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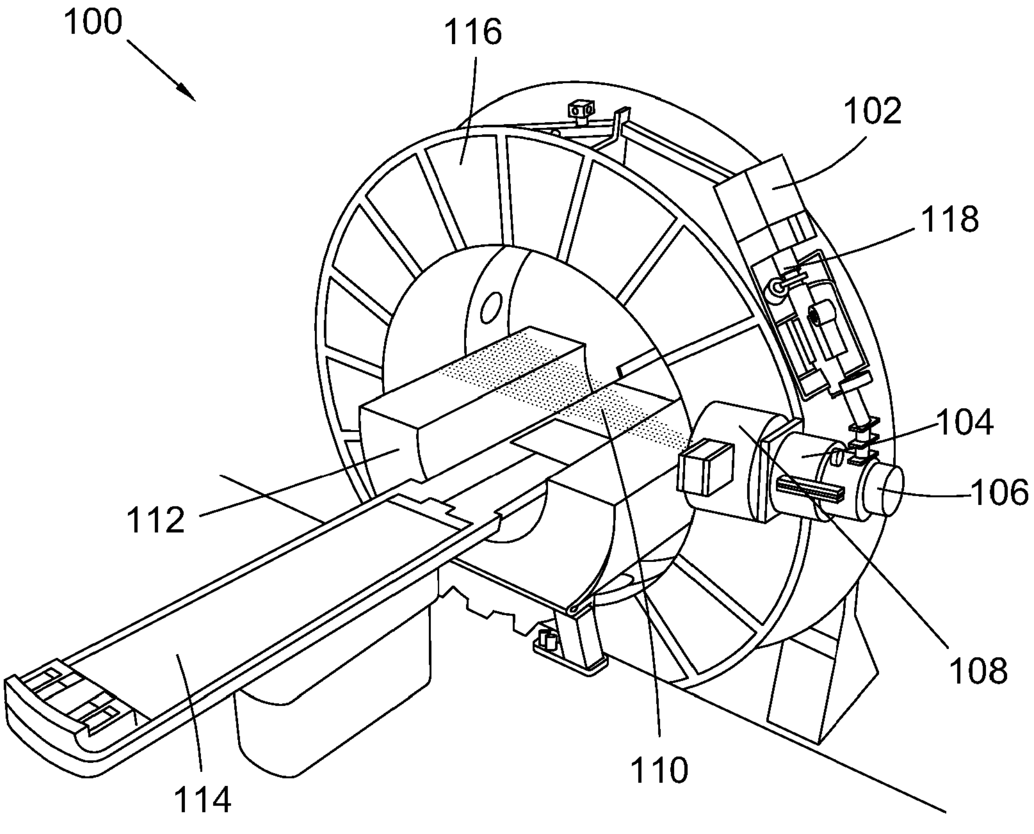

FIG. 1

28 10 22

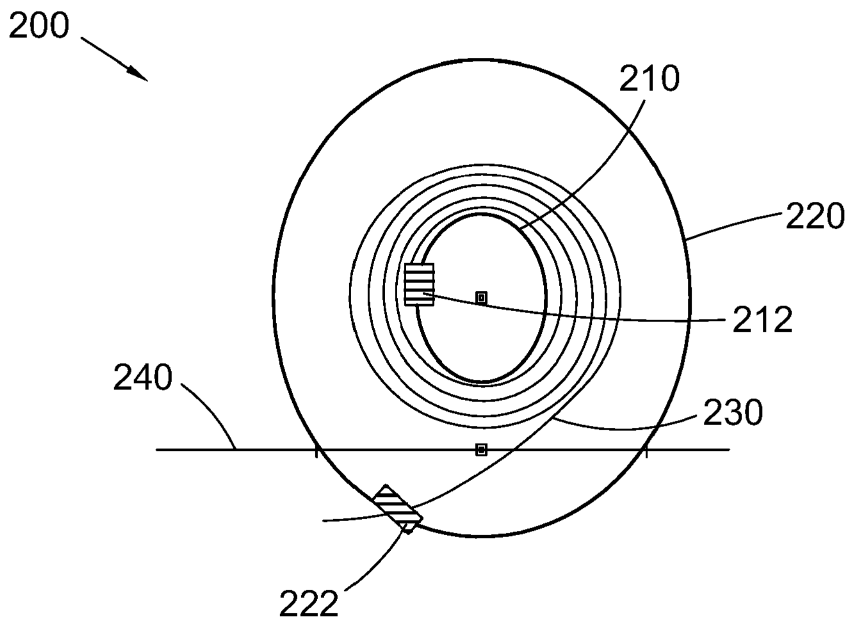

FIG. 2a

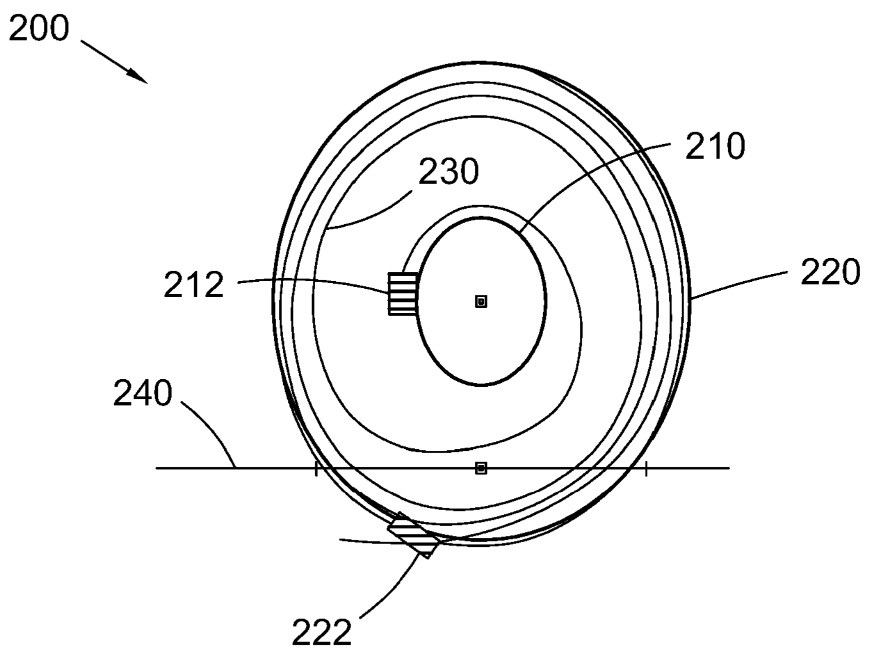

FIG. 2b

28 10 22

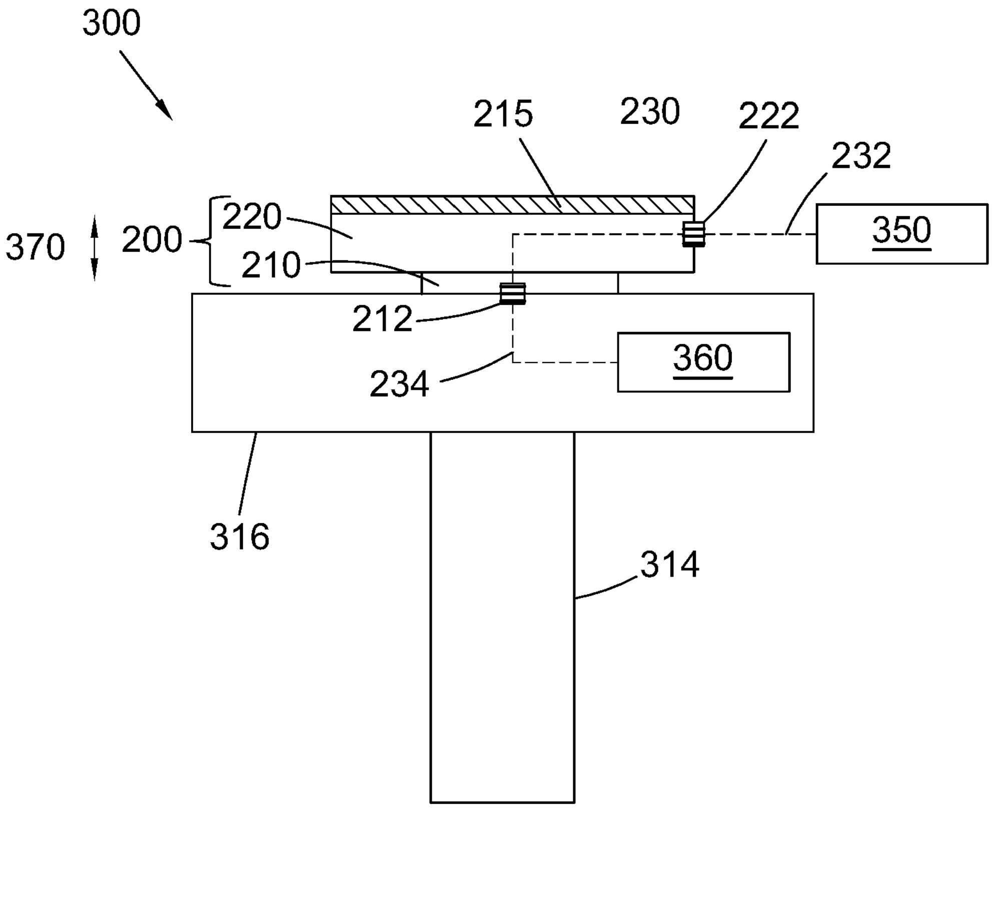

FIG. 3

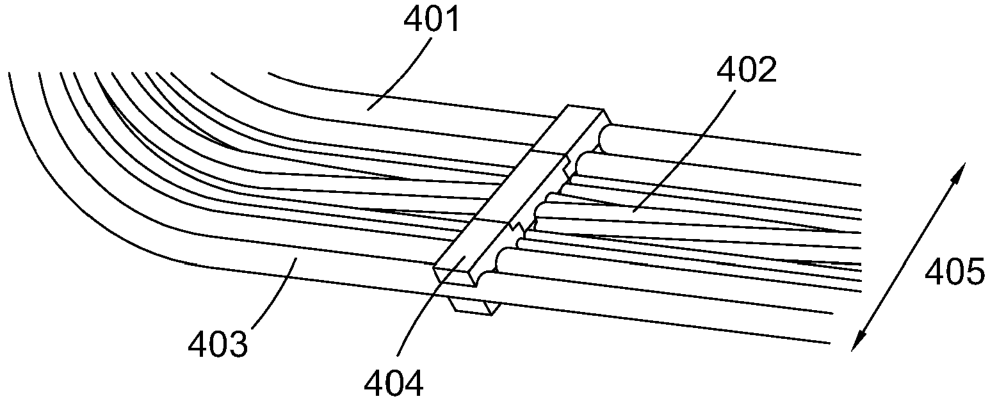

FIG. 4

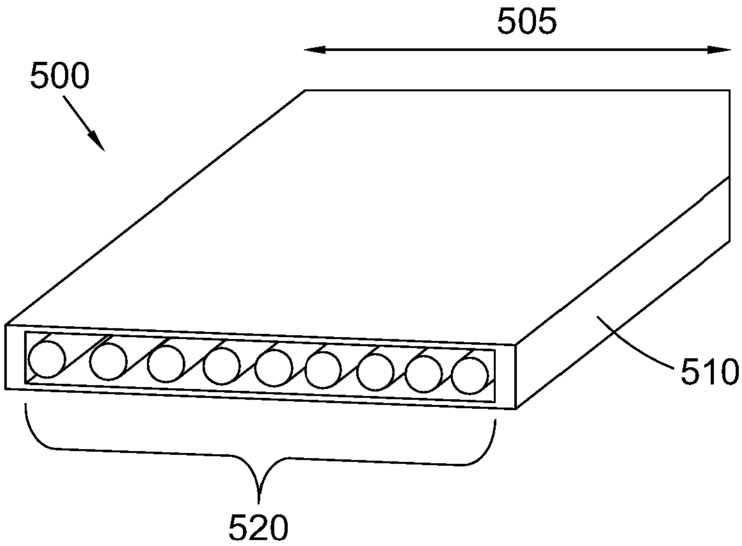

FIG. 5

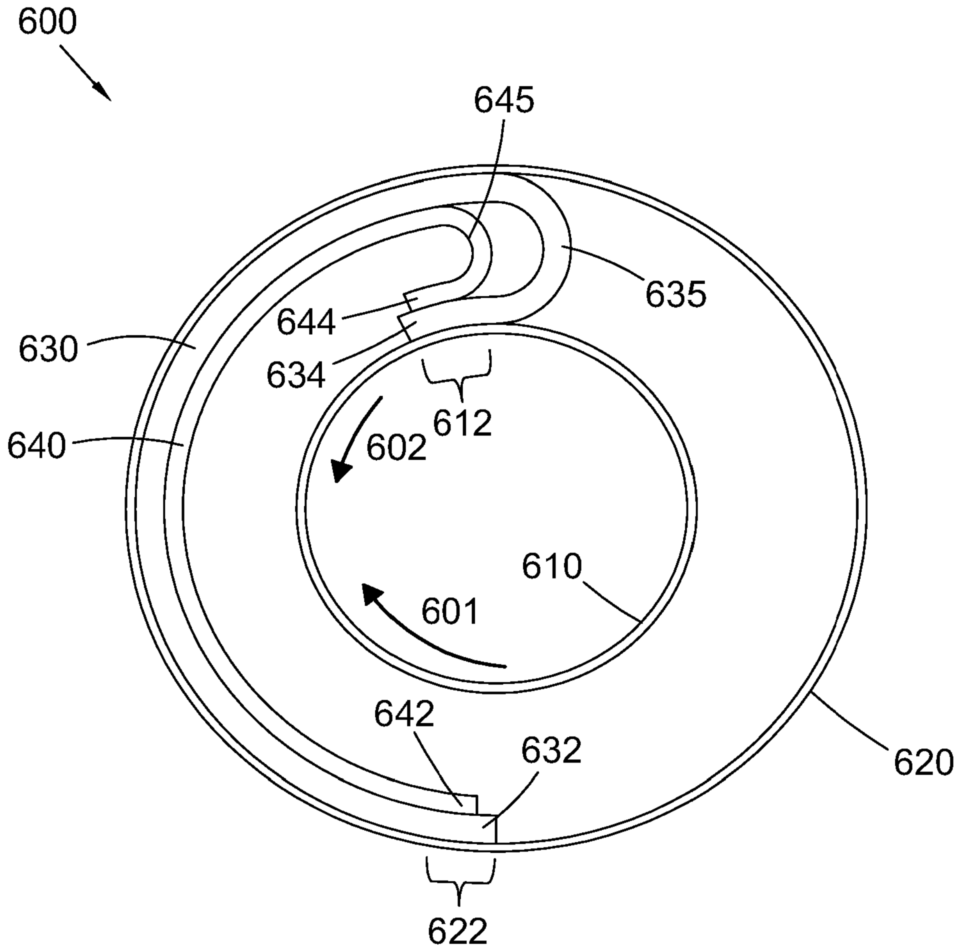

FIG. 6

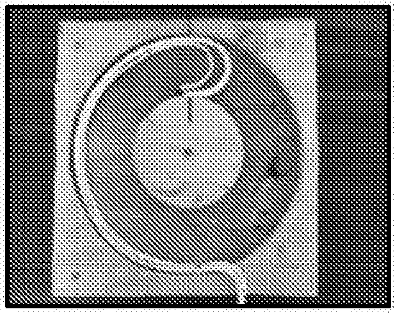

FIG. 7a

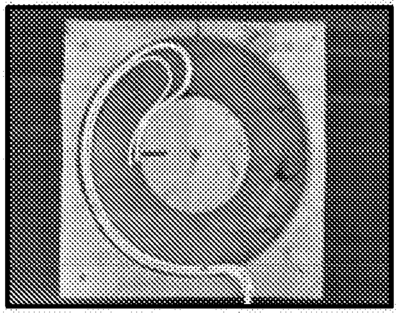

FIG. 7b

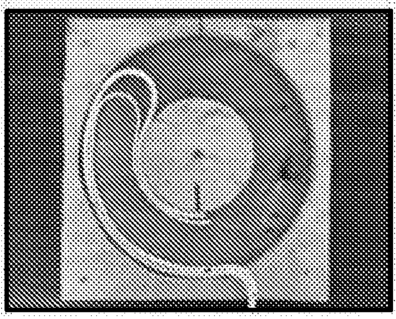

FIG. 7c

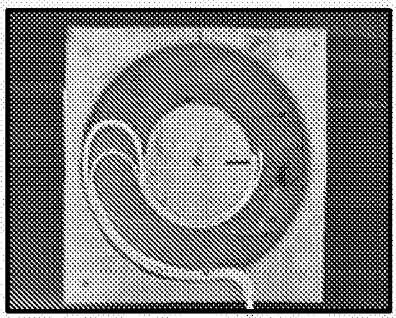

FIG. 7d

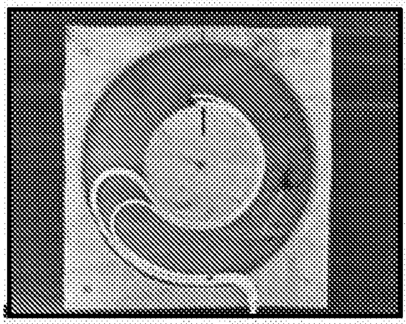

FIG. 7e

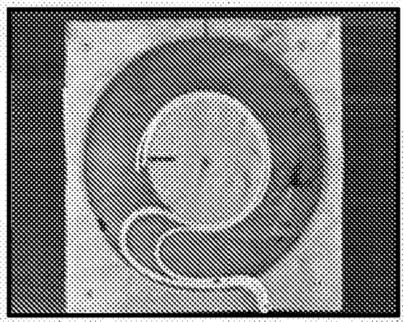

FIG. 7f

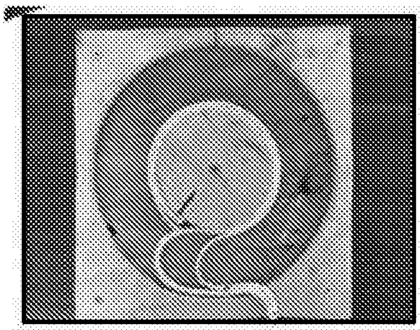

FIG. 7g

28 10 22

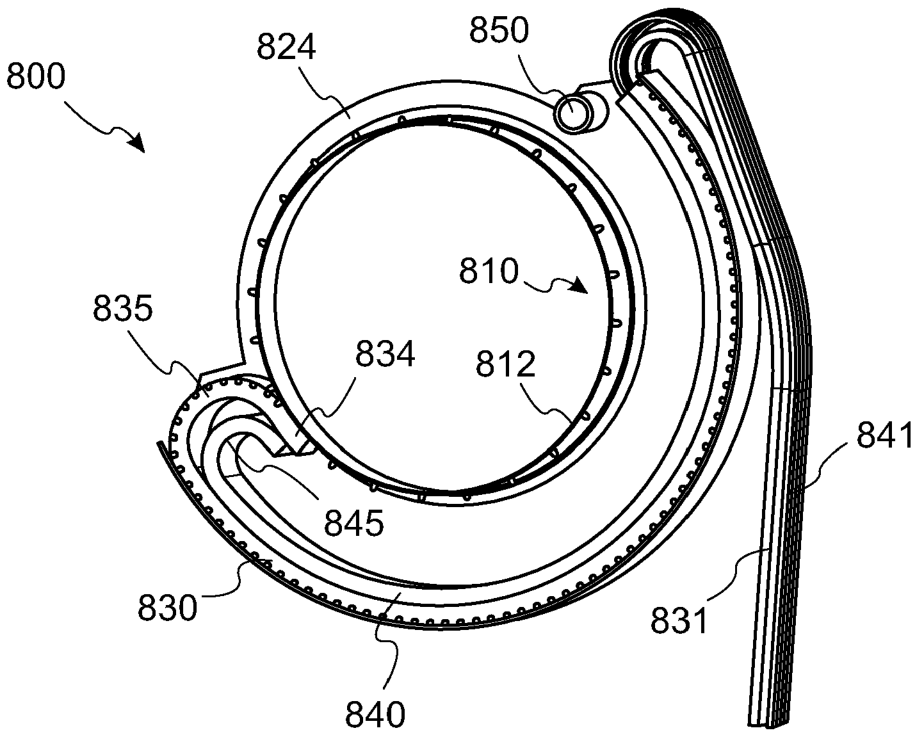

FIG. 8a

28 10 22

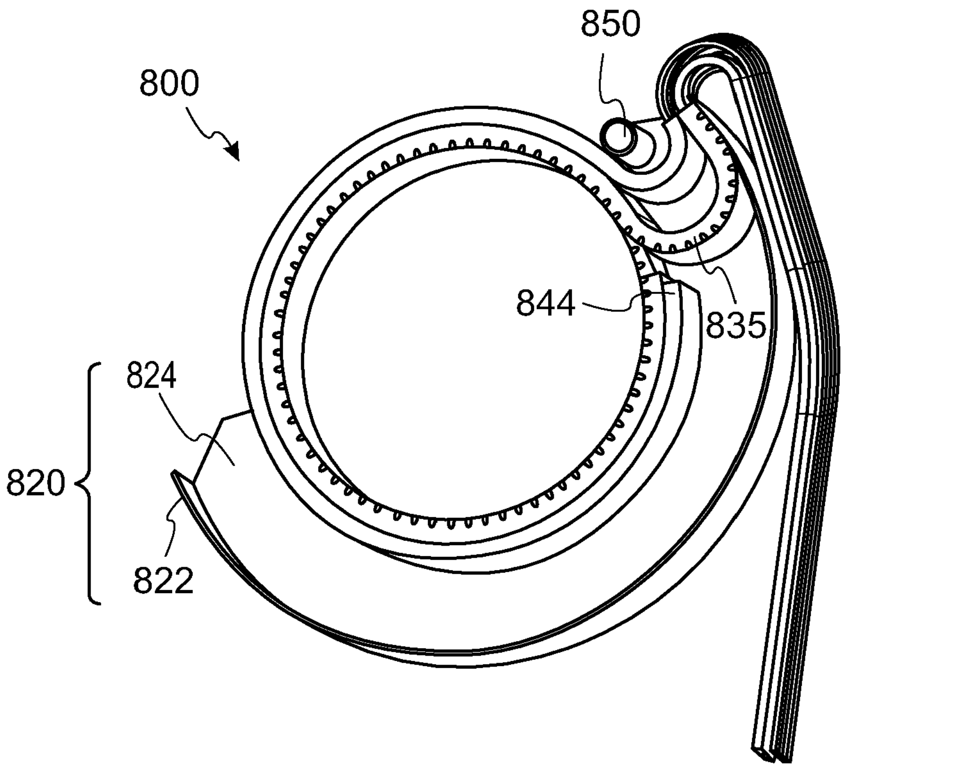

FIG. 8b

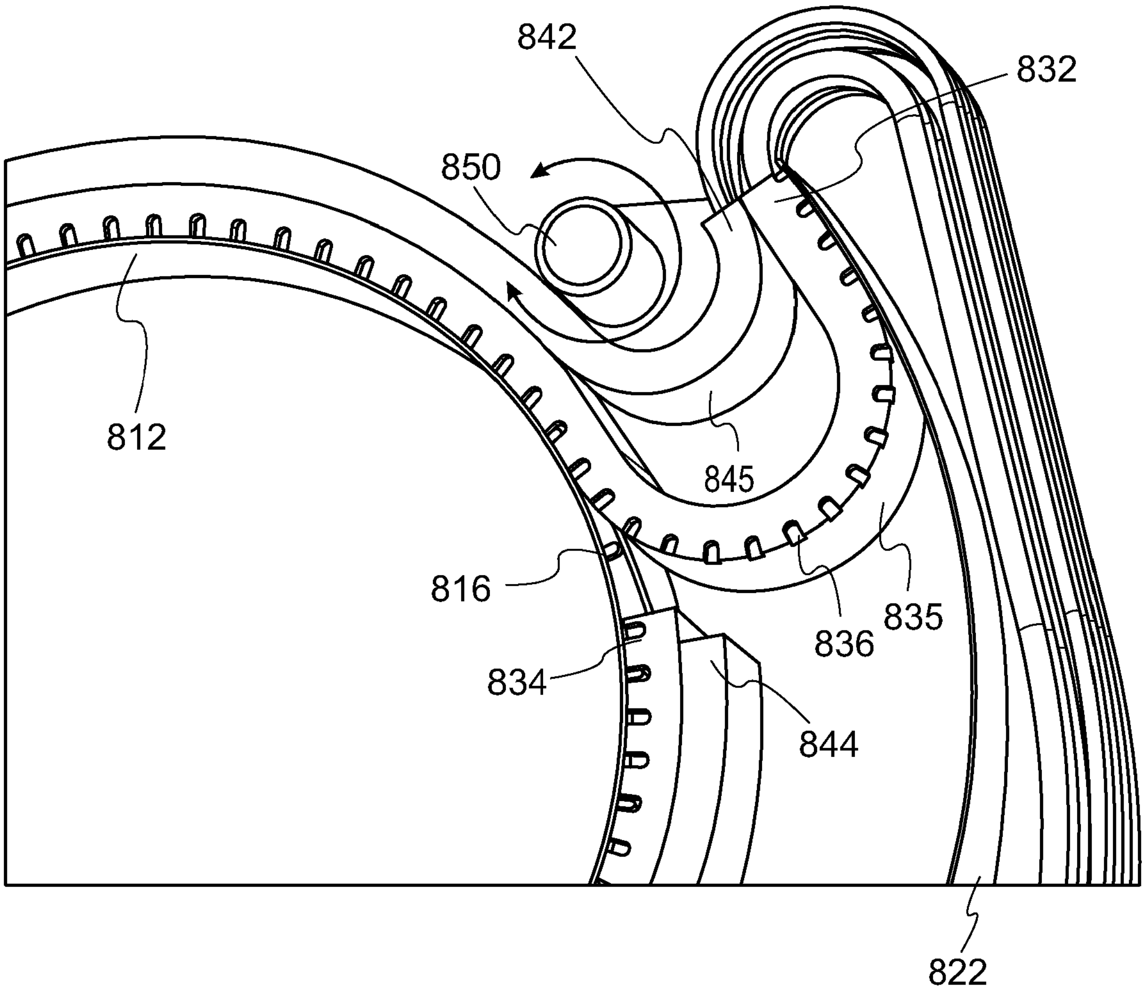

FIG. 8c

28 10 22

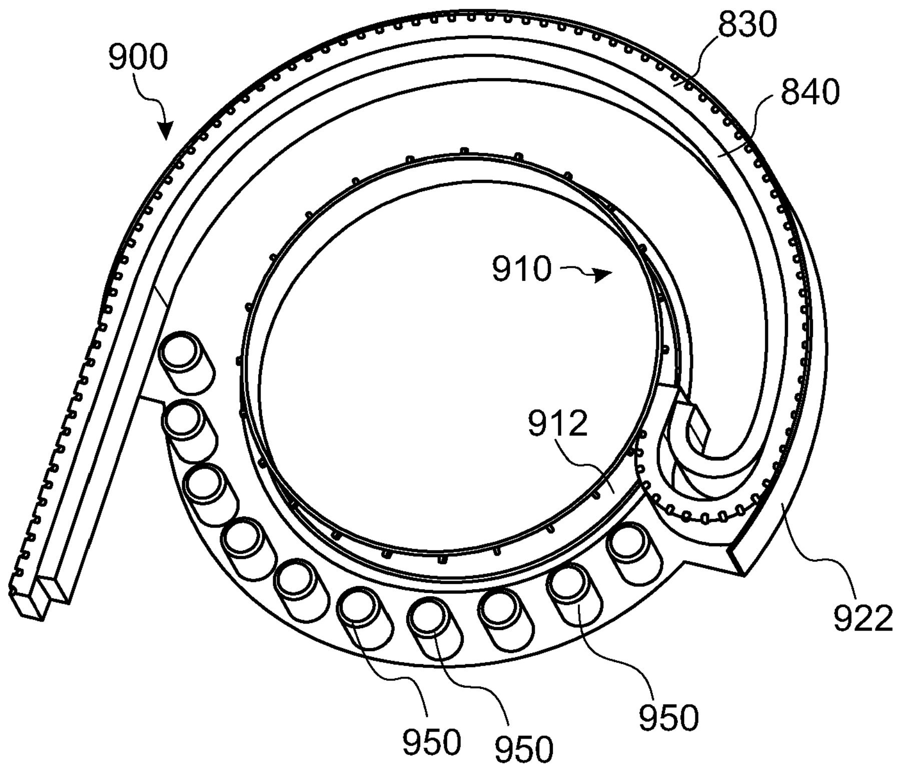

FIG. 9a

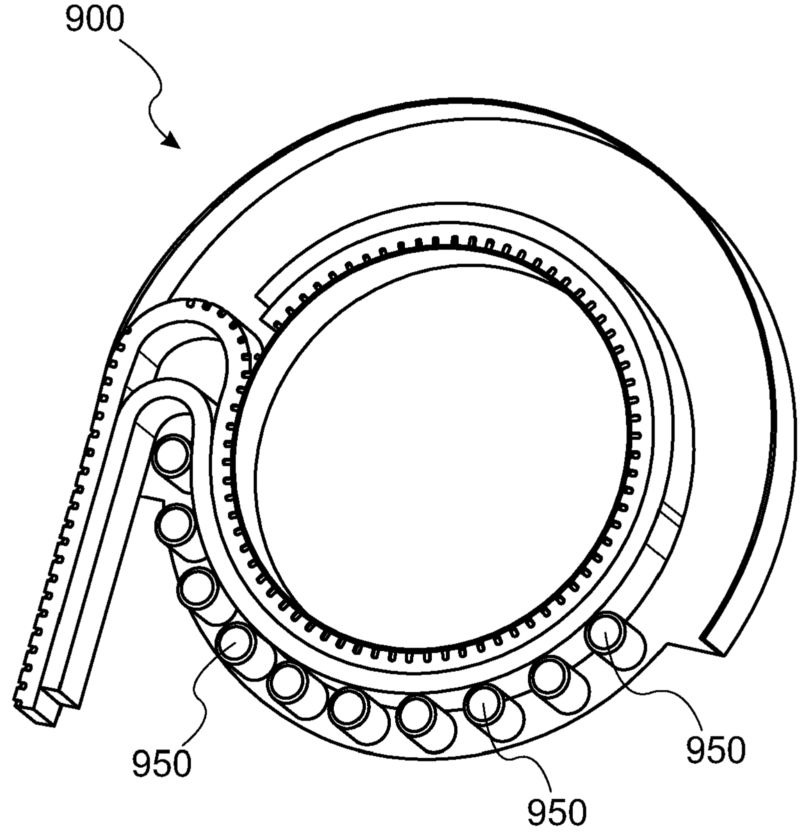

FIG. 9b

28 10 22

Connector management system

This disclosure relates to a connector management system, and in particular to a connector management system for a connector for transferring at least one of power, data, and fluid between a stationary system and at least one rotatable component of a radiotherapy apparatus.

Background

Radiotherapy can be described as the use of ionising radiation, such as X-rays, to treat a human or animal body. Radiotherapy is commonly used to treat tumours within the body of a patient or subject. In such treatments, ionising radiation is used to irradiate, and thus destroy or damage, cells which form part of the tumour.

A radiotherapy device typically comprises a rotatable gantry which supports a beam generation system configured to generate a beam of therapeutic radiation. In such radiotherapy devices, it is often necessary or desirable to transfer signals and power between a stationary off-gantry system and the rotatable on-gantry components. It is known to use slip rings, otherwise known as rotary electrical interfaces, for this purpose.

An alternative to using a slip ring system is to use one or more connectors, such as cables, which connect the stationary off-gantry components with the rotatable on-gantry components. Cables are a reliable, efficient, and cost effective means for transmitting power and signals, and provide a high bandwidth for power and data transfer between the stationary and rotatable components. However, existing designs which make use of cables do not make efficient use of space. In addition, where cables are used, they may be damaged during use unless they are suitably protected and managed by a cable chain, cable ties, or similar cable management system. The length of the cable and the design of such prior cable management systems has, to date, imposed a restriction on the rotational range of the gantry. In fact, most prior radiotherapy systems which make use of cables for power and data transfer are limited to a gantry rotational range of +/- 180 degrees. While this range is acceptable for most radiotherapy treatment, the restriction creates a need to reverse the rotational direction of the gantry when the rotational limit has been reached. This disadvantageously increases the duration of treatment.

It is also advantageous to provide coolant to components located on the rotatable gantry. Several components of a linac device generate heat as they operate, for example transformers, magnets and the components of the beam generation system. Typically, a linac may generate several kWs of heat during beam-on. For such components, it is desirable to provide coolant to the on-gantry component in order to regulate their temperature. However, the transport of fluid onto the gantry is a difficult engineering challenge.

In heat management systems for devices in other technical fields with large rotating parts, such as may be used in industrial machinery, coolant may be transported across a rotating joint. However, this technology is complex, expensive, and is reliant on sliding seals which may develop leaks over time. This is not acceptable in the field of radiotherapy. Furthermore, these sliding seals are particularly ill-suited for the large diameter bores which are required for modern radiotherapy devices. Known solutions in the field of radiotherapy may make use of flexible pipes, though again currently known solutions impose restrictions on the rotational range of the gantry and do not make efficient use of space.

The present disclosure seeks to address these and other disadvantages encountered in the prior art.

Summary

An invention is set out in the claims. Aspects of this invention are set out in the independent claims, and optional features are set out in the dependent claims.

According to a first aspect of the present disclosure, a connector winding system for a radiotherapy apparatus and a radiotherapy apparatus comprising such a system are provided.

The connector winding system is for a radiotherapy apparatus comprising a rotatable gantry. The connector winding system comprises an inner ring structure and an outer member arranged radially outward from the inner ring structure. One of the outer member and the inner ring structure is coupled to the rotatable gantry to rotate therewith such that relative rotation between the inner ring structure and outer member may be effected. The connector winding system comprises a connector having at least a portion of its length arranged between the inner ring structure and the outer member, the connector for use in a connection system configured to transfer at least one of power, data, and fluid between an off-gantry system and at least one on-gantry component. The connector is coupled at an inner portion to the inner ring structure and at an outer portion to the outer member. The connector is wound, with more than one turn, around the inner ring structure to form a spiral shape.

According to a second aspect of the present disclosure, a connector management system for a radiotherapy apparatus and a radiotherapy apparatus comprising such a system are provided.

The connector management system is for a radiotherapy apparatus comprising a rotatable gantry. The connector management system comprises an inner ring structure and an outer member arranged radially outward from the inner ring structure. One of the outer member and the inner ring structure is coupled to the rotatable gantry to rotate therewith such that relative rotation between the inner ring structure and outer member may be effected. The system comprises a plurality of connectors comprising at least a first and a second connector, each connector having at least a portion of its length arranged between the inner ring structure and the outer member, and each of the plurality of connectors for use in a connection system configured to transfer at least one of power, data, and fluid between an off-gantry system and at least one on-gantry component. Each connector of the plurality of connectors has an outer portion and an inner portion and is constrained, at its outer portion, with respect to the outer member to lie in a first rotational direction, and is constrained, at its inner portion, with respect to the inner ring structure to lie in a second rotational direction, such that a curve in each of the plurality of connectors is formed between the outer member and the inner ring structure. The curve of the second connector is arranged inside the curve of the first connector.

Figures

Specific embodiments are now described, by way of example only, with reference to the drawings, in which:

Figure 1 depicts an example of a radiotherapy apparatus according to the present disclosure;

Figures 2a and 2b depict a connector winding system according to the present disclosure;

Figure 3 depicts an overhead view of a radiotherapy apparatus comprising a connector winding system according to the present disclosure;

Figure 4 depicts a portion of a connector according to the present disclosure;

Figure 5 depicts an alternative portion of a connector according to the present disclosure;

Figure 6 depicts a connector management system according to the present disclosure;

Figures 7a-7g depict the connector management system of figure 6 moving through its rotational range;

Figures 8a-8c depict a connector management system according to the present disclosure;

Figures 9a, 9b depict a connector management system according to the present disclosure.

Detailed Description

The present disclosure relates to connector management systems which aim to address the disadvantages in the prior art discussed in the background section, as well as other disadvantages found in prior designs. Different implementations of two systems are disclosed in the present disclosure.

For the purposes of facilitating a quick understanding of these systems, a brief and non-limiting overview of certain implementations of the two systems is provided. Both connector management systems comprise an outer member, such as an outer ring structure, and an inner member, such as an inner ring structure. The inner and outer ring structures may be referred to as drums. One of the outer member and the inner member is coupled to a rotatable gantry of a radiotherapy device, such that relative rotation between the inner member and outer member may be effected as the gantry rotates. At least a portion of the lengths of one or more connectors is positioned between the outer and inner members to form part of a connector system which transports any of power, data, and fluids between an off-gantry system and one or more components located on the rotatable gantry. The connector(s) may be led away from the outer member to connect directly to the off-gantry system, in which case the portion of the length of connector positioned between the outer and inner member is only a portion of the connector's total length. Alternatively, the connector(s) may interface with the outer member to be connected to a different portion of the connection system, which then transports the power, data, and/or fluid from the outer member to the off-gantry system, in which case the length of connector positioned between the inner and outer member may be the total length of the connector.

The first and second systems of the disclosure manage connectors in different ways, but both seek to make more efficient use of available space than prior designs, particularly in an axial direction. Both systems also seek to increase the rotational range available to the gantry from the typical range of +/- 180 degrees found in prior arrangements.

According to a first system of the disclosure, shown primarily in figures 2a and 2b, at least the inner member is a ring structure, and the portion of the connector positioned between the inner and outer member is wound, with more than one turn, around the inner member to form a spiral shape. Thus, the rotational range of the rotatable gantry can be extended significantly compared to prior designs.

According to a second system of the disclosure, shown primarily in figures 6 to 9b, at least the inner member is a ring structure, and a plurality of connectors is provided. A first connector is constrained, at an outer portion, to lie in a first rotational direction with respect to the outer member, for example, along a surface of the outer member. The first connector is further constrained, at an inner portion, to lie in a second rotational direction with respect to the inner ring structure, for example along a circumference of the inner ring structure. A second connector is similarly constrained. For example, the second connector may be constrained, at an outer portion, to lie in the first rotational direction along the outer portion of the length of the first connector and may also be constrained, at an inner portion, to lie in the second rotational direction along the inner portion of the length of the first connector. By virtue of the constraints, each connector is bent back on itself to form a substantially U-shaped curve. By positioning these curves inside one another, a plurality of connectors may be incorporated into the volume between the outer and inner members in a way that makes efficient use of space, and the rotational range of the gantry may be extended significantly in comparison with prior arrangements.

Figure 1 depicts a radiotherapy device suitable for delivering, and configured to deliver, a beam of radiation to a patient during radiotherapy treatment. The device and its constituent components will be described generally for the purpose of providing useful accompanying information for the present invention. The device depicted in figure 1 is in accordance with the present disclosure and is suitable for use with the disclosed systems and apparatuses. While the device in figure 1 is an MR-linac, the implementations of the present disclosure may be any radiotherapy device, for example a linac device.

The device 100 depicted in figure 1 is an MR-linac. The device 100 comprises both MR imaging apparatus 112 and radiotherapy (RT) apparatus which may comprise a linac device. The MR imaging apparatus 112 is shown in cross-section in the diagram. In operation, the MR scanner produces MR images of the patient, and the linac device produces and shapes a beam of radiation and directs it toward a target region within a patient's body in accordance with a radiotherapy treatment plan. The depicted device does not have the usual 'housing' which would cover the MR imaging apparatus 112 and RT apparatus in a commercial setting such as a hospital.

The MR-linac device depicted in figure 1 comprises a source of radiofrequency waves 102, a waveguide 104, a source of electrons 106, a source of radiation 106, a collimator 108 such as a multi-leaf collimator configured to collimate and shape the beam, MR imaging apparatus 112, and a patient support surface 114. In use, the device would also comprise a housing (not shown) which, together with the ring-shaped gantry, defines a bore. The moveable support surface 114 can be used to move a patient, or other subject, into the bore when an MR scan and/or when radiotherapy is to commence. The MR imaging apparatus 112, RT apparatus, and a subject support surface actuator are communicatively coupled to a controller or processor. The controller is also communicatively coupled to a memory device comprising computer-executable instructions which may be executed by the controller.

The RT apparatus comprises a source of radiation and a radiation detector (not shown). Typically, the radiation detector is positioned diametrically opposed to the radiation source. The radiation detector is suitable for, and configured to, produce radiation intensity data. In particular, the radiation detector is positioned and configured to detect the intensity of radiation which has passed through the subject. The radiation detector may also be described as radiation detecting means, and may form part of a portal imaging system.

The radiation source may comprise a beam generation system. For a linac, the beam generation system may comprise a source of RF energy 102, an electron gun 106, and a waveguide 104. The radiation source is attached to the rotatable gantry 116 so as to rotate with the gantry 116. In this way, the radiation source is rotatable around the patient so that the treatment beam 110 can be applied from different angles around the gantry 116. In a preferred implementation, the gantry is continuously rotatable. In other words, the gantry can be rotated by 360 degrees around the patient, and in fact can continue to be rotated past 360 degrees. The gantry may be ring-shaped. In other words, the gantry may be a ring-gantry.

The source 102 of radiofrequency waves, such as a magnetron, is configured to produce radiofrequency waves. The source 102 of radiofrequency waves is coupled to the waveguide 104 via circulator 118, and is configured to pulse radiofrequency waves into the waveguide 104. Radiofrequency waves may pass from the source 102 of radiofrequency waves through an RF input window and into an RF input connecting pipe or tube. A source of electrons 106, such as an electron gun, is also coupled to the waveguide 104 and is configured to inject electrons into the waveguide 104. In the electron gun 106, electrons are thermionically emitted from a cathode filament as the filament is heated. The temperature of the filament controls the number of electrons injected. The injection of electrons into the waveguide 104 is synchronised with the pumping of the radiofrequency waves into the waveguide 104. The design and operation of the radiofrequency wave source 102, electron source and the waveguide 104 is such that the radiofrequency waves accelerate the electrons to very high energies as the electrons propagate through the waveguide 104.

The design of the waveguide 104 depends on whether the linac accelerates the electrons using a standing wave or travelling wave, though the waveguide typically comprises a series of cells or cavities, each cavity connected by a hole or 'iris' through which the electron beam may pass. The cavities are coupled in order that a suitable electric field pattern is produced which accelerates electrons propagating through the waveguide 104. As the electrons are accelerated in the waveguide 104, the electron beam path is controlled by a suitable arrangement of steering magnets, or steering coils, which surround the waveguide 104. The arrangement of steering magnets may comprise, for example, two sets of quadrupole magnets.

Once the electrons have been accelerated, they may pass into a flight tube. The flight tube may be connected to the waveguide by a connecting tube. This connecting tube or connecting structure may be called a drift tube. The electrons travel toward a heavy metal target which may comprise, for example, tungsten. Whilst the electrons travel through the flight tube, an arrangement of focusing magnets act to direct and focus the beam on the target.

To ensure that propagation of the electrons is not impeded as the electron beam travels toward the target, the waveguide 104 is evacuated using a vacuum system comprising a vacuum pump or an arrangement of vacuum pumps. The pump system is capable of producing ultra-high vacuum (UHV) conditions in the waveguide 104 and in the flight tube. The vacuum system also ensures UHV conditions in the electron gun. Electrons can be accelerated to speeds approaching the speed of light in the evacuated waveguide 104.

The source of radiation is configured to direct a beam 110 of therapeutic radiation toward a patient positioned on the patient support surface 114. The source of radiation may comprise a heavy metal target toward which the high energy electrons exiting the waveguide are directed. When the electrons strike the target, X-rays are produced in a variety of directions. A primary collimator may block X-rays travelling in certain directions and pass only forward travelling X-rays to produce a treatment beam 110. The X-rays may be filtered and may pass through one or more ion chambers for dose measuring. The beam can be shaped in various ways by beam-shaping apparatus, for example by using a multi-leaf collimator 108, before it passes into the patient as part of radiotherapy treatment.

In some implementations, the source of radiation is configured to emit either an X-ray beam or an electron particle beam. Such implementations allow the device to provide electron beam therapy, i.e. a type of external beam therapy where electrons, rather than X-rays, are directed toward the target region. It is possible to 'swap' between a first mode in which X-rays are emitted and a second mode in which electrons are emitted by adjusting the components of the linac. In essence, it is possible to swap between the first and second mode by moving the heavy metal target in or out of the electron beam path and replacing it with a so-called ‘electron window’. The electron window is substantially transparent to electrons and allows electrons to exit the flight tube.

The subject or patient support surface 114 is configured to move between a first position substantially outside the bore, and a second position substantially inside the bore. In the first position, a patient or subject can mount the patient support surface. The support surface 114, and patient, can then be moved inside the bore, to the second position, in order for the patient to be imaged by the MR imaging apparatus 112 and/or imaged or treated using the RT apparatus. The movement of the patient support surface is effected and controlled by a subject support surface actuator, which may be described as an actuation mechanism. The actuation mechanism is configured to move the subject support surface in a direction parallel to, and defined by, the central axis of the bore. The terms subject and patient are used interchangeably herein such that the subject support surface can also be described as a patient support surface. The subject support surface may also be referred to as a moveable or adjustable couch or table.

The radiotherapy apparatus / device depicted in figure 1 also comprises MR imaging apparatus 112. The MR imaging apparatus 112 is configured to obtain images of a subject positioned, i.e. located, on the subject support surface 114. The MR imaging apparatus 112 may also be referred to as the MR imager. The MR imaging apparatus 112 may be a conventional MR imaging apparatus operating in a known manner to obtain MR data, for example MR images. The skilled person will appreciate that such a MR imaging apparatus 112 may comprise a primary magnet, one or more gradient coils, one or more receive coils, and an RF pulse applicator. The operation of the MR imaging apparatus is controlled by the controller.

The controller is a computer, processor, or other processing apparatus. The controller may be formed by several discrete processors; for example, the controller may comprise an MR imaging apparatus processor, which controls the MR imaging apparatus 110; an RT apparatus processor, which controls the operation of the RT apparatus; and a subject support surface processor which controls the operation and actuation of the subject support surface. The controller is communicatively coupled to a memory, e.g. a computer readable medium.

The linac device also comprises several other components and systems as will be understood by the skilled person. For example, in order to ensure the linac does not leak radiation, appropriate shielding is also provided.

Figure 3 depicts an overhead view of a radiotherapy apparatus 300 comprising a connector winding system 200, which is depicted in figures 2a and 2b. Like reference numerals refer to like parts in the figures.

Figure 3 depicts a radiotherapy apparatus 300 comprising a gantry 316 and a patient positioning surface 314, which may take a similar form to the gantry 316 and patient positioning surface 314 described above in relation to figure 1. The apparatus 300 further comprises a connector winding system 200, as will be described in greater detail with respect to figure 2. The apparatus 300 comprises an off-gantry system 350 connected to an on-gantry component 360 via a connection system. In the apparatus depicted in figure 3, the connection system comprises a first connector 232 which connects the off-gantry system 350 with the connector winding system 200 . The connection system further comprises a second connector 230 which connects an outer member 220 of the connector winding system 200 to an inner member 210 of the connector winding system 200 in a manner which will be described below. Finally, a third connector 234 connects the connector winding system 200 to the on-gantry component 360.

The radiotherapy apparatus 300 comprises the on-gantry component 360, which is located on the gantry 316 and configured to rotate with the gantry 316. By way of example, the on-gantry component 360 may be any of a beam generation system or its constituent components such as a magnetron and/or an electron gun, and/or beam shaping apparatus such as an MLC or other collimator. The on-gantry component may be a processor or other controller, and / or any of a plurality of sensors configured to monitor the performance of the various on-gantry components. The on-gantry component is configured to rotate with the gantry, for example via its fixed attachment to the rotatable gantry. The fixed attachment can be created via any suitable means, for example screw, bolts, and strong epoxy glues.

The on-gantry component 360 may require power to operate, and this power must be transferred to the on-gantry component 360 from an external power source located off the gantry. The on-gantry component 360 may generate data as it operates. For example, the on-gantry component 360 may be a current sensor configured to monitor the current supplied to the electron gun, in which case it is necessary to transfer the data generated by the on-gantry sensor to an off-gantry processor so that the data can be, for example, recorded, reviewed, and monitored.

The on-gantry component 360 may generate heat during its operation. Several components of a linac device generate heat as they operate, for example transformers, magnets and the components of the beam generation system. It may therefore be desirable to provide coolant to the on-gantry component 360 in order to regulate its temperature.

The radiotherapy apparatus 300 comprises an off-gantry system 350. This off-gantry system 350 may comprise many different components depending on the requirements of the application, for example a CPU configured to control the transmission of power, data and/or fluid to the gantry. The off-gantry system 350 may be connected to an external hospital power and/or water supply. One or more of power, data and fluid may be transferred from the off-gantry system 350 to the on-gantry component 360.

The above examples are given by way of examples only. There may be many components which must be connected to the off-gantry system, and therefore the on-gantry component 360 may be a plurality of on-gantry components, with the plurality of components comprising, for example, any of the examples above.

The on-gantry component 360 is connected to the off-gantry system 350 via a connection system. The connection system may comprise three connectors 232, 230, 234, as shown in figure 3. However, in a simple implementation, the connection system may instead comprises a single connector which links the off-gantry system 350 with the on-gantry component 360. For example, the connector may comprise a pipe which acts as a conduit for fluid to flow between the system 350 and the component 350, or a cable or wire which acts as a conduit for data and/or power to flow between the system 350 and the component 350. In which case, only a portion of the connector's total length is positioned between the inner member 210 and the outer member 220 of the connector winding system 200.

For transferring a fluid, the connection system may comprise valves, regulators, pumps and the like. For transferring power and data, the connection system may comprise various electronic components such as processors, wires, cables, I/O devices, voltage regulators and the like. The invention presented herein is not dependent on specific details of the connection system, and the skilled person will be able to implement a suitable connection system which is suitable for the requirements of the application at hand.

In the implementation depicted in figure 3, the off-gantry system 350 is connected with the connector reeling system 200 cable via a first portion, or first connector, 232 of the connection system to an outer member connection module or interface 222. The power, data and/or fluid is transferred from the outer member connection interface 222 to an inner member connection interface 212 via a second portion, or second connector 230, of the connection system. The second connector 230 is the portion of the cable management or winding system 200 which is positioned between the outer and inner members 210, 220 of the cable management or winding system 220. Then, any of power, data or fluid is transferred from the inner ring structure connection module or interface 212 to the on-gantry component 360 via a third portion, or third connector, 234 of the connection system.

As will be described below, the inner member 210 is rotationally mounted with respect to the outer member 220. The inner member 210 may be fixed to the gantry 316 to rotate with the gantry 316. The outer member 220 remains stationary and is held in position via a suitable support structure (not shown). The support structure fixes the outer member with respect to the ground 240. The inner member 210 may be a rotor ring structure and the outer member may be a stator ring structure.

<u>Connector management system in the form of a winding system – as depicted primarily in figures 2a, 2b</u>

Turning to figures 2a and 2b, these figures depict an implementation of a connector winding system 200 for a radiotherapy apparatus according to the present disclosure. The connector winding system 200 may also be referred to as a connector reeling system herein. Figure 2a depicts the system 200 after the gantry has been rotated in a first direction, and figure 2b depicts the system 200 after the gantry has been rotated in a second, opposite direction. Figures 2a and 2b depict the system without an optional cap 215, which is shown in the top-down view of figure 3.

The connector winding system 200 comprises an inner member in the form of an inner ring structure 210 and an outer member 220. The inner ring structure 210 is arranged radially inwardly from the outer member 220. The outer member 220 is arranged radially outwardly from the inner ring structure 210. One of the inner ring structure 210 and the outer member 220 is rotationally mounted with respect to the other. One of the outer member 220 and the inner ring structure 210 is coupled to, for example mounted to, the rotatable gantry 316 such that it rotates with the gantry 316. In this way, relative rotation between the inner ring structure 210 and outer member 220 may be effected. As the gantry 316 rotates, whichever of the inner ring structure 210 and the outer member 220 is mounted to the gantry is rotated with the gantry 316. In the implementation depicted in the figures, the outer member 220 is an outer ring structure 220. The inner ring structure is coupled with the gantry, and the inner ring structure 210 is coaxially and concentrically arranged with respect to the outer ring structure 220.

The inner ring structure 210 may have a greater axial length than the outer ring structure 220, such that the inner ring structure extends axially outward from the cable winding system 200. The axial dimension is into the page of figures 2a and 2b, and is depicted by arrow 370 in figure 3. This allows the inner ring structure 210 to be mounted to the gantry 316 such that the inner ring structure 210 rotates with the gantry 316.

The connector winding system 200 comprises a connector 230. The connector 230 is for use with, and may form part of, a connection system suitable for transferring at least one of power, data, and fluid between an off-gantry system 350 and at least one on-gantry component 360. The connector 230 has at least a portion of its length between the inner ring structure 210 and the outer member 220. The at least a portion of the length of a connector 230 is therefore the part of the connection system which forms the interface between the stationary and rotating structures. The connector 230 transfers the at least one of power, data, and fluid between the inner ring structure 210 and the outer ring structure 220. The at least a portion of the length of a connector 230 extends between an outer member interface 222, which forms part of the outer member 220, and an inner member interface 212, which forms part of the inner member 210.

In the implementation depicted in figures 2a, 2b, and 3, an annular volume is defined between the outer member 220, which here takes the form of ring structure 220, and the inner ring structure 210. The connector 230, or a portion of its length, is positioned within this volume. The connector winding system 200 may comprise a cap 215 at an axial end of the winding system 200 such that an annular or ring-shaped chamber is defined between the outer ring structure 220, the inner ring structure 210, the cap 215, and the gantry 316. The connector 230 or a portion of its length is wound around the inner ring structure 210 within this annular chamber. The cap 215 may act to prevent the connector from unspooling, which is of particular importance in the absence of cable management in the form of clamps 404 and cable chains.

The cap 215 may be substantially circular, or substantially annular, i.e. ring-shaped. The cap 215 may face away from the radiotherapy apparatus 300 when the winding system is mounted to a radiotherapy apparatus 300. This cap 215 may be a removable cap, and may be affixed to the outer member 220 and/or inner ring structure 210 by suitable attachment means which allow removal of the cap, for example screws. The provision of a removable cap 215 facilitates servicing and repair of the winding system 200.

The inner ring structure 210 is configured to be mounted to the gantry 316 of the radiotherapy apparatus 300. The inner ring structure 210 may be coupled with, mounted to, or fixedly attached to the gantry 316 such that the inner ring structure may rotate with the gantry 316. The gantry 316 may be rotated by a motor, for example the motor of a gantry rotation mechanism (not shown), which is configured to rotate the gantry 316. The rotation imparted to the gantry 316 by the motor is imparted to the inner ring structure 210. The inner ring structure 210 is configured to rotate with respect to the outer ring structure 220, which remains stationary during operation of the connector reeling system 200.

At an inner portion of the connector 230, the connector 230 is coupled to the inner ring structure 210, and at an outer portion of the connector 230, the connector 230 is coupled with the outer ring structure 220. The inner ring structure 210 comprises an inner connection member / connection interface 212 which couples the inner portion of the connector 230 to the inner ring structure 210. The outer ring structure 220 comprises an outer connection member / connection interface 222 which couples the outer portion of the connector 230 to the outer ring structure 220.

For the systems described herein, the gantry has a rotational range. This rotational range extends between a maximum of rotational movement in a first rotational direction and a maximum of rotational movement in a second direction. Figure 2a depicts the system at, or near, its rotational limit in a first rotational direction (anti-clockwise from the view shown in figure 2a), and figure 2b depicts the system at, or near, its rotational limit in a second rotational direction (clockwise from the view shown in figure 2b). Throughout the rotational range of the system 200, the connector 230 forms a spiral shape in the annular volume between the inner and outer members.

The connector 230 is wound around the inner ring structure 210 in a spiral shape. The connector 230 may be referred to as “spiral-wound” and as a spiral-wound rotary connector. The length of connector 230 is such that it is wound more than once around the inner ring structure 210. Herein, a distinction is made between a spiral shape and a helical shape. The connector 230 forms a spiral shape, and hence the connector 230 is wound around the inner ring structure 210 such that the connector 230 emanates radially outward as it winds.

Rotation of the inner ring structure 210 in a first direction relative to the outer ring structure causes the connector 230 to be wound more tightly around the inner ring structure 210, and rotation of the inner ring structure 210 in a second direction relative to the outer member causes the connector 230 to be wound less tightly around the inner ring structure 210.

The connector 230 therefore has more than one turn with respect to the inner ring structure 210. By providing a number of turns which is greater than one, the rotational range of the gantry is increased. In a preferred implementation, the connector has 2 or more turns with respect to the inner ring structure. This allows for continuous rotation by 360°, in at least on direction, when starting from any rotational state of the gantry. Thus, the range of treatment types which the radiotherapy apparatus can provide is increased. In another implementation, the connector has 5 or more turns. This many turns allows for helical treatment to be performed.

Optionally, the connector 230 may comprise one or more resilient elements along its length. The one or more resilient elements extend along the connector 230. The resilient elements may be the constituent units which, together, form a flexible cable chain. These resilient elements are connected together in turn to form a chain. Each element is connected to the next element in line via a hinged connection, which allows the cable chain to form a curve. The hinged connections may allow only a certain range of rotation between each cable chain element. By controlling this range of rotation between each cable chain element, it is possible to provide a cable chain which can be curled tightly around the inner ring structure 230 when the system 200 is rotated in a first direction, but which resists curling when the system 200 is rotated in a second, opposite direction. Therefore, when the system is rotated in the second direction, the connector 230 expands outwards and away from the inner ring structure 210. A similar effect can be achieved by running a length of resilient material along the length of the connector 230 to form a coil spring which resists tightening of the spiral shape.

Figure 4 depicts a section of a connector for use in either the first or the second system disclosed herein. The connector has a width 405. The connector comprises a plurality of conduits. A first fluid conduit 401 carries fluid from the off gantry system, for example from a pumping system, to the gantry 316. The fluid, e.g. coolant, is pumped around various on-gantry components before being carried off the gantry via a second fluid conduit 403. These first and second fluid conduits 401, 403 thus form part of a heat transfer system which keeps components on the gantry at their required operating temperatures. Other fluid conduits, not shown in figure 4, may also form part of the connector 23. For example, conduits may be provided to supply SF6 gas, or another type of dielectric gas, to the radio frequency system which forms part of the beam generation system. This dielectric gas may be pumped into the electron-accelerating waveguide.

The connector also comprises a bundle of conduits 402 in the form of cables. These cables transfer data and/or power between the off-gantry system and the various on-gantry components. By way of an example, the data cables, which may be described as signal cables, may be ethernet network cables, can/bus cables, or hard interlock cables which prevent the radiation beam turning on while the treatment room door is open. The power cables may take the form of mains cables and/or single phase cables. The various conduits 401-403 may be held together via a cable clamp 404.

The conduits which comprise the connector may have an inherent resilience which acts to prevent the connector from being tightly wound. Alternatively, the connector could comprise a support or substrate which provides this resilience. In an implementation in which the connector comprises a cable chain, such as that depicted in figure 5, the cable chai itself may provide this resilience. This resilience acts to increase the distance between coils / turns of the spirally wound connector and hence reduce any damage associated with the turns of the connector rubbing against each other as the gantry is rotated.

Rather than being managed via a cable clamp, the various conduits which form the connector 230 may be managed via a cable chain, as depicted in figure 5 and described in more detail below. The cable chain 510 surrounds the various conduits (cables, pipes) to protect them from wear and tear e.g. due to friction. The conduits 520 may be managed, either via clamps or cable chains, such that they are resistant to movement in an axial direction. The connectors depicted in figures 4 and 5 may be used in any of the systems and implementations described herein.

While the conduits 401-403 are depicted as cables being held together via cable clamps 404 in figure 4, figure 5 shows a connector 500 in which the conduits 520 are instead held together via a cable chain 510. The connector 500 has a width 505 defined by the cable chain 510. The cable chain 510 may be referred to as a cable carrier or a drag chain. The cable chain 510 has an internal section inside which the conduits 520 lie.

In use, for example during radiotherapy treatment, the motor of the gantry rotation mechanism rotates the gantry 316 in order to rotate the beam generation system around a patient in accordance with the requirements of a treatment plan. In an implementation in which the inner ring structure 210 is mounted to the gantry 316, the inner ring structure 210 rotates as the gantry 316 rotates. Rotation of the inner ring structure 210 in a first direction (anti-clockwise from the views depicted in figures 2a and 2b) causes the connector 230 to be wound more tightly around the inner ring structure. Rotation of the inner ring structure 210 in a second direction (clockwise from the views depicted in figures 2a and 2b) causes the connector 230 to be wound less tightly around the inner ring structure 210.

In the present disclosure, the connector may be managed either via a cable chain (as depicted in figure 5) or via a plurality of cable clamps (as depicted in figure 4). The conduits which comprise the connector are managed such that they are each laid flat, in-line with one another and side-by side. This ensures that, as the connector bends as the inner ring structure 210 is rotated, each of the conduits bends at the same radius. Thus, the conduits do not rub against each other during use.

In an implementation comprising resilient elements extending along the connector 230, e.g. the constituent units of a cable chain, as the system 200 is wound in the second direction from the rotational limit shown in constituent units of the cable chain the resilient elements prevent the connector 230 from falling under gravity against the inner ring structure 210. Instead, the turns of the connector 230 increase in radius, and the connector 230 is pushed against the inner surfaces of the outer member 220. The connector 230 is pushed radially outwards as the winding becomes less tight by virtue of the resilient elements. Thus, the spiral shape is maintained, and the connector 230 does not become entangled with itself.

The inner ring structure may have a diameter of ~1m and the outer ring structure may have a diameter of ~3m. The inner and outer members may be made from any suitable material, for example rigid plastic or metal. The structures may be formed of aluminium or steel, or may be formed via known large plastic moulding techniques such as rotational moulding and/or spin moulding. An appropriate material may therefore be spincast polyurethane.

To provide a clear and concise description, reference has been made primarily to an inner ring structure which is rotationally outed with respect to a stationary outer structure. However, in an implementation, the outer structure may be mounted so as to rotate with the gantry, relative to a stationary inner ring structure. In this implementation, the length of connector is still spirally-wound with respect to the inner ring structure as is described above. Accordingly, it will be appreciated that the present disclosure relates to a system wherein one of the outer member and the inner ring structure is mounted to the rotatable gantry such that relative rotation between the inner ring structure and outer member may be effected.

The outer member has been primarily described as a ring structure. However, the outer member may not be ring-shaped, but may be instead take any of multiple shapes. In an implementation, the outer member is U-shaped. The base of the U-shape is positioned substantially underneath the inner ring structure to prevent the connector falling downward under gravity. Similarly, the outer member may be arc-shaped. In each example, the outer member at least partially surrounds the inner ring structure, and is positioned underneath the inner ring structure so as to prevent the connector falling onto the floor and to contain the connector so that it does not become entangled with moving machine parts.

While reference has been made herein to a connector 230 which connects the outer and inner ring structures and which forms part of a connection system, it will be appreciated that the connector 230 may extend from the connector winding system 200. For example, the outer connection module 222 may comprise a clamp or other arrangement for holding a portion of the connector in place and which allows the connector 230 to extend out from the connector winding assembly to connect directly to the off-gantry system 350. In this arrangement, the connector has a portion of its length arranged between the inner and outer ring structures, and another portion of its length is arranged externally to the outer ring structure in order to connect the winding system to the off-gantry system 360. Accordingly, disclosed herein is at least one connector having at least a portion of its length arranged between the inner and outer ring structures, the at least one connector being part of a connection system configured to transfer at least one of power, data, and fluid from a stationary off-gantry system to at least one on-gantry component, the at least a portion of the connector being coupled at a first end to the inner ring structure and at a second end to the outer ring structure. In an implementation, the connector 230 comprises a cable chain formed by a plurality of cable chain units, each connected together to form a hinged connection. The cable chain units at each end of the connector may be screwed, bolted or otherwise fixed directly to the inner and outer members 210, 220, forming the inner and outer connection interfaces 212, 222. An opening in the inner and outer members 210, 220 allows the conduits within the cable chain to run out from the inner and outer members 210, 220 toward the on-gantry component 360 or off-gantry system 350.

The connector 230 may take many forms, for example a multi-core flat connector or cable, and may comprise a plurality of such connectors. The at least one connector 230 may comprise a cable or a plurality of cables for the transfer of power and / or data, or a pipe or other fluid conduit for the transfer of fluid.

Disclosed herein is a connector winding system for a radiotherapy apparatus in which rotation of the gantry in a first direction causes a connector to be wound more tightly around an inner ring structure, and rotation of the gantry in a second direction causes the connector to be wound less tightly around the inner ring structure. This is in contrast with prior cable management systems for radiotherapy devices, which may for example unspool cable onto the floor and create a trip hazard.

Also, by managing the connector by increasing and lessening the tightness of its winding around an inner ring structure as the gantry is rotated, the rotational range of the gantry can be extended compared to known apparatuses while removing the need for a helically wound connector which extends in an axial direction relative to the bore of the radiotherapy apparatus. The effect of this can be appreciated by inspection of figure 3. Arrow 370 depicts the extent of the cable winding system 200 in an axial dimension. The system 200 is significantly shorter in this dimension than if, for example, the cable was wound in a helical shape with an axis parallel to arrow 370, i.e. a helical formation which extends away from the radiotherapy apparatus. Accordingly, the present connector winding system 200 makes efficient use of available space. This is particularly relevant for radiotherapy apparatuses which comprise a ring / donut shaped gantry, in which a circular space with a large diameter can be made available at the rear or front of the gantry. While radial space can be made readily available for the present connector winding system in a radiotherapy apparatus bunker, axial space is significantly more precious. It is generally desirable to reduce the extent of the radiotherapy apparatus in the axial direction because to do so allows you to reduce the size of the treatment room. In other words, the design utilises the diameter rather than the depth of the apparatus, which enables a shorter distance between the isocentre and the backwall, and therefore enables a smaller size of bunker / treatment room.

The connector of the present apparatus and system may be wound more than once around the inner ring structure, and may therefore have more than one turn with respect to the inner ring structure. The connector is wound in a spiral shape around the inner ring structure. Again, this arrangement enables a large rotational range of the gantry while making better use of available radial space and more efficient use of axial space.

In some implementations of the present application, the connector is contained within an annular volume or housed within an annular chamber. This feature ensures better cable management and avoids the connector / cable does not become tangled with other components or form a trip hazard during repair of the device. The annular volume comprises an axial depth which is substantially equal to the width 405 of the length of connector 230.

Connector management system – as depicted schematically in figure 6

A second aspect of the present application relates to a connector management system comprising a plurality of connectors. This aspect is similar in some respects to the first aspect described above in relation to figures 2a-b. According to the second aspect, the inner and outer members are joined via at least two connectors which are constrained in a manner which makes better use of available volume between the inner and outer members than prior designs, and which allows the extension of the rotational range of the gantry while ensuring the connectors behave in a predictable manner throughout the full range of rotational motion.

As described above in relation to figures 4 and 5, conduits such as cables and pipes may be managed via cable clamps or cable chains. Cable chains and clamps may be used to protect the conduits, and to ensure the conduits behave in a predictable and safe way as the gantry rotates. Connectors are used to connect the inner and outer members of the connector management system, in order to allow connection between the stationary and rotatable parts of a radiotherapy device. Connectors may take several forms, for example simply the conduits themselves, the conduits plus one or more cable clamps, or the conduits inside a cable chain.

The conduits are typically positioned side-by-side, e.g. within a cable chain, in a manner which protects the conduits and prevents friction between them. For example, to be positioned in a standard cable chain 510 as depicted in figure 5, the cables and hoses / pipes must be positioned side-by-side, and therefore a very wide cable chain is required if the number of cables and hoses is large. For a typical radiotherapy device, the number of conduits needed is typically very large, as power and coolant must be provided to multiple on-gantry components and large amounts of data and signals must be transferred to and from components located on the gantry.

A first problem that presents itself when using a cable chain for a radiotherapy apparatus is that wide enough cable chains may not exist. In addition, and as described elsewhere herein, space in the axial dimension (i.e. parallel to the gantry rotation axis) is at a premium in radiotherapy treatment rooms. The wide cable chain requires significant space in this axial dimension. The cable chain may be positioned in a connector management system in front of or behind the gantry, in which case the cable chain takes up space in the axial dimension in addition to the space that the gantry takes up. Alternatively, the cable chain may be positioned in a structure around the gantry, thus taking up space around, on, or adjacent to the gantry in which other components could be usefully positioned.

The presently disclosed second aspect of the disclosure addresses this problem by using a plurality of connectors between the outer member and the inner member in a manner which reduces the axial space required for a given number of conduits. For example, if two connectors are used rather than one connector, the width of each connector may be halved compared to a system with just one connector, while retaining the same total number of conduits connecting the off-gantry system with on-gantry components.

Figure 6 depicts a schematic of the connector management system 600 according to the second aspect of the disclosure. The connector management system 600 comprises an inner member in the form of an inner ring structure 610. The connector management system 600 further comprises an outer member in the form of an outer ring structure 620. These inner and outer ring structures 610, 620 may take a similar or identical form as the forms described above with respect to the first aspect of the disclosure, or may take alternative forms (as will be described with respect to figures 8a-c). The connector management structure 600 may be used with the system 300 depicted in figure 3, for example by replacing the system 200 shown in figure 3 with the system 600 of figure 6.

The connector management system 600 is for a radiotherapy apparatus or device which comprises a rotatable gantry. The outer ring structure 620 is arranged radially outward from the inner ring structure 610. One of the outer ring structure 620 and the inner ring structure 610 is coupled to the rotatable gantry to rotate with the gantry. In this manner, relative rotation between the inner ring structure 610 and outer ring structure 620 may be effected by rotating the gantry. Relative rotation may be affected in one of two rotational directions, 601 and 602. In an implementation of the connector management system 600, the inner ring structure 610 is rotatable with respect to the outer ring structure 620. In such an implementation, as depicted in figure 6, the inner ring structure may be rotated both in a first rotational direction 601, in this case clockwise, and in a second rotational direction 602, in this case anti-clockwise. In some implementations, the inner ring structure 610 is fixed to an outer circumference or portion of the gantry so as to rotate therewith, and hence the cable management system 600 may be located around the gantry.

The connector management system 600 comprises a plurality of connectors. Each of the connectors has at least a portion of its length arranged between the inner ring structure 610 and the outer ring structure 620. The plurality of connectors comprises both a first connector comprising such a portion of its length 630, and a second connector comprising such a portion of its length 640. The first and second connectors are for use in a connection system configured to transfer at least one of power, data, and fluid between an off-gantry system and at least one on-gantry component in the manner described above in relation to the first aspect. In some implementations, the connectors extend between the off-gantry system and the on-gantry component(s), and as such only a portion of the total length of each connector is arranged between the inner and outer ring structures 610, 620. However, figure 6 depicts an implementation in which the connectors 630, 640 interface with other components of the connection system (not shown) at the inner and outer ring structures, such that the lengths of connector depicted in figure 6 are the total lengths of the connectors.

Each of the two connectors 630, 640 has an outer portion constrained with respect to the outer ring structure 620, and an inner portion constrained with respect to the inner ring structure 610. The outer regions of the connectors 630, 640 are constrained in a first direction 601, and the inner regions are constrained in a second, different direction 602. These constraints are such that a curve or bend 635, 645 is formed in each connector 630, 640 in the volume between the outer and inner ring structures 620, 630. The curves 635, 645 are present for at least a majority of the rotational range of motion, and preferably for the entire range of motion (as can be appreciated by inspection of figures 7a-7g). The curve 645 of the second connector 640 has a smaller radius of curvature than the curve 635 of the first connector 630 and fits inside the curve 635 of the first connector 630 for at least a majority of the range of rotational motion. The curves 635, 645 are U-shaped, and are formed by bending the connectors 630, 640 back upon themselves. By constraining the connectors such that curves are formed along their length, and such that the curve of a second connector is formed inside, or within, the curve of a first connector, the system 600 makes more efficient use of space between the inner and outer members 810, 820. It is, in part, this more efficient use of space which allows the rotational range of the connector management system to be extended in comparison to known systems.

The first connector 630 (or a length / portion of the first connector 630) has a first end which couples with the outer ring structure 620 and a second end which couples with the inner ring structure 610. The form of these couplings depends on the particular implementation; for example, the coupling at the first end may be a clamping or connection with the outer ring structure 620 which allows the connector to be led away from the outer ring structure for connection with the off-gantry system. Similarly, the coupling at the second end may be a clamping or connection with the inner ring structure 610 which allows the connector to be led away from the inner ring structure 610 for connection with a component on the gantry of the radiotherapy device.

The first connector 630 is constrained, at an outer portion 632 of the first connector 630, with respect to the outer ring structure 620. The outer portion 632 may be constrained to lie along the circumference of the outer ring structure 620, for example along a portion 622 of the inner circumference of the outer ring structure 620. The outer portion 632 of the first connector 630 is constrained to lie in a first rotational direction 601 with respect to the circumference of the outer ring structure 620. The first connector 630 is also constrained, at an inner portion 634 of the first connector 630, with respect to the inner ring structure 610. The inner portion 634 may be constrained to lie along an outer circumference of the inner ring structure 610, for example along a portion 612 of the inner ring structure 610. The inner portion 634 of the first connector 630 is constrained to lie along the circumference of the inner ring structure 610 in a second rotational direction 602. The first connector 630 is constrained with respect to the inner and outer ring structures 610, 620 in different directions, such that the first connector 630 is bent back upon itself within the annular volume defined by the outer and inner ring structures 620, 610.

Similarly, the second connector 640 is constrained, at an outer portion 642 of the second connector 640, with respect to the inner ring structure 610. The outer portion 642 may be constrained to lie along the outer portion 632 of the first connector 630. As with the outer portion 632 of the first connector 630, the outer portion 642 of the second connector 630 is constrained to lie in a first rotational direction 601 with respect to the circumference of the outer ring structure 620. The second connector 640 is also constrained, at an inner portion 644 of the second connector 640, with respect to the inner ring structure 610. The inner portion 644 may be constrained to lie along the inner portion 634 of the first connector 635. The inner portion 644 of the second connector 640 is constrained to lie in the second rotational direction 602 with respect to the inner ring structure 610. The second rotational direction is opposite the first rotational direction. The second connector 640 is constrained with respect to the inner and outer ring structures 610, 620 in different directions, such that the second connector 640 is bent back upon itself within the annular volume defined by the outer and inner ring structures 620, 610.

As can be appreciated from figure 6, the first connector 630 is doubled back on itself to form a first curve 635 by virtue of being constrained in different directions at its outer portion 632 and its inner portion 634. The first connector 630 is constrained with respect to the inner and outer ring structures 610, 620 in different directions, such that the first connector 630 is bent back upon itself within the annular volume defined by the outer and inner ring structures 620, 610. Similarly, the second connector 640 is doubled back on itself to form a second curve 645 by virtue of being constrained in different directions at its outer portion 642 and inner portion 644. Throughout the range of rotational motion, the lengths of connectors move inside the annular volume defined between the inner and outer ring structures 610, 620, though for at least a majority of the range of rotational motion, and preferably throughout the entire range of rotational motion, the second curve 645 is arranged inside the first curve 635. In this way, efficient use is made of available space between the inner and outer ring structure 810, 820

Data, fluid, or power passing from the off-gantry system to the gantry enters the connector management system 600 at a first end of a length of one of the first or second connectors. It travels along the connector and, when the data, fluid of power passes through the connector at the outer constrained portion of the connector, it is travelling in the first rotational direction 601. The data, fluid or power continues to travel along the connector until it reaches the bend / curve in the connector, at which point the direction of flow of the data, fluid or power is doubled back on itself and begins travelling in the second rotational direction 602. When the data, fluid of power passes through the connector at the inner constrained portion of the connector, it is travelling in the second rotational direction 602. The data, fluid, or power continues toward the second end of the length of first or second connector and then toward the on-gantry components.

The direction of constraint should be considered consistently, e.g. by considering the direction of travel of the data, fluid or power being transported by the conduits of the connector either in a direction from the outer ring structure 620 to the inner ring structure 610, or in a direction from the inner ring structure 620 to the outer ring structure 610.

The form of constraint is not depicted in figure 6, but may take multiple forms. The constraints at the inner portions 634, 644 of the connectors 630, 640 may cause the connectors 630, 640 to be fixed with respect to the inner member (e.g. ring structure) 610, for example by virtue of being fixed to the inner ring structure 610. The constraints at the outer portions 632, 642 of the connectors 630, 640 may cause the connectors 630, 640 to be fixed with respect to the outer member (e.g. ring structure) 620, for example by virtue of being fixed to the outer ring structure 620. The constraints may take any suitable form which causes the relevant portions of the connector to be fixed with respect to the inner or outer members.

The constraints may take a simple form, and may be formed for example by cable ties or epoxy glue. In an example where the connectors 630, 640 comprise cable chains, the ends of each cable chain may comprise one or more fixable chain elements. The fixable chain elements may be positioned at each end of the connectors. These fixable chain elements may be fixed to the inner and outer members 610, 620, for example by screws or rivets. In such an implementation, each connector comprises a first fixable cable element at its inner portion and a second fixable cable elements at its outer portion. In an example, the fixable cable elements of the first connector are fixed, for example via screws, to both the inner and outer member, whereas the fixable cable elements of the second connector may be fixed to the fixable cable elements of he first connector. The fixable cable elements may each be one of a plurality of cable elements which together form the cable chain. As described above, bendable cable chains may be formed by connecting together a plurality of cable elements. These cable elements are connected together in turn, side-by-side, in a known manner to form the cable chain. Each element is connected to the next element in line via a hinged connection, which allows the cable chain to bend and form a curve.

Figures 7a-7g depict the system of figure 6 travelling through its range of rotational motion. Figure 7a depicts the system 600 at, or near, a limit of rotational motion in the first rotational direction 601. Figure 7g depicts the system 600 at, or near, a limit of rotational motion in the second rotational direction 602. Figures 7b-f depict rotation of the inner ring structure in the second rotational direction 602 (anti-clockwise) at approximately 90° intervals. As will be appreciated, the range of rotational motion is approximately 480°. This range of rotation is significantly greater than known cable management systems for radiotherapy machines.

Figures 8a to 8c show a connector management system 800. System 800 is similar in form and function to the system depicted in the schematic diagrams of figures 6 and 7a-g. Figure 8a depicts the system 800 at, or near, a limit of rotational motion in the first rotational direction (clockwise). Figure 8a thus approximately corresponds with the configuration of the system depicted in figure 7a. Figure 8b depicts the system 800 at, or near, a limit of rotational motion in the second rotational direction (anti-clockwise). Figure 8b thus approximately corresponds with the configuration of the system depicted in figure 7g. Figure 8c depicts a roller and engagement features of the system 800 in more detail.

Connector management system 800 comprises an inner member 810 and an outer member 820. Inner member 810 may be described as a ring structure, and comprises an inner curved wall 812. The inner curved wall 812 has a centre of curvature. Outer member 820 may also be described as a ring structure. Outer member 820 comprises an outer curved wall 822 and a radially extending substantially annular support surface 824. The inner and outer curved walls have the same centre of curvature, though the outer curved wall 822 has a larger radius of curvature than the inner curved wall 812. The curved walls extend in an axial direction. Support surface 824 extends from the outer curved wall 822 in a radial direction toward the inner ring structure 810. The inner ring structure 810 is coupled with the gantry of a radiotherapy device (not shown) so as to rotate therewith. The inner ring structure 810 is configured to rotate with respect to the outer curved wall 822 and support surface 824, and the other features of the outer ring structure 820.

As with system 600, system 800 comprises a plurality of connectors, each with at least a portion of their length arranged between the inner and outer members 810, 820. In the implementation depicted in figures 8a-8c, a length of a first connector 830 and a length of a second connector 840 are positioned between the inner and outer members 810, 820. Figures 8a-c also depict the conduits of each connector extending away from the connector management system 800 for connection with the off-gantry heat transfer system (not shown). The conduits 831 form part of the first connector, and the conduits 841 form part of the second connector.

As described above in relation to figure 6, each connector 830, 840 is constrained with respect to the inner member 810 and the outer member 820 such that a bend / curve 835, 845 is formed. An outer portion 832 of the first connector 830 is constrained to lie in a first rotational direction with respect to the outer ring structure 820. An outer portion 842 of the second connector 840 is also constrained to lie in the first rotational direction with respect to the outer ring structure 840. An inner portion 834 of the first connector 830 is constrained to lie in a second rotational direction with respect to the inner ring structure 810. An inner portion 834 of the second connector 840 is also constrained to lie in the second rotational direction with respect to the inner ring structure 810. The first connector 830 comprises a first curve 835, which has a larger radius of curvature than a second curve 845 formed by the second connector 840. The second curve 845 is arranged within the first curve 835, thereby making more efficient use of available space between the inner and outer members 810, 820 and thereby extending the rotational range of the connector management system 800.

The outer portion 832 of the first connector 830 and the outer portion 842 of the second connector 840 are both depicted in figure 8c. These outer portions 832, 842 are constrained with respect to the outer ring structure 820, and in particular are constrained with respect to the outer curved wall 822. It can be appreciated that the outer portion 832 of the first connector 830 is constrained to lie in a first rotational direction along a circumference of the outer member 820, and in particular to lie in a first rotational direction along an outer curved wall 822 of the outer member 820. The outer portion 842 of the second connector 840 is also constrained with respect to the outer ring structure 820, and in particular is constrained to lie along the outer portion 832 of the first connector 830.

The inner portion 834 of the first connector 830 and the inner portion 844 of the second connector 840 are also depicted in figure 8c. These inner portions 834, 844 are constrained with respect to the inner ring structure 810, and in particular are constrained with respect to the inner curved wall 812. It can be appreciated that the inner portion 834 of the length 830 of the first connector is constrained to lie in a second rotational direction along a circumference of the inner member 810, and in particular to lie in a second rotational direction along the inner curved wall 812 of the inner member 810. The inner portion 844 of the second connector 840 is also constrained with respect to the inner ring structure 810, and in particular is constrained to lie along the inner portion 834 of the first connector 830.

The connector management system 800 also comprises at least one roller 850 configured, and positioned, to press the plurality of connectors against the inner ring structure 810, and in particular against the inner curved wall 812. The roller 850 is substantially cylindrical, with an axis along its length that extends in an axial direction from the support surface 824. The roller 850 is configured to rotate, and has an axis of rotation which aligns with its length axis. The rotational axis of the roller 850 is parallel to a rotational axis of the rotatable gantry. This rotation is depicted via an arrow in figure 8c.

In the implementation of figures 8a-8c, the roller 850 is positioned between the inner ring structure 81 and the outer portions 832, 842 of the first and second connectors 830, 840. This positioning allows the connectors 830, 842 to behave in the manner depicted in figures 7a-g during the range of rotational motion meaning that this positioning of the roller 850 does not impede motion of the connectors 830, 840 during rotation.

The roller 850 serves to ensure the connectors are pressed tightly against the inner ring structure 810 while the system 800 rotates. The roller 850 serves to prevent detachment of the connectors 830, 840 and prevents friction between them. This in turn not only reduces wear, but also the noise of the system 800 during operation. Reducing noise is of paramount importance for radiotherapy devices in order to increase patient comfort.

As can best be seen in figure 8c, as the inner ring structure 810 rotates, the connectors 830, 840 are compressed as they pass between the inner ring structure 810 and the roller 850. In some implementations, the roller 850 is passive, and is caused to rotate by friction with the connectors 830, 840 as they pass through the gap defined between the inner ring structure 810 and the roller 850.

In other implementations, the connector management system 800 further comprises an actuator / actuation mechanism configured to drive rotation of the roller 850. In this implementation, the roller 850 is driven in order to help pull the connectors 830, 840 as the system 800 rotates, and thus take load away from other areas of the system 800, and in particular away from the inner and outer constrained portions of the connectors 830, 840. The actuator is configured to drive rotation of the roller at the same, of a greater, rotational speed as the rotatable gantry, but in the opposite rotational direction as the rotatable gantry. In an implementation, an electric motor drives the roller

850 at slightly higher rotational speed than the gantry and thereby acts to pull the connectors 830, 840 as the gantry rotates. Alternatively, roller 850 could also be driven by a gear transmission from the rotation of the inner drum / member 810.

The cable management system of the second aspect will likely be positioned vertically in use, i.e. when coupled to a radiotherapy device. This means that the rotation axis of the relative rotation between the outer and inner members will be substantially horizontal. This rotation axis may be parallel with, or possibly aligned with, the rotational axis of the gantry of the radiotherapy device. Designing a cable management system suitable to be used with a radiotherapy device and thus positioned vertically in this manner presents significant design challenges. Several features shown in figures 8a-c assist with this vertical positioning, for example the outer curved wall 822, the roller 850, and engagement features 816, 817.

The outer curved wall 822 extends underneath the inner ring structure 810. This allows the outer member 820 to bear the weight of the connectors 830, 840 during certain regions of the range of rotational motion. This is depicted in figure 8a. The outer curved wall 822 also extends around the inner ring structure 810 to a point located above a majority of the inner ring structure. In other words, the outer curved wall 822 extends around the inner ring structure 810 to a point above the centre of curvature of the inner ring structure 810. The outer portions 832, 842 of the connectors 830, 840 are constrained at a region of the outer curved wall 822 above the centre of curvature of the inner ring structure 810. The outer curved wall 822 may not extend around the entire inner ring structure 810. The curved outer wall 822 may define a portion of a full circumference of a circle. This implementation of a curved wall 822, as depicted in figures 8a-8c, means that the connector s 830, 840 are supported throughout the range of motion of the system 800 by either the outer member 820 or the inner ring structure 810.

By providing an outer curved wall 822 in the form depicted in figures 8a-c which does not extend completely around the inner ring structure 810, the system 800 makes more efficient use of space than prior devices. The space directly above the inner ring structure and to the upper left of the inner ring structure (from the view depicted in the figures) can be used for other components of the radiotherapy device.

A system 800 according to the second aspect of the disclosure may also comprise engagement features, which act to increase engagement between the inner ring structure 810 and the connectors 830, 840. The engagement features 816, 836 help reduce the likelihood that the connectors 830, 840 will detach from the central inner ring structure 810 when the system 800 is stood up, i.e. positioned vertically, in use on a radiotherapy device.

The connector management system 800 depicted in figures 8a-c comprises a first set of engagement features 816 and a second set of engagement features 836. The first set of engagement features 816 take the form of extensions formed on the inner ring structure 810. The extensions extend outwards from an outer rim, or outer circumference, of the inner ring structure 810. The extensions depicted in figures 8a-c are spaced regularly and equally around the circumference of the inner ring 810. The second set of engagement features 836 are formed on the length 830 of the first connector, and take the form of notches. The notches are sized and positioned so as to engage with the extensions.

To facilitate the understand of the function of each component depicted in figures 8a-c, the system 800 will now be described in use. The system 800 as depicted in figure 8a is at, or near, its rotational maximum in a first direction (clockwise from the view depicted in figure 8a). The majority of the weight of the connectors 830,840 is being supported by the curved wall 822 of the outer member 820. During radiotherapy treatment, the gantry (not shown) is rotated in order to adjust the relative positioning of the radiation source and the patient. By virtue of the coupling of the gantry to either the inner ring structure 810 or the outer member 820, relative rotation between these components is effected. Considering an implementation in which the gantry is coupled to the inner ring structure: as the gantry rotates in the second direction (anticlockwise), the inner ring structure 820 also rotates anticlockwise. The first and second connectors 830, 840 are constrained, at their respective inner portions 834, 844, with respect to the inner ring structure 810 and thus rotate with the inner ring structure 810.

As the inner ring structure 810 rotates in the second direction, the length 830 of first connector is peeled away from the outer member 820, and in particular from the outer curved wall 822. By virtue of the resilience of the lengths 830, 840 of connector, the connectors 830, 840 are pressed against the inner ring structure 810 as it rotates. An increasing number of extensions 816 of the inner ring structure 810 are pressed into the notches 836 of the first connector 830 as the inner ring structure 810 rotates in the second direction. Thus, the connectors 830, 840 are engaged with the inner ring structure 810 as it rotates, and the weight of the connectors 830, 840 is not borne only by the constraints at the inner portions 834, 844 of the connectors 830 840. As the gantry continues to rotate in the second rotational direction, the inner portions 834, 844 reach the roller 850, which further acts to increase the engagement of the connectors 830, 840 with the inner ring structure 810 by pressing the connectors 830, 840 against the inner ring structure 810. By keeping the connectors 830, 840 engaged with and/or pressed against the inner ring structure 810 during rotation, the weight of the connectors 830, 840 is managed throughout the full range of rotational motion of the system 800 and detachment of the connectors from the inner ring structure 810 or outer member 820 is avoided. The constraints, engagement features and roller each also act to prevents friction between the connectors 830, 840. This reduces wear and damage to the connectors and reduces noise. In an implementation where the roller 850 is driven in the opposite direction as the gantry as the gantry rotates, the roller 850 also assists in pulling the connectors 830, 840, taking further strain away from the inner portions 834, 844 of the connectors 830, 840.

As the inner ring structure 810 continues to rotate in the second direction, it is increasingly the inner ring structure 810 which supports the weight of the connectors 830, 840. Eventually, the system 800 will reach the configuration depicted in figure 8b, in which the system 800 is at or near its maximum rotation in the second direction. As will be appreciated, the system 800 can achieve over 360° of rotation, and in fact can achieve approximately 480° of rotation.

While the second aspect of the disclosure is primarily described as having two connectors each with a length between the inner and outer member, a system according to the second aspect could incorporate three, or more, connectors. Such a system would comprise a plurality of connectors, each connector having a length arranged between the inner ring structure and the outer member. A third connector could be added to the implementations depicted in figures 6-9, by constraining an outer and inner portion of the third connector with respect to the inner and outer members such that the length of the third connector forms a curve inside the curve of the length of the second connector. In fact, a large number of connectors could be incorporated into the system by constraining each connector in the manner described herein such that each subsequent curve, or bend, in a connector fits inside the curve of the previous connector.

Figures 7a-7g and 8a-8c depict a particular implementation of the second aspect of the disclosure in which, at the system's rotational limit in a first direction (figures 7a, 8a) the inner and outer portions of the connectors are separated by approximately 180°, and at the opposing rotational limit, in the second direction (figures 7g, 8b), the inner and outer portions of the connectors are separated by 60° or less, having travelled through a rotational range of approximately 480° or more. This placement of the points at which the connectors are connected to / fixed to the inner and outer drums is advantageous because it allows for a large rotational range, while ensuring that the connectors are well-supported throughout that range, e.g. by the curved wall 822 as shown in figure 8b. However, other connection points have been considered by the present inventor. The skilled person will understand, given the teaching of the present disclosure, that the connection points can be adjusted according to the design requirements of the particular implementation. Therefore, the figures should not be considered as limiting in this regard.

Figures 8a-8c depict an implementation showing multiple features which act to manage the connectors during relative rotation of the inner and outer members, and in particular to manage the weight of the connectors as the system moves through its rotational range. These features include a roller and engagement features such as extensions and notches. While these features are advantageous, it should be noted that they are optional. Further, while an implementation is shown which incorporates both a roller and the engagement features, possible implementations in which only the roller or only the engagement features, are included are also possible.

In implementations of the second aspect of the disclosure, relative rotation between the inner and outer members is effected. While reference has been primarily made to coupling the inner member to the rotatable gantry such that the inner member rotates inside and with respect to the outer member, it should be understood that the alternative implementation in which the outer member is coupled to the gantry so as to rotate therewith is equally possible.

Engagement features taking the form of extensions and notches have been described herein. Extensions may take the form of teeth, or sprockets. The notches may take the form of recesses, or holes. The engagement features could also take other forms, for example magnets. For example, magnets may be positioned along the inner circumference of the inner member (e.g. ring structure), and the connector may be ferro magnetic. This may be achieved by utilising ferromagnetic cable chains. Engagement features may also be provided between each connector, for example on the first and second connector, in order to increase the engagement between the first and second connector. By keeping the connectors tight against one another,

Figures 9a and 9b depict a second implementation according to the second aspect of the disclosure. Figures 9a-9b depict a connector management system 900 in which the weight of the connectors 830, 840 is supported by a plurality of rollers 950. System 900 is similar in form and function to system 800 and the functions of each feature will not be described again in order to avoid duplication. For clarity of illustration, not all rollers depicted in figures 9a and 9b are labelled as 950. The rollers 950 are identical in form and function to roller 850 described in relation to figures 8a-c, though are positioned underneath the inner ring structure 910 in order to support the connectors 930, 940 throughout at least part of the range of rotation motion of the system 900. The rollers 950 are configured to bear the load of the plurality of connectors.

The following numbered examples are disclosed herein. The examples relate primarily, though not necessarily exclusively, to the connector management system in the form of a winding system depicted primarily in figures 2a, 2b.

1. A connector winding system for a radiotherapy apparatus comprising a rotatable gantry, the connector winding system comprising:

an inner ring structure and an outer member arranged radially outward from the inner ring structure, wherein one of the outer member and the inner ring structure is coupled to the rotatable gantry to rotate therewith such that relative rotation between the inner ring structure and outer member may be effected;

a connector having at least a portion of its length arranged between the inner ring structure and the outer member, the connector for use in a connection system configured to transfer at least one of power, data, and fluid between an off-gantry system and at least one on-gantry component, the connector being coupled at an inner portion to the inner ring structure and at an outer portion to the outer member; and

wherein the connector is wound, with more than one turn, around the inner ring structure to form a spiral shape.

2. The connector winding system of example 1, wherein the length of connector is wound, with more than one turn, around the inner ring structure to form a spiral shape such that each subsequent turn of the length of connector has a greater radius than the previous turn.

3. The connector winding system of example 1 or example 2, wherein the outer member at least partly surrounds the inner ring structure.

4. The connector winding system of any preceding example, wherein the outer member is substantially U-shaped or arc-shaped.

5. The connector winding system of any preceding example, wherein rotation of the gantry in a first direction causes the connector to be wound more tightly around the inner ring structure, and rotation of the inner ring structure in a second direction relative to the outer ring structure causes the connector to be wound less tightly around the inner ring structure.

6. The connector winding system of any preceding example, wherein the inner ring structure is mounted to the gantry to rotate with the gantry and with respect to the outer member.

7. The connector winding system of any preceding example, wherein the outer member is an outer ring structure.

8. The connector winding system of example 7, wherein the inner and outer ring structures define an annular volume therebetween, and the at least a portion of the length of the connector is arranged in the annular volume.

9. The connector winding system of example 7 or example 8, wherein the inner and outer ring structures are coaxially arranged with respect to one another.

10. The connector winding system of any preceding example, wherein the outer member is stationary during use of the connector winding system.

11. The connector winding system of any preceding example, where the connector forms part of the connection system.

12. The connector winding system of any preceding example, the connector comprising a plurality of conduits, each configured to transfer at least one of power, data, and fluid between the outer member and the inner ring structure.

13. The connector winding system of example 12, wherein the plurality of conduits comprises a first conduit and a second conduit, and the at least one on-gantry component comprises a first on-gantry component and a second on-gantry component;

    the first conduit being configured to transfer at least one of power and data between the off-gantry system and the first on-gantry component; and

    the second conduit being configured to transfer fluid between the off-gantry system and the second on-gantry component.

14. The connector winding system of any preceding example, further comprising a cap positioned at a first axial end of the outer ring structure and a second cap positioned at a second axial end of the outer ring structure, wherein an annular chamber is defined between the inner and outer ring structures and the first and second cap; and the at least a portion of the at least one connector is arranged in the annular chamber.

15. The connector winding system of example 14, wherein the annular volume comprises an axial depth which is substantially equal to the width of the connector.

16. The connector winding system of any preceding example, wherein the inner ring structure comprises an inner connection interface which couples with the inner portion of the connector ; and / or wherein the outer member comprises an outer connection interface which couples with the outer portion of the connector.

17. A radiotherapy apparatus comprising a connector winding system according to any preceding example.

18. The radiotherapy apparatus of example 17, wherein the inner ring structure is mounted to the rotatable gantry so as to rotate therewith.

19. The radiotherapy apparatus of example 17 or example 18, further comprising a motor to effect rotation of the inner ring structure with respect to the outer ring structure.

20. The radiotherapy apparatus of example 17, 18 or 19, wherein the motor is configured to rotate the gantry, to thereby effect relative rotation between the inner ring structure with respect to the outer member.

21. The radiotherapy apparatus further comprising the off-gantry system, the at least one on-gantry component, and the connection system.

It is to be understood that the above description is intended to be illustrative, and not restrictive. Many other implementations will be apparent to those of skill in the art upon reading and understanding the above description. Although the present disclosure has been described with reference to specific example implementations, it will be recognized that the disclosure is not limited to the implementations described, but can be practiced with modification and alteration within the spirit and scope of the appended claims. Accordingly, the specification and drawings are to be regarded in an illustrative sense rather than a restrictive sense. The scope of the disclosure should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

Claims

1. A connector management system for a radiotherapy apparatus comprising a rotatable gantry, the connector management system comprising:

an inner ring structure and an outer member arranged radially outward from the inner ring structure, wherein one of the outer member and the inner ring structure is coupled to the rotatable gantry to rotate therewith such that relative rotation between the inner ring structure and outer member may be effected;

a plurality of connectors comprising at least a first and a second connector, each connector having at least a portion of its length arranged between the inner ring structure and the outer member, each of the plurality of connectors for use in a connection system configured to transfer at least one of power, data, and fluid between an off-gantry system and at least one on-gantry component;

wherein each connector of the plurality of connectors has an outer portion and an inner portion and is constrained, at its outer portion, with respect to the outer member to lie in a first rotational direction, and is constrained, at its inner portion, with respect to the inner ring structure to lie in a second rotational direction, such that a curve in each of the plurality of connectors is formed between the outer member and the inner ring structure; and

wherein the curve of the second connector is arranged inside the curve of the first connector; wherein the inner ring structure comprises a first set of engagement features and at least one of the connectors comprises a second set of engagement features, wherein the first set of engagement features is configured to engage with the second set of engagement features during rotation of the gantry.

2. The connector management system of claim 1, wherein the plurality of connectors further comprises a third connector, wherein the curve of the third connector is arranged inside the curve of the length of the second connector.

3. The connector management system of any preceding claim, wherein the first connector is:

constrained, at its outer portion, to lie in the first rotational direction along a surface of the outer member; and

constrained, at its inner portion, to lie in the second rotational direction along a circumference of the inner ring structure.

4. The connector management system of any preceding claim, wherein the second connector is:

constrained, at its outer portion, to lie along the outer portion of the first connector; and

constrained, at its inner portion, to lie along the inner portion of the first connector.

5. The connector management system of any preceding claim, wherein the inner ring structure is coupled to the gantry and is configured to rotate with respect to the outer member.

6. The connector management system of any preceding claim, further comprising at least one roller configured and positioned to press the plurality of connectors against the inner ring structure during at least part of a range of motion of the system.

7. The connector management system of claim 6, wherein the at least one roller is positioned between the inner ring structure and the constrained outer portions of the plurality of connectors.

8. The connector management system of claim 6 or claim 7, wherein the at least one roller is configured to rotate at the same or a greater rotational speed as the rotatable gantry, but in

the opposite rotational direction.

9. The connector management system of claim 8, further comprising an actuation mechanism configured to rotate the at least one roller as the gantry is rotated.

10. The connector management system of any of claims 6 to 9, wherein the at least one roller is positioned underneath the inner ring structure and is configured to bear the load of the plurality of connectors.

11. The connector management system of any of claims 6 to 10, wherein the at least one roller is a plurality of rollers.

12. The connector management system of any preceding claim, wherein the curve in each of the plurality of connectors is a substantially U-shaped curve formed by bending each connector back upon itself.

13. The connector management system of any preceding claim, wherein the outer portions of each connector of the plurality of connectors are constrained at the same region of a curved wall of the outer member.

14. The connector management system of any preceding claim, wherein the inner portions of each connector of the plurality of connectors are constrained at the same region of an outer circumference of the inner ring structure.

15. The connector management system of any preceding claim, wherein the second rotational direction is opposite the first direction.

16. The connector management system of any preceding claim, wherein the first set of engagement features comprises notches and/or extensions, and the second set of engagement features comprises extensions and/or notches.

17. The connector management system of any preceding claim, wherein each of the connectors comprises a plurality of conduits, each conduit configured to transport one of power, data or fluid.

18. The connector management system of any preceding claim, wherein each connector comprises a cable chain.

19. The connector management system of any preceding claim, wherein the relative rotation between the inner ring structure and outer member occurs about a substantially horizontal axis of rotation.

20. A radiotherapy apparatus comprising a connector management system according to any preceding claim.

21. The radiotherapy apparatus of claim 20, wherein the inner ring structure is mounted to the rotatable gantry so as to rotate with the gantry.

22. The radiotherapy apparatus of claim 20 or claim 21, further comprising a motor to effect rotation of the inner ring structure with respect to the outer member.

23. The radiotherapy apparatus of claim 22, wherein the motor is configured to rotate the gantry, to thereby effect relative rotation between the inner ring structure with respect to the outer member.