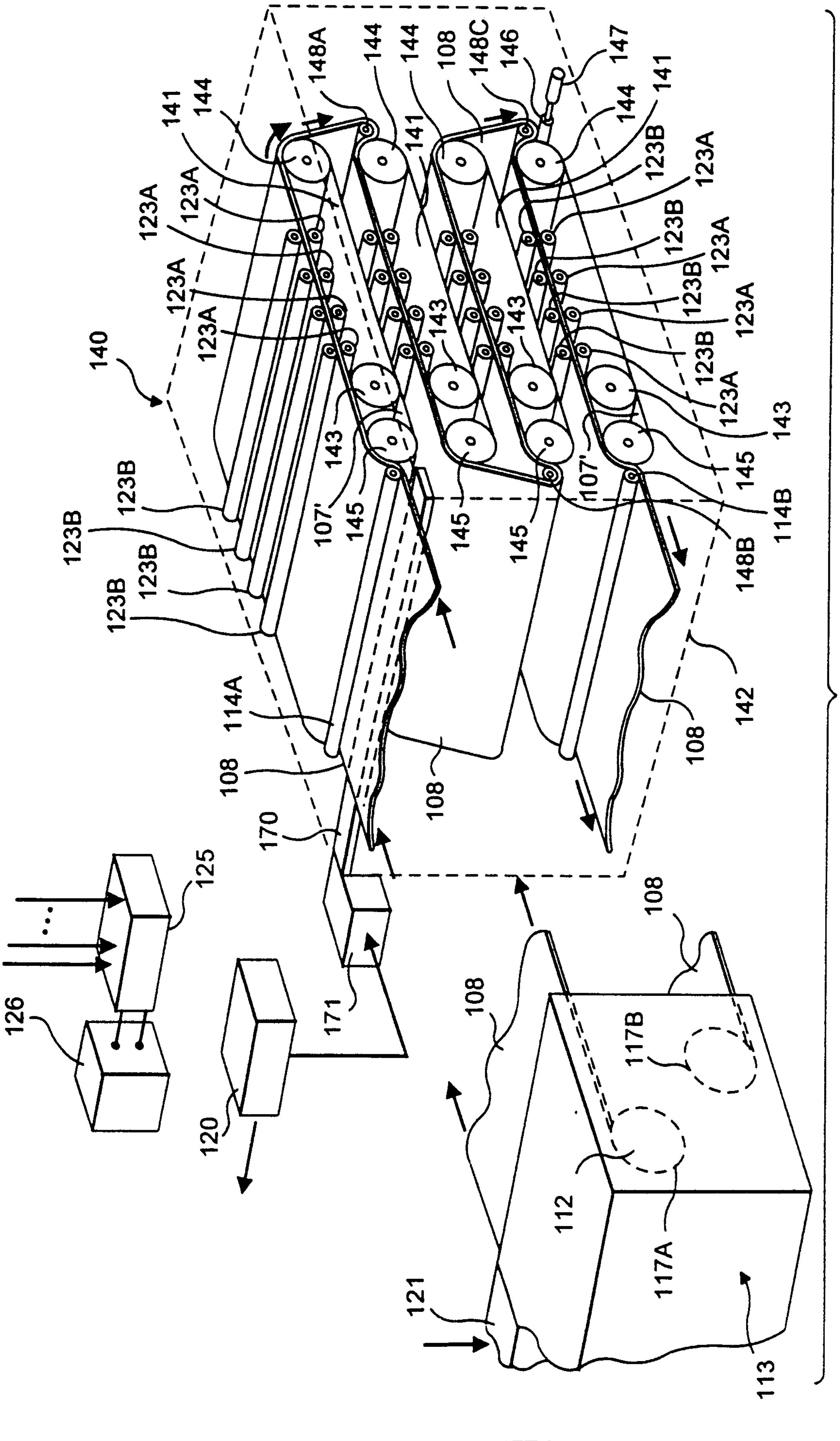

140
141
144
148A
144
144
108
148C
146
147
141
144
141
123A
123B
143
145
107'
114B
148B
142
108
114A
170
171
125
126
120
121
112
117A
117B
113

FIG. 16

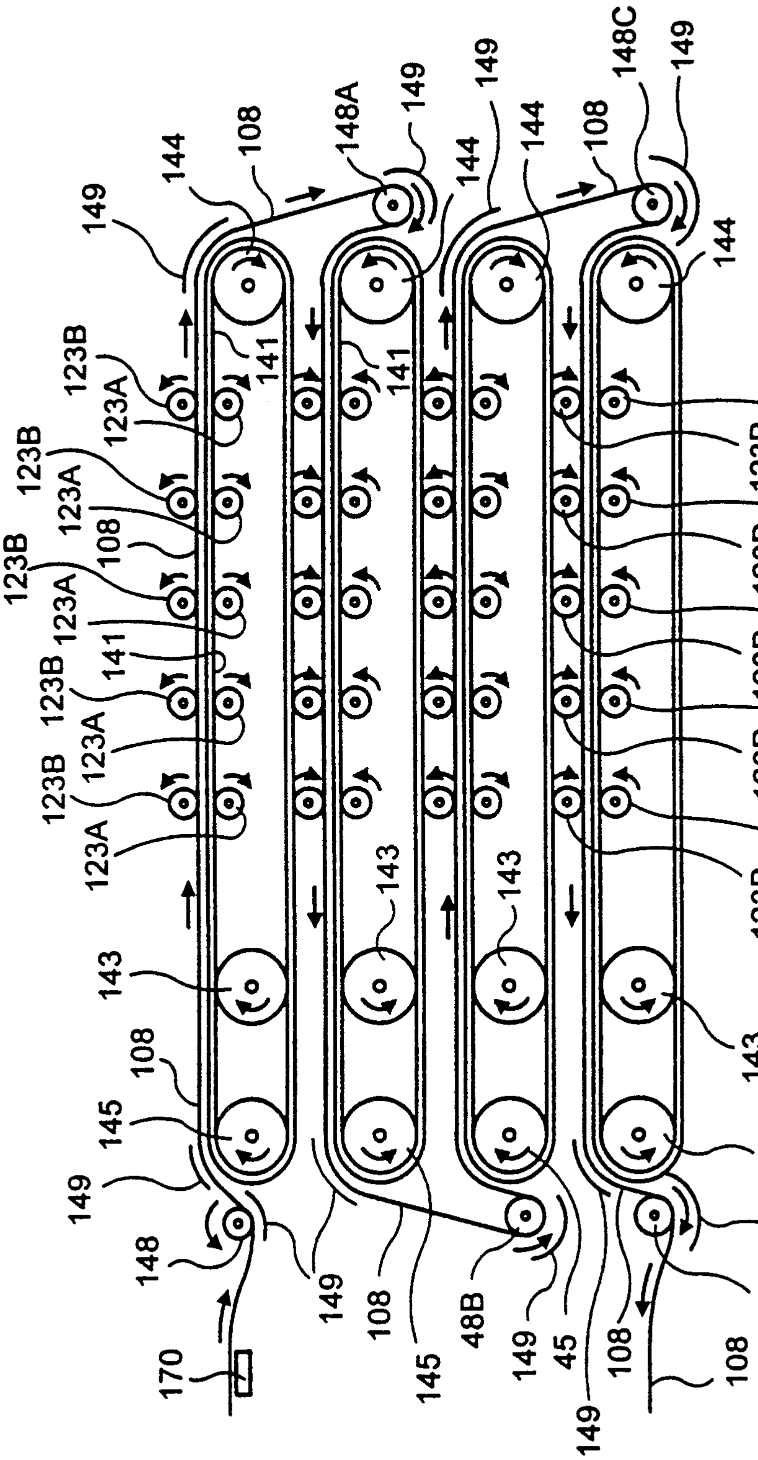


FIG.16A

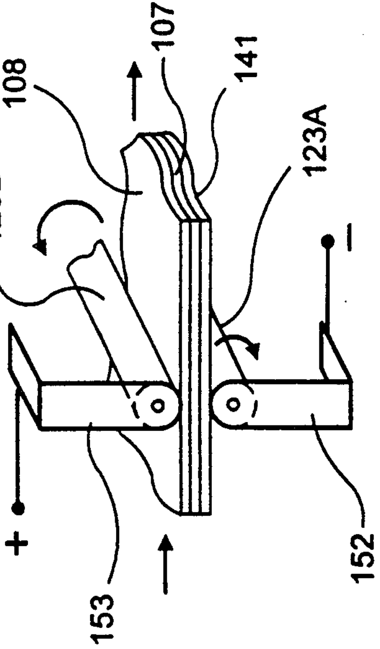
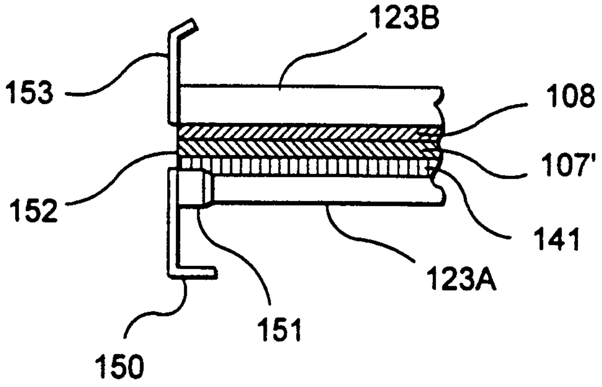
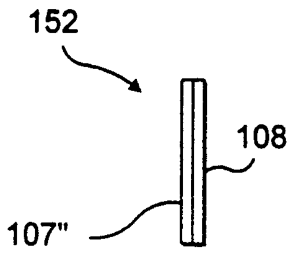


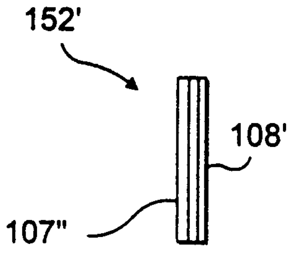
FIG.16B



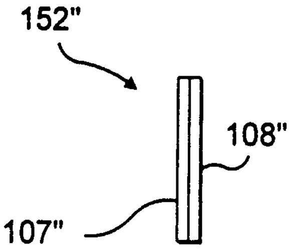
F I G. 16C



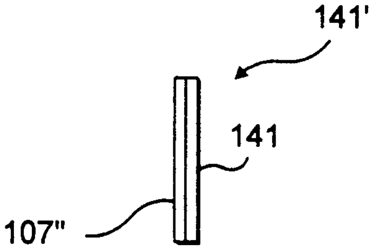
F I G. 17A



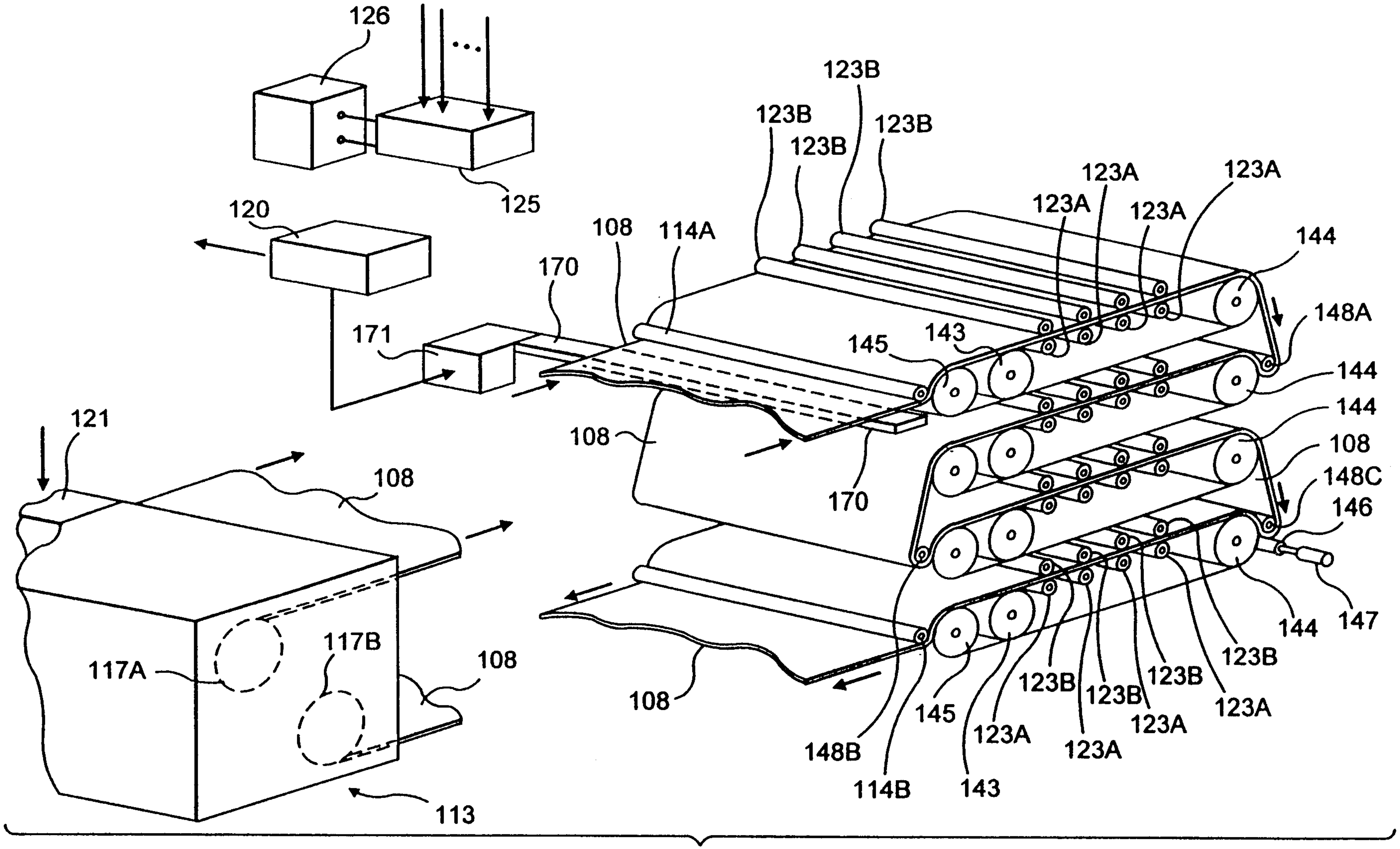
F I G. 17B



F I G. 17C



F I G. 18


126
125
120
171
170
108
114A
123B
123B
123B
123B
123B
123A
123A
123A
123A
144
148A
145
143
144
144
108
148C
146
147
144
121
108
108
170
117A
117B
108
113
108
148B
114B
145
143
123A
123B
123A
123B
123A
123B
123A
123B
123A

F I G. 19

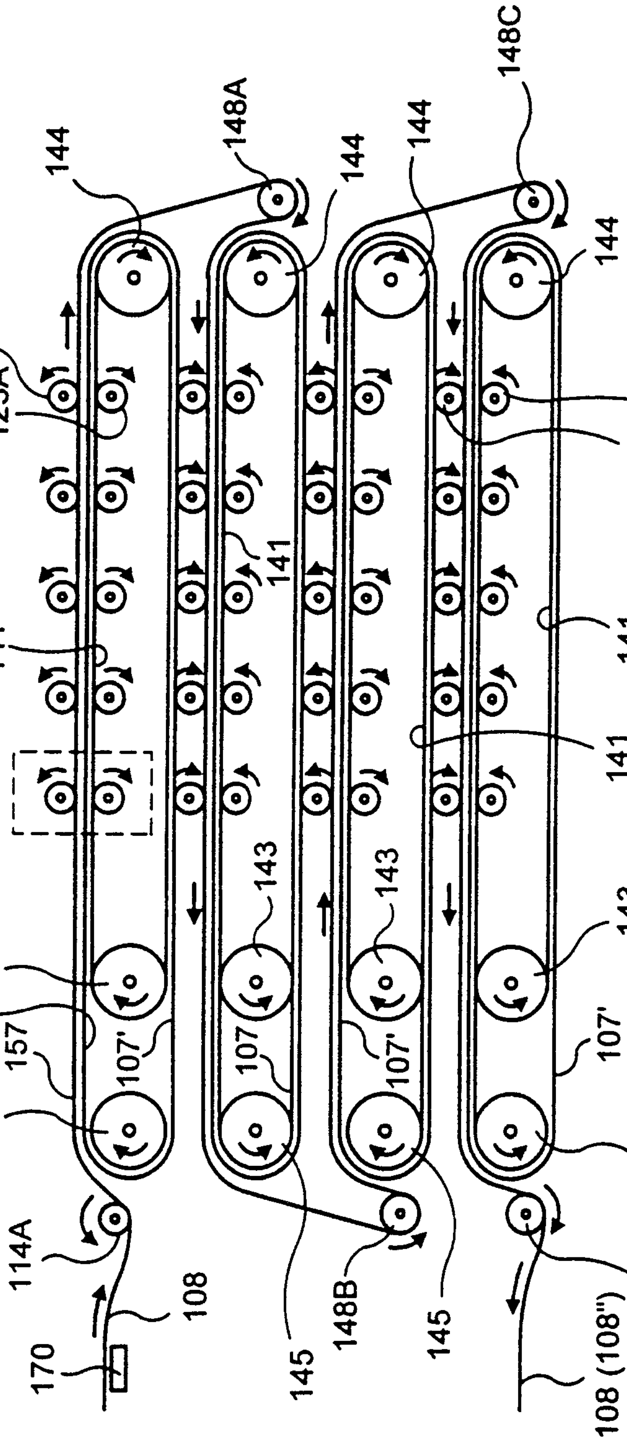


FIG.19A

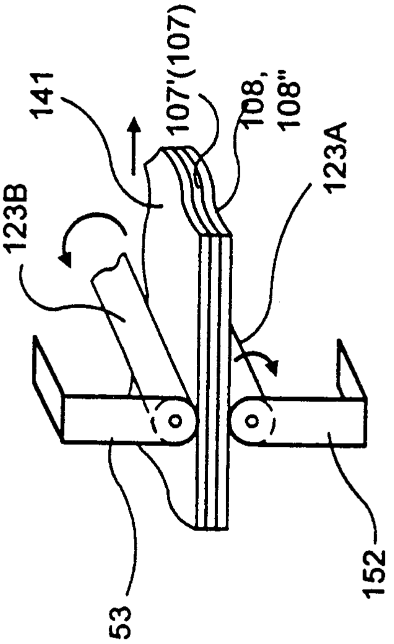
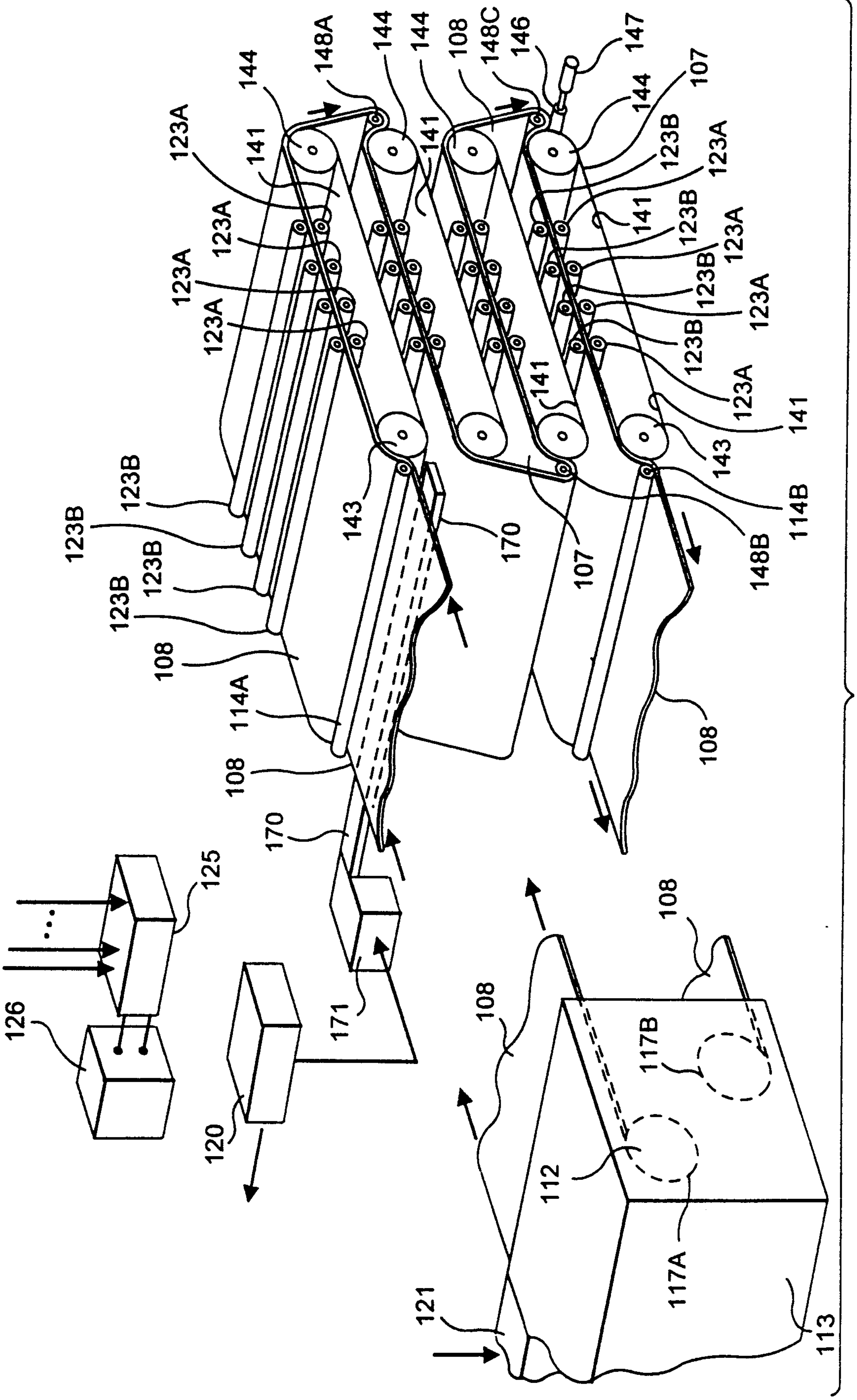
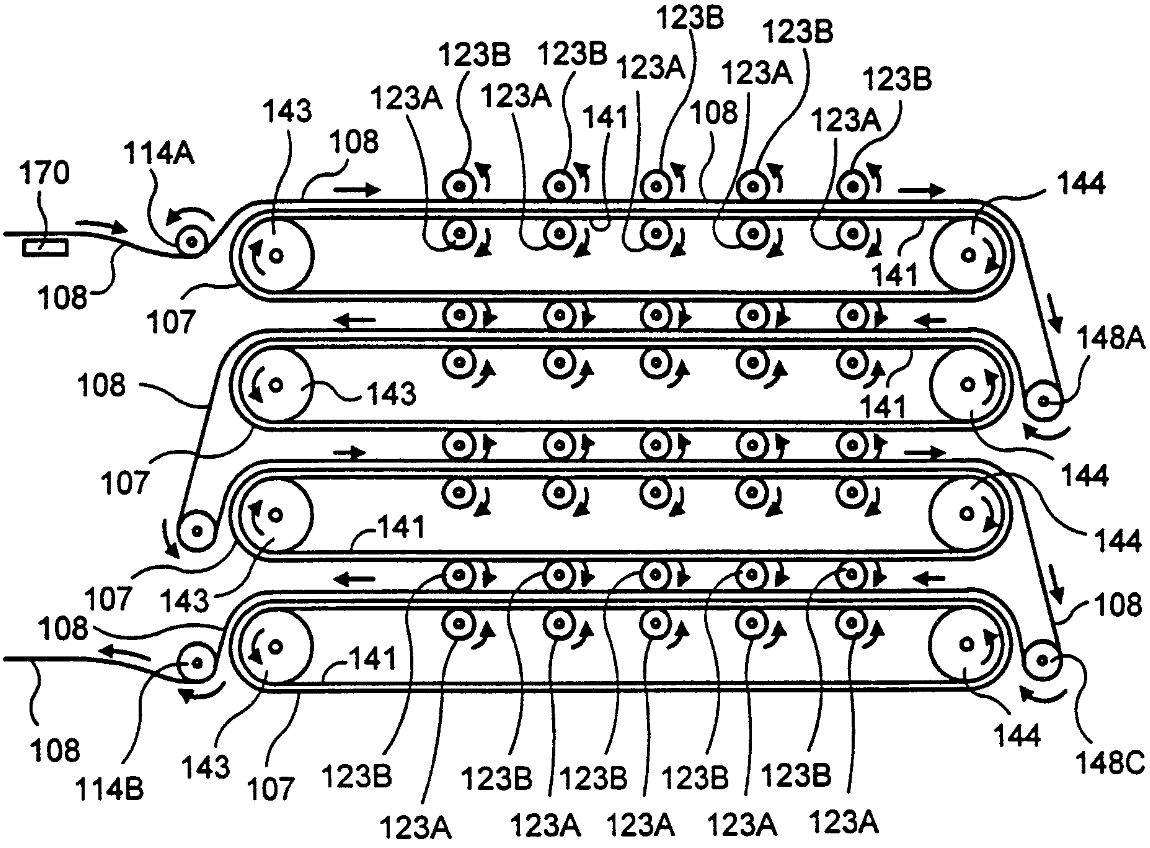


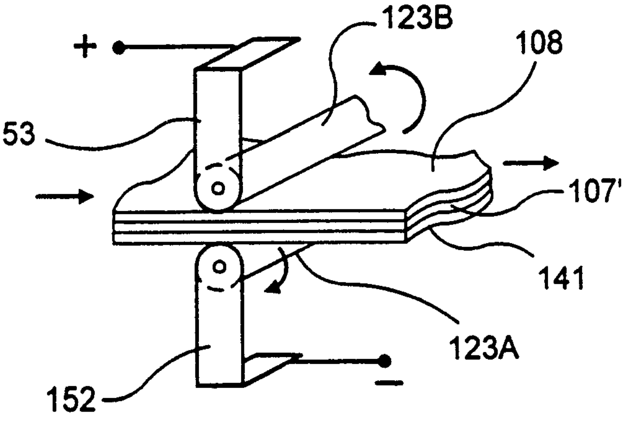
FIG.19B


144
148A
144
144
108
148C
146
147
107
144
123A
141
141
123A
123B
123A
123A
141
123B
123A
123A
123B
123A
123A
123B
123A
123A
141
141
143
143
123B
123B
123B
123B
123B
170
107
148B
114B
108
114A
108
170
125
126
171
120
108
108
117B
112
117A
121
113

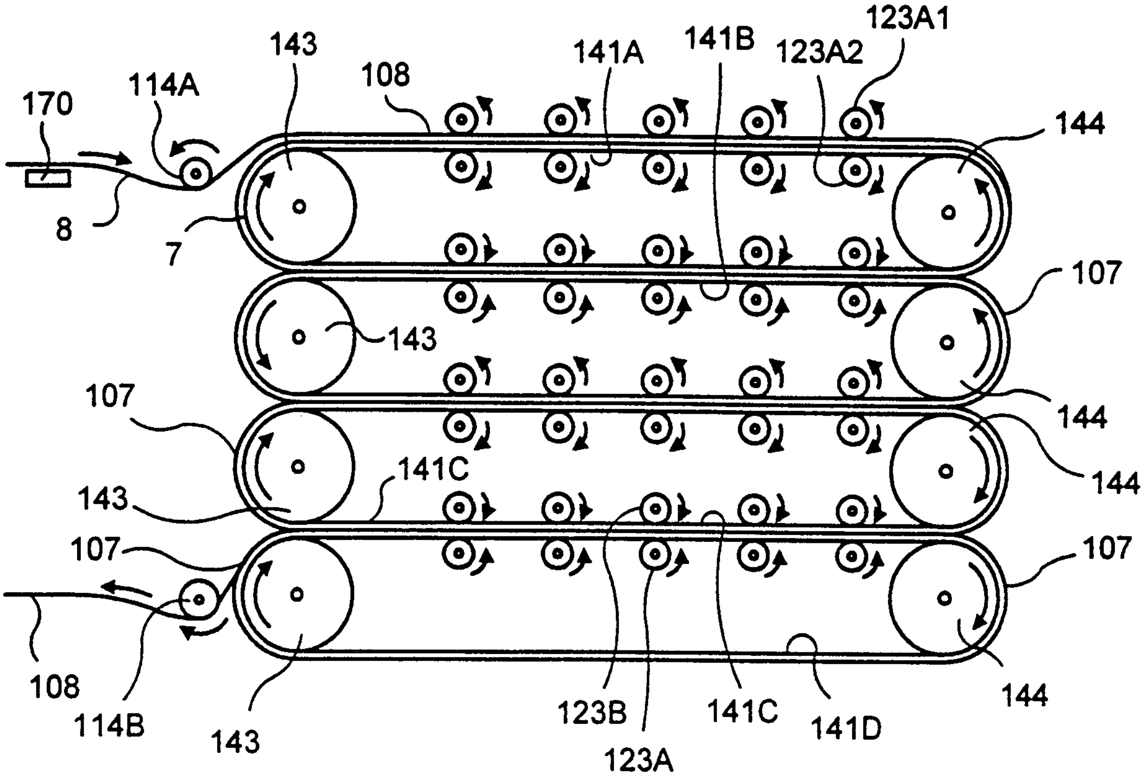
F I G. 20



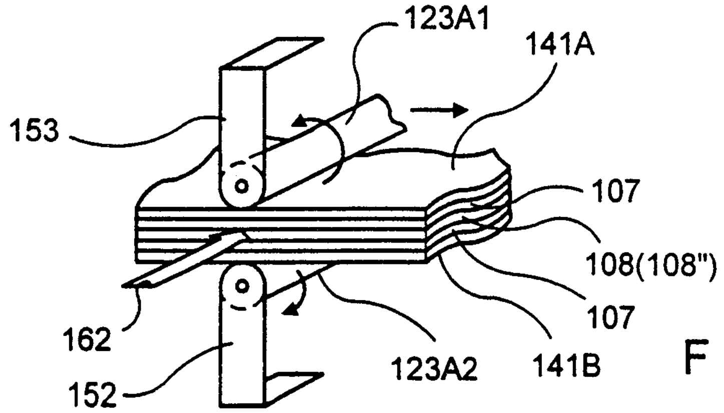
F I G.20A



F I G.20B



F I G. 21



F I G. 21A

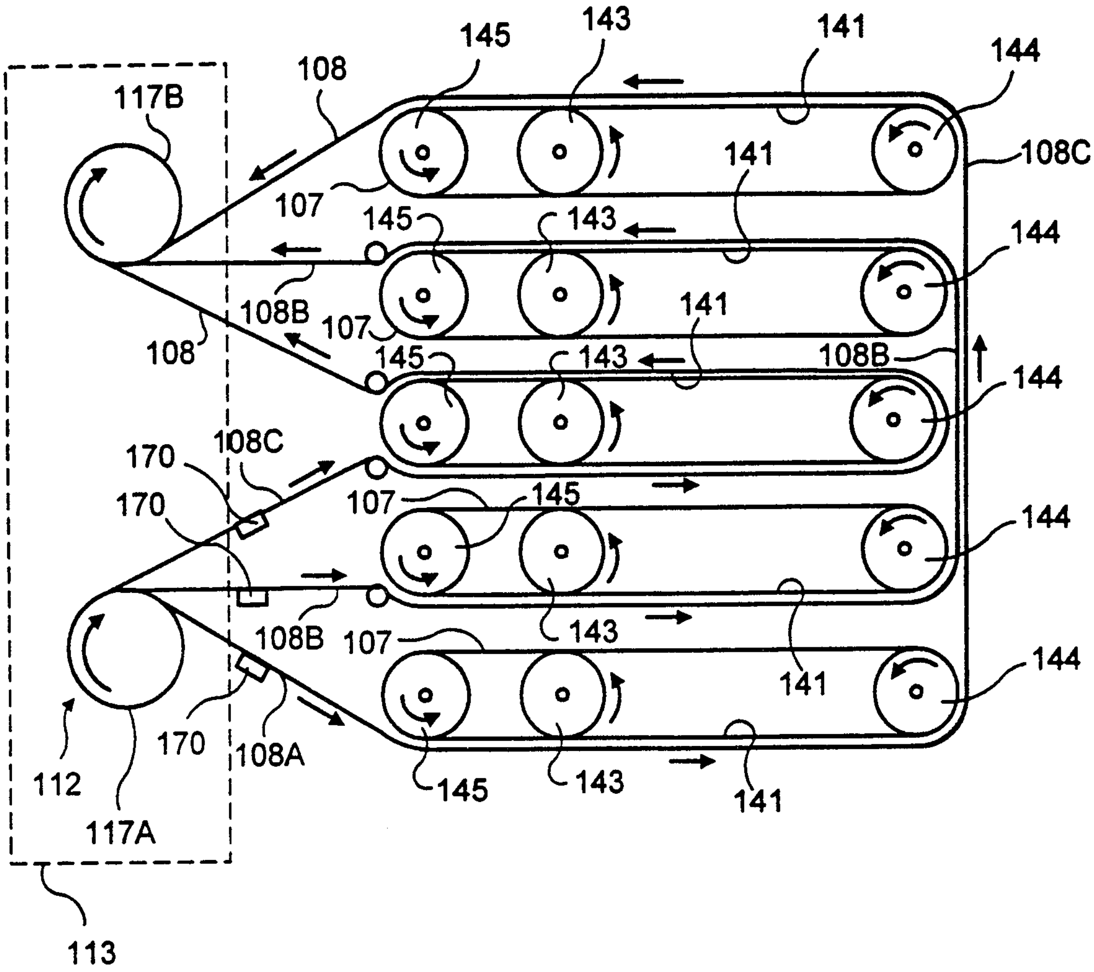
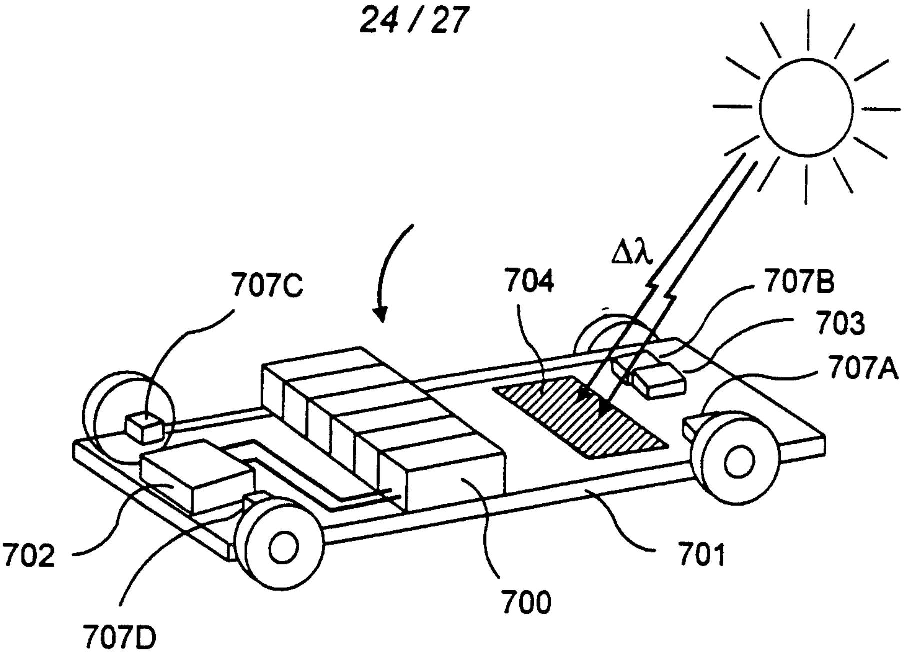
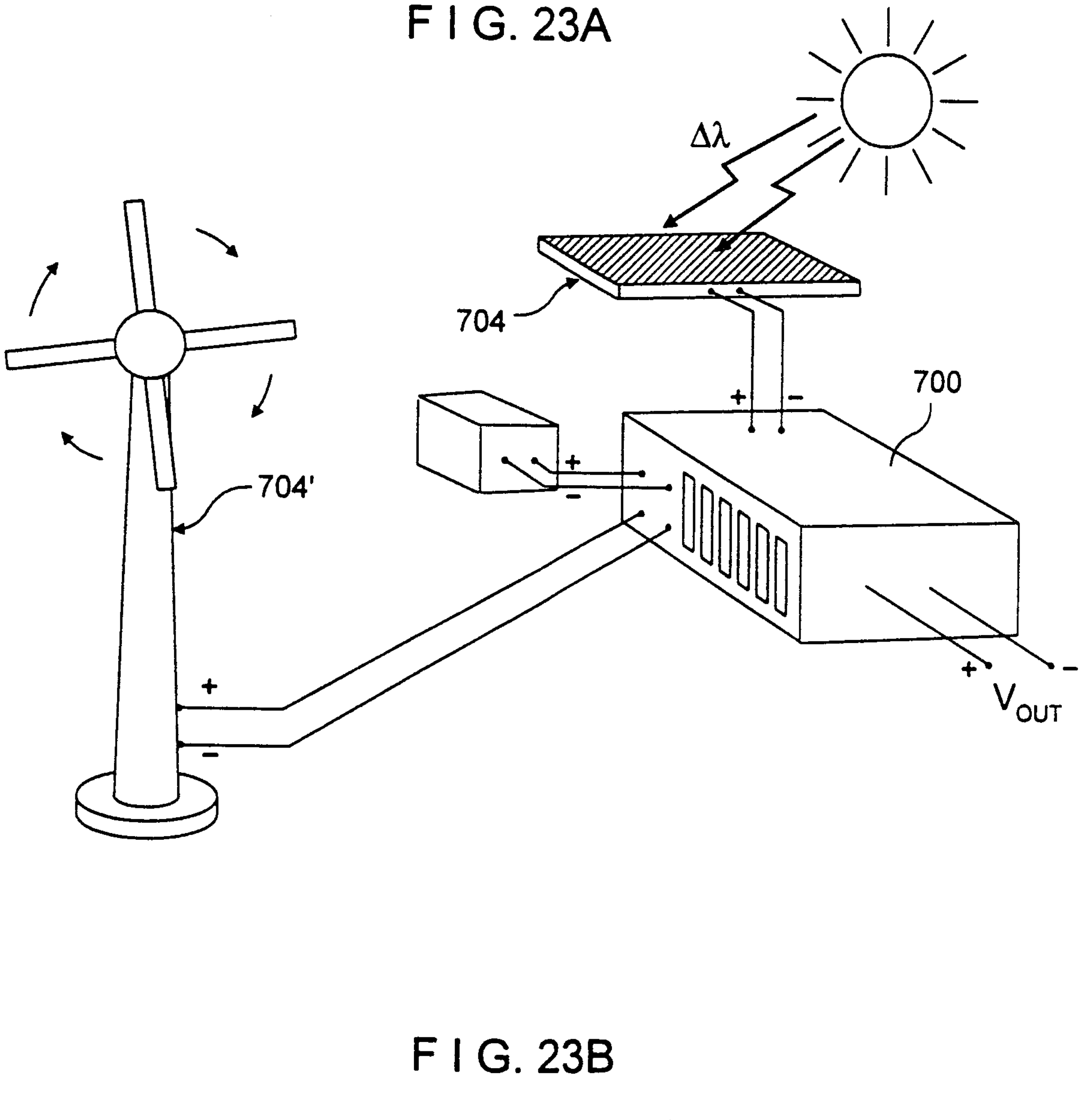

145
143
141
144
108
117B
108C
107
145
143
141
144
108B
108
107
145
143
141
108B
144
170
108C
170
107
145
144
108B
143
141
144
112
170
108A
107
145
143
141
117A
113

FIG. 22



F I G. 23A



F I G. 23B

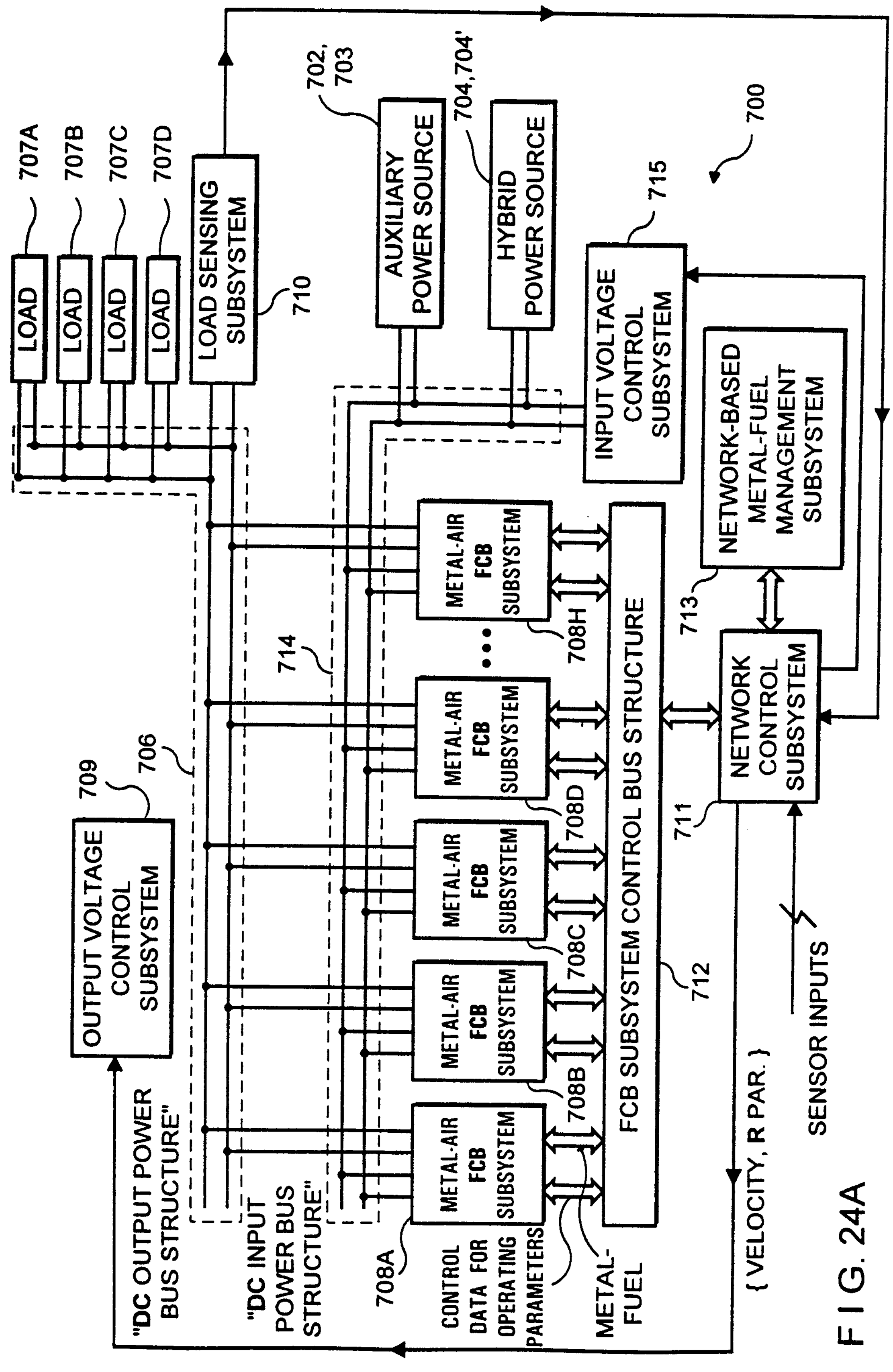
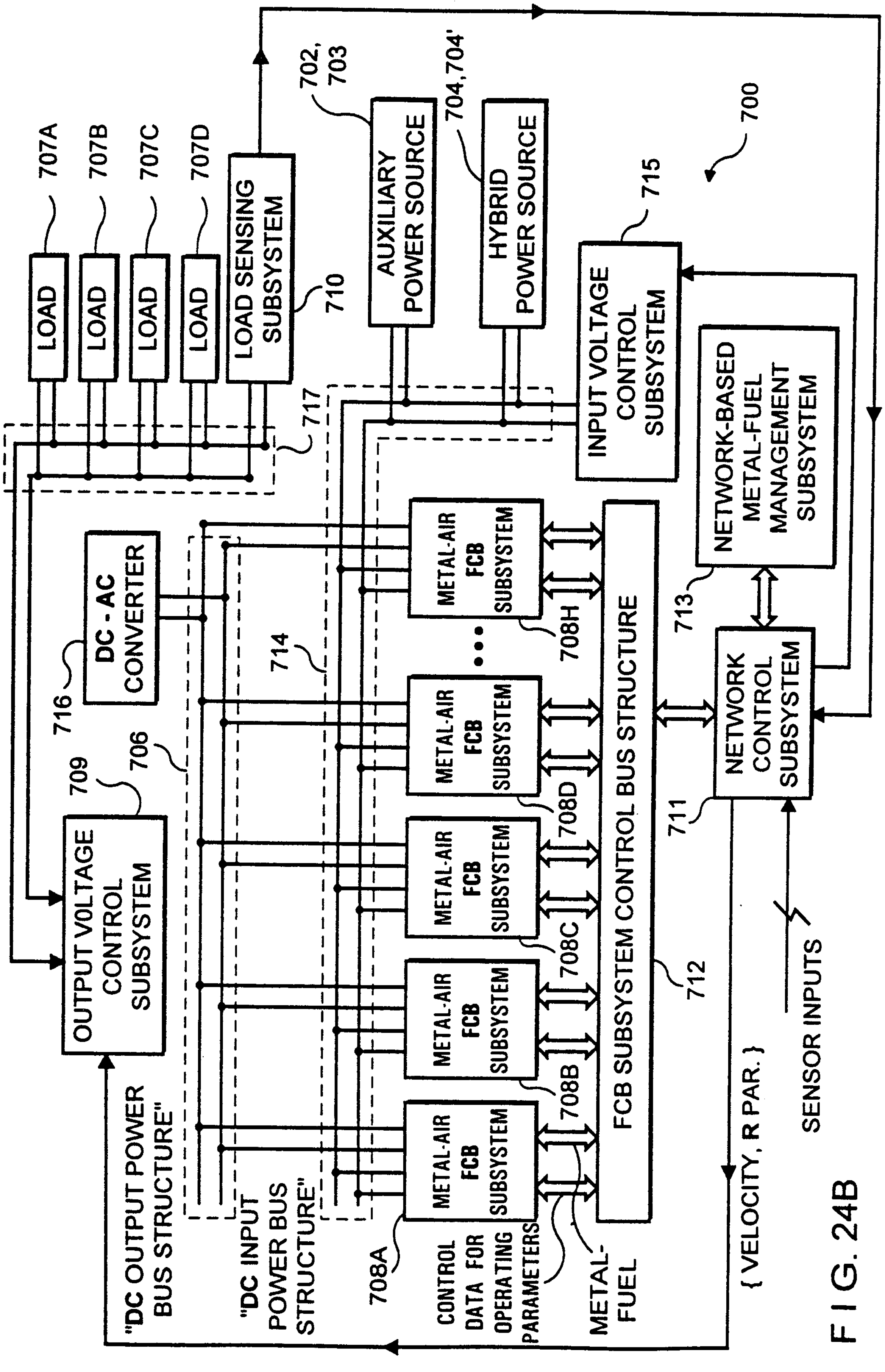

LOAD
LOAD
LOAD
LOAD
707A
707B
707C
707D
LOAD SENSING SUBSYSTEM
710
AUXILIARY POWER SOURCE
702, 703
HYBRID POWER SOURCE
704,704'
700
INPUT VOLTAGE CONTROL SUBSYSTEM
715
NETWORK-BASED METAL-FUEL MANAGEMENT SUBSYSTEM
713
NETWORK CONTROL SUBSYSTEM
711
SENSOR INPUTS
{VELOCITY, R PAR.}
FCB SUBSYSTEM CONTROL BUS STRUCTURE
712
METAL-AIR FCB SUBSYSTEM
708H
METAL-AIR FCB SUBSYSTEM
708D
METAL-AIR FCB SUBSYSTEM
708C
METAL-AIR FCB SUBSYSTEM
708B
METAL-AIR FCB SUBSYSTEM
708A
714
706
OUTPUT VOLTAGE CONTROL SUBSYSTEM
709
"DC OUTPUT POWER BUS STRUCTURE"
"DC INPUT POWER BUS STRUCTURE"
CONTROL DATA FOR OPERATING PARAMETERS
METAL-FUEL

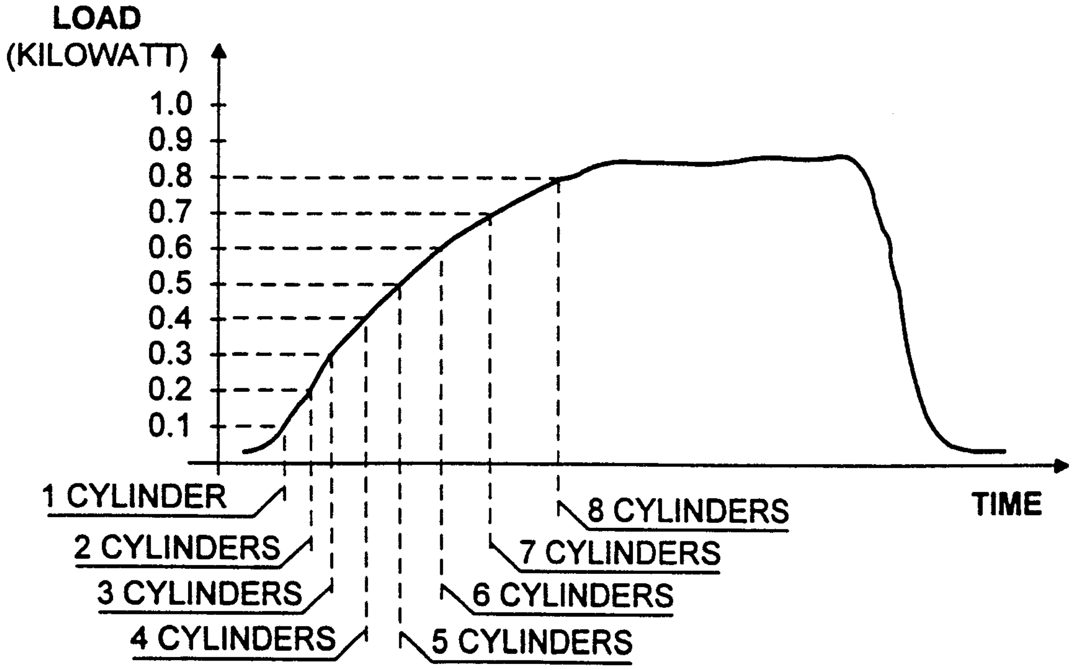
FIG. 24A


LOAD
LOAD
LOAD
LOAD
707A
707B
707C
707D
LOAD SENSING SUBSYSTEM
710
AUXILIARY POWER SOURCE
702, 703
HYBRID POWER SOURCE
704,704'
700
INPUT VOLTAGE CONTROL SUBSYSTEM
715
NETWORK-BASED METAL-FUEL MANAGEMENT SUBSYSTEM
713
NETWORK CONTROL SUBSYSTEM
711
717
DC - AC CONVERTER
716
714
OUTPUT VOLTAGE CONTROL SUBSYSTEM
709
706
METAL-AIR FCB SUBSYSTEM
708H
METAL-AIR FCB SUBSYSTEM
708D
METAL-AIR FCB SUBSYSTEM
708C
METAL-AIR FCB SUBSYSTEM
708B
METAL-AIR FCB SUBSYSTEM
708A
FCB SUBSYSTEM CONTROL BUS STRUCTURE
712
"DC OUTPUT POWER BUS STRUCTURE"
"DC INPUT POWER BUS STRUCTURE"
CONTROL DATA FOR OPERATING PARAMETERS
METAL-FUEL
{ VELOCITY, R PAR. }
SENSOR INPUTS

F I G. 24B

TIME	FCB SUBSYSTEM No. 1	FCB SS No. 2	FCB SS No. 3	FCB SS No. 4	FCB SS No. 5	FCB SS No. 6	FCB SS No. 7	FCB SS No. 8
t_1	FIG, 5B16	FIG, 5B16						
t_2								
t_3								
t_2								
	⋮					⋮		
t_n								

F I G. 24C



F I G. 25