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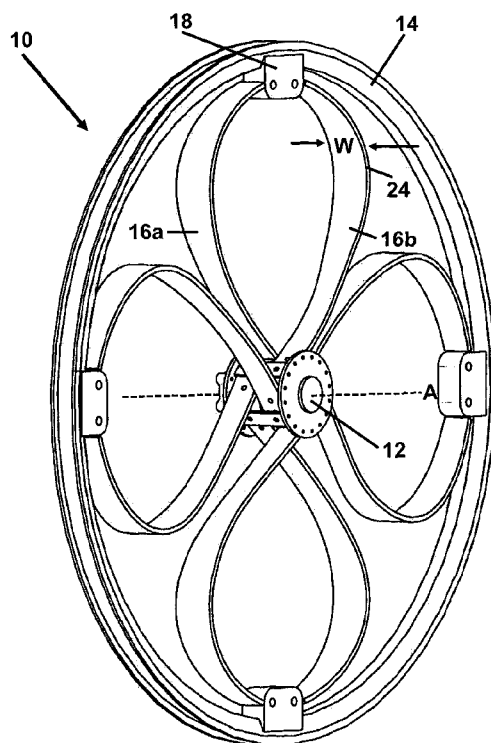


Figure 3

(57) Abstract: A wheel (10) comprises a hub (12), a rim (14) and a plurality of resilient spokes arranged to define pairs of opposed spokes (16a, 16b) spaced circumferentially around the wheel (10). The hub (12) defines an axis of rotation (A) of the wheel (10) and each spoke is connected at or towards one end to the hub (12) and at or towards its other end to the rim (14). The spokes of each pair of opposed spokes (16a, 16b) are connected to the hub (12) on opposite sides of a circumferential hub line (20) that extends about an outer circumferential surface of the hub (12). Each spoke is connected to the rim (14) on a circumferential rim line (22) that extends about an inner circumferential surface of the rim (14) and is concentrically aligned with the circumferential hub line (20). The spokes of each pair of opposed spokes (16a, 16b) are shaped to follow curved profiles extending towards each other as they extend towards the rim (14).



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RESILIENT WHEEL

The invention relates to a wheel.

5 Wheel-based vehicles and machinery often experience shock and/or a loss of control when one or more of the wheels is subjected to an impact or is driven over an uneven driving surface. In order to overcome this problem such vehicles and machinery are often equipped with suspension systems including springs and dampers connected to each of the wheels so as to absorb impacts and to assist in the control of the wheels. The
10 inclusion of such suspension also helps to ensure that the wheels of such vehicles and machinery remain in control with a driving surface, regardless of the condition of the surface, and thereby helps to ensure the comfort and well-being of any occupants.

Conventionally the suspension systems used are distinct apparatus connected to each of
15 the wheels. The inclusion of one or more suspension systems therefore increases the size, weight and manufacturing costs of wheel-based vehicles and machinery.

Wheels having integrated suspension systems are disclosed in US 1,445,522 and EP 2
20 020 308.

According to an aspect of the invention there is provided a wheel comprising a hub, a rim and a plurality of resilient spokes arranged to define pairs of opposed spokes spaced circumferentially around the wheel, the hub defining an axis of rotation of the wheel and each spoke being connected at or towards one end to the hub and at or towards its other
25 end to the rim, wherein the spokes of each pair of opposed spokes are connected to the hub at circumferentially spaced locations and on opposite sides of a circumferential hub line that extends about an outer circumferential surface of the hub, and each spoke being connected to the rim on a circumferential rim line that extends about an inner circumferential surface of the rim and is concentrically aligned with the circumferential
30 hub line, the spokes of each pair of opposed spokes being shaped to follow curved profiles extending towards each other as they extend towards the rim.

The use of resilient spokes defining curved profiles along at least part of their lengths allows displacement of the hub radially relative to the rim and thereby provides an
35 integrated suspension system. Each of the spokes behaves as a resilient spring when, for example, the hub experiences a force that results in displacement of the hub radially relative to the rim and the spoke is either elongated or compressed under the resultant

radial load. This removes the need for external suspension and therefore reduces the number of components that would otherwise be associated with the wheel, thereby resulting in size and cost benefits.

- 5 Arranging the spokes so as to define pairs of opposed spokes in which curved profiles of the spokes are oriented to oppose each other allows the spokes to apply opposing turning forces to the hub when a driving force is applied to either the hub or the rim. Consequently the arrangement of spokes acts to resist rotation of the hub relative to the rim and thereby reduces any lag between rotation of the hub and rotation of the rim when
10 any such driving torque is applied. This is the case regardless of whether the driving torque acts to accelerate or decelerate rotation of the wheel, and regardless of the direction of the driving torque applied to the hub or the rim.

- Connecting the spokes of each pair of opposed spokes to the hub on opposite sides of a
15 circumferential hub line that extends about an outer circumferential surface of the hub, and connecting each spoke to the rim on a circumferential rim line that extends about an inner circumferential surface of the rim and is concentrically aligned with the circumferential hub lines has been found to be particularly advantageous. It improves the lateral stability of the wheel by resisting lateral or twisting movement of the hub relative to
20 the rim when a lateral force is applied to the rim or the hub.

- Such positioning of the connections between the spokes of each pair of opposing spokes and the hub and rim, relative to the circumferential hub and rim lines, also allows adjacent spokes to pass each other so as to assist with the positioning of the spokes
25 within the normal envelope of a rim and hub, particularly in the event the spokes are compressed during movement of the hub relative to the rim causing adjacent pairs of opposing spokes to move towards each other. There is a risk otherwise that the adjacent spokes might collide and thereby reduce the effectiveness of the damping effect provided by the use of the resilient spokes.

- 30 The circumferential hub line may be centrally located relative to the width of the outer circumferential surface of the hub. Similarly the circumferential rim line may be centrally located relative to the width of the inner circumferential surface of the rim. It will however be appreciated that such central positioning of the circumferential hub and rim lines is not
35 necessary, provided that the circumferential rim line is concentrically aligned with the circumferential hub line.

The lateral stability of the wheel may be further improved by connecting the spokes of each pair of opposed spokes to the hub at circumferentially spaced locations along the length of the circumferential hub line. Increasing the distance between the hub connections of each pair of opposing spokes increases the ability of the spokes to resist turning of the hub relative to the rim, particularly when accelerating or decelerating, and also helps to resist lateral and twisting movement of the hub relative to the rim.

The sizes of the balanced forces created on the application of a driving torque to the hub or rim may also be increased by increasing the size of the hub. Increasing the cross-sectional diameter of the hub increases the distance between the connections of the spokes to the hub and the axis of rotation of the wheel, and so increases the turning forces.

In particularly preferred embodiments of the invention the spokes of each pair of opposed spokes are connected to the hub so as to extend tangentially from the outer circumferential surface of the hub. Such an arrangement of the spokes results in trajectories from the hub that allow the use of longer spokes within a given hub-rim configuration than would otherwise be possible by connecting the spokes to extend perpendicularly from the outer circumferential surface of the hub. It also increases the strength and the ability of the opposing spokes to absorb and withstand the turning forces that are generated when a driving torque is applied to either the hub or the rim. It thus improves the strength of the wheel and also helps to further increase the lateral stability of the wheel, further improving the ability of the spokes to resist lateral or twisting movement of the hub relative to the rim.

The ability of the spokes to resist rotation of the hub relative to the rim may be further enhanced by arranging the spokes of each pair of opposed spokes to extend from the hub generally towards each other, the spokes of each pair of opposed spokes being shaped to pass each other and thereafter follow curved profiles extending back towards each other as they extend towards the rim.

Crossing of the spokes of each pair of opposed spokes has also been found to further improve the lateral stiffness of the wheel, and thus helps to further improve the lateral stability of the wheel and prevent lateral or twisting movement of the hub relative to the rim.

Such crossing of the spokes also increases the strength and ability of the opposing spokes to absorb and withstand the turning forces that are generated when a driving torque is applied to the either the hub or the rim, particularly when coupled with a relatively greater circumferential spacing between the hub connections of the spokes of each opposing pair of spokes.

In other embodiments each spoke of each pair of opposed spokes may extend from the hub generally towards an opposed spoke of an immediately adjacent pair of opposed spokes. In such embodiments the spoke are shaped to pass the opposed spoke of the immediately adjacent pair of opposed spokes and thereafter follow a curved profile so that the spokes of each pair of opposed spokes extend towards each other as they extend towards the rim.

Crossing of each spoke of each pair of opposed spokes with an opposed spoke of an immediately adjacent pair of opposed spokes again improves the lateral stiffness of the wheel, and thus helps to further improve the lateral stability of the wheel to prevent lateral or twisting movement of the hub relative to the rim. It also improves the strength and ability of the opposing spokes to absorb and withstand the turning forces that are generated when a driving torque is applied to either the hub or the rim.

The performance of the spokes on the application of a force causing radial displacement of the hub relative to the rim may be altered by varying the orientation of the spokes relative to each other as they extend towards the rim.

In preferred embodiments of the invention the spokes of each pair of opposed spokes meet substantially end to end at the rim. In other embodiments it is envisaged that the spokes of each pair of opposed spokes extend past each other as they extend towards the rim.

Shaping the spokes to extend past each other as they approach the rim increases the length of the curved profile of each spoke relative to the distance between the hub and the rim and thereby increases the extent to which the spokes may extend or compress on the application of a force resulting in displacement of the hub relative to the rim. This is particularly advantageous in small wheels where the space available to receive the spokes between the hub and the rim is limited. In small wheel, more rigid spokes might otherwise be required to absorb forces tending to cause radial displacement of the hub relative to the rim.

Preferably each spoke is shaped to vary in width between the hub and the rim, in a direction parallel to the axis of rotation of the wheel, such that the width is greatest through the curved profile of the spoke.

5

Increasing the width of each spoke in the curved profile of the spoke helps to improve the lateral stability of the wheel, improving the spokes' ability to resist lateral and twisting forces applied to the hub and/or the rim. It also improves the strength of the spokes in the curved profiles, which are subjected to flexing and elongation upon the application of forces causing displacement of the hub relative to the rim.

10

In embodiments of the invention the length of the curved profile may be increased through the use of a C-shaped profile, i.e. a profile having a relatively small radius of curvature when compared with the radial distance separating the hub and the rim in a given wheel.

15

Increasing the length of the spokes in a given wheel increases the resilience of the spoke and increases the amount of energy that can be stored in the spoke. It also increases the amount of movement of the hub relative to the rim that is available on the application of a radial load to the hub or rim. This in turn facilitates the use of spokes formed softer or otherwise more flexible materials than would otherwise be the case, and thereby tailor the response of the wheel for use in a particular application. This is particularly useful in relatively small wheels, such as wheels used on pushchairs or strollers, where the space available between the hub and rim is limited.

20

25

In one particular embodiment, each spoke may define a curved profile along its entire length, the curved profile having a constant radius of curvature along its length which is equal to the radial distance between the outer circumferential surface of the hub and the inner circumferential surface of the rim so as to maximise the length of the curved profiles.

30

In order to maximise the strength of the wheel, and facilitate construction of the wheel, the spokes of each pair of opposed spokes may be formed integrally with one another to define a unitary spring unit.

35

The use of a unitary spring unit further improves the strength and lateral stability of the wheel, as well as simplifying its construction.

Preferably each unitary spring unit is secured to the hub in a pre-tensioned condition.

5 Securing each unitary spring unit to the hub in a pre-tensioned condition allows for an increase in the lateral stability of the wheel, i.e. an increase in the resistance of the hub to twisting relative to the rim, without the need to increase the width of each spoke. Accordingly such an arrangement provides the option of utilising a thinner spoke so as to reduce the overall mass of the wheel while maintaining the same degree of lateral stability in the wheel.

10

Optionally each unitary spring unit has a uniform width along the length thereof. The inclusion of respective spring units which have a uniform width helps to rationalise the manufacture of the wheel and, where appropriate, allows any fibres from which the unitary spring units may be made to extend uniformly and consistently along the length of
15 each spring unit.

20

It will be appreciated that compression of the spokes on radial movement of the hub towards the rim in the direction of the spokes will cause movement of adjacent spokes towards each other. So as to reduce the risk of the adjacent spokes colliding when they are compressed, each spoke may be connected at or towards the one end to the hub so as to extend from the hub at an angle relative to the circumferential hub line.

25

Alternatively, or in addition, each spoke may be connected at or towards the other end to the rim so as to extend from the rim at an angle relative to the circumferential rim line.

30

Angling the spokes relative to the hub and/or rim of the wheel allows the curved profiles of the spokes to flex outwardly of the wheel, and the angle is preferably chosen so that each spoke follows its own trajectory in its own plane. This helps to improve the lateral stiffness of the wheel, reducing the risk of twisting or other lateral movement of the hub relative to the rim. It also further reduces the risk of collisions between adjacent spokes and, in turn, allows a greater number of spokes to be incorporated into the wheel, as well
35 as allowing for an increase in the length of the curved profile of each spoke.

In embodiments of the invention, the curved profile of the spoke may be twisted so that the connection between the spoke and the hub is skewed relative to the outer circumferential surface of the hub.

- 5 This means that the connection between the spoke and the hub is skewed relative to the outer circumferential surface of a cylindrical element axially aligned with the axis of rotation of the wheel. It will be appreciated that the outer circumferential surface of the hub may be shaped to define skewed mounts to receive the ends of the spokes so as to facilitate the creation of connections between the ends of the spokes and the
- 10 circumferential surface of the hub that are skewed relative to the outer circumferential surface of the cylindrical element axially aligned with the axis of rotation of the wheel.

- Alternatively, or in addition, the curved profile of the spoke may be twisted so that the connection between the spoke and the rim is skewed relative to the inner circumferential
- 15 surface of the rim.

- Introducing a twist into the curved profile of each spoke further alters the direction in which the curved profile is able to compress on radial movement of the hub towards the rim and thereby further reduces the risk of collisions between adjacent spokes whilst
- 20 minimising the outward movement of the spokes. A twist also helps to pre-tension each spoke.

- The performance of the spokes on the application of a force causing radial displacement of the hub relative to the rim may be altered by varying the orientation of the spokes
- 25 relative to each other as they extend towards the rim.

- Each spoke may, for example, be one of fixedly connected to the hub at or towards one end and pivotably connected to the rim at or towards the other end, and fixedly connected to the rim at or towards one end and pivotably connected to the hub at or
- 30 towards the other end.

- Rigidly connecting one end of each spoke to the hub or the rim improves the lateral stability of the wheel, and further reduces the risk of any twisting movement of the hub relative to the rim. Pivotably connecting one end of each spoke to the other of the rim or
- 35 the hub allows pivoting movement of the spoke relative to the rim and reduces the stresses applied to the spoke during compression and elongation of the spoke. It therefore reduces the risk of the spokes snapping and allows the use of a material that is

less flexible than might otherwise be required if the spokes were rigidly connected to the rim.

5 It is envisaged that in such embodiments, depending on the desired performance of the spokes, the spokes could be fixedly connected at both ends or pivotably connected at both ends. In such embodiments however it is preferred that each spoke is pivotably connected to the hub and fixedly connected to the rim. Such an arrangement absorbs energy on compression and extension of the spokes and provides a damping effect to reduce oscillating movement of the hub relative to the rim on the application of a force
10 causing displacement of the hub radially relative to the rim.

In embodiments of the invention, each spoke may be formed from a laminated structure including two or more alternate layers of reinforcing material and epoxy resin in order to achieve the required resilience.

15

In such embodiments, the reinforcing material may be chosen from glass fibre, carbon fibre, Kevlar (RTM) and hemp, and the reinforcing material is preferably arranged within the laminated structure so as to follow the shape of the spoke so as to provide a uni-directional strengthening effect and to enhance the performance of the spoke.

20

It will be appreciated that the material used to form the spokes will depend greatly on the intended use or application of the wheel. The flexibility and elasticity of the material will affect the speed of response of the spokes. The stiffer the material the slower the spokes will be to respond to the application of a radial load to the hub or rim and so the better
25 the damping effect of the spokes. Such spokes will also however be slow to respond to bumps encountered during rotation of the wheel along the ground and will not therefore compensate well for such bumps, which is undesirable. Such spokes may also be more likely to snap when the wheel encounters a sudden bump.

30 In contrast, the more elastic and flexible the material chosen, the more quickly the spokes will respond to the application of a radial load to the hub or rim. Such spokes will however provide less of a damping effect.

It is envisaged that in most applications the material chosen will exhibit mid-range
35 properties in terms of its flexibility and resilience during rotation of the wheel.

Depending on the shapes of the spokes and the positioning of the spokes relative to each other, and the resilient properties of the spokes, the spokes may be located circumferentially about the hub so as to define spring units arranged to balance the compression and elongation of the spokes on radial displacement of the hub relative to the rim. Balancing the compression and elongation in this manner assists balancing any displacement of the hub relative to the rim and increases the damping available from the spring units, thereby reducing the risk of uneven oscillation of the hub relative to the rim.

In such embodiments, the spokes of each pair of opposed spokes may define a spring unit and the spring units may be arranged circumferentially about the hub to define co-operating pairs of opposed spring units such that movement of the hub towards the rim in a radial direction of one of the spring units of a co-operating pair of spring units causes compression of the spokes of the one spring unit and extension of the spokes of the other spring unit of the co-operating pair of spring units.

It is envisaged that in further embodiments, the resilient properties of the spokes and the connections between each spoke and the hub and the rim may be chosen such that balancing of spring units circumferentially about the hub is not required to balance any displacement of the hub relative to the rim and to reduce the risk of uneven oscillation. In such embodiments, it will be appreciated that the number of spokes included in the wheel may be chosen to produce an odd number of pairs of opposing spokes or spring units.

It is also envisaged that in yet further embodiments, the intended use of the wheel is such that balancing of any displacement of the hub relative to the rim to reduce the risk of uneven oscillation is not required. Again it will be appreciated that in such embodiments the number of spokes included in the wheel may be chosen to produce an odd number of pairs of opposing spokes or spring units.

In further embodiments the plurality of spokes may be formed integrally with one another to define a unitary spring assembly. The provision of a single, unitary spring assembly improves the overall strength of the wheel by helping to ensure the uniform distribution of loading forces between adjacent spring units.

Preferred embodiments of the invention will now be described with reference to the accompanying drawings in which:

Figure 1 is a plan view of a wheel according to a first embodiment of the invention;

Figure 2 illustrates a pair of opposed spokes of the wheel of Figure 1;

Figure 3 is a perspective view of the wheel of Figure 1;

Figure 4 is a cross-sectional view along line I-I of Figure 1;

5 Figure 5 is a plan view of a wheel according to a second embodiment of the invention;

Figure 6 illustrates opposed spokes of the wheel of Figure 5;

Figure 7 is a perspective view of the wheel of Figure 5;

Figure 8 illustrates an integrally formed pair of spokes of the wheel of Figure 5;

10 Figure 9 is a plan view of a wheel according to a third embodiment of the invention;

Figures 10 and 11 illustrate opposed spokes of adjacent pairs of opposed spokes of the wheel of Figure 9;

Figure 12 is a perspective view of the wheel of Figure 9;

15 Figure 13 illustrates an integrally formed pair of spokes of the wheel of Figure 9;

Figure 14 is a perspective view of a wheel according to a fourth embodiment of the invention;

Figure 15 is a perspective view of a unitary spring unit which forms a part of the wheel shown in Figure 14;

20 Figure 16 is a partial view of the unitary spring units forming part of the wheel shown in Figure 14;

Figure 17 is a perspective view of a wheel according to a fifth embodiment of the invention;

25 Figure 18 is a perspective view of a wheel according to a sixth embodiment of the invention;

Figure 19 is a further perspective view of the wheel shown in Figure 18;

Figure 20 is a perspective view of a wheel according to a seventh embodiment of the invention;

Figure 21 is partial view of the wheel shown in Figure 20;

30 Figure 22 is a perspective view of a wheel according to an eighth embodiment of the invention;

Figure 23 is an elevational view of the further wheel shown in Figure 22;

Figure 24 is a perspective view from a first side of a wheel according to a ninth embodiment of the invention;

35 Figure 25 is a perspective view from a second side opposite the first side of the wheel shown in Figure 24;

Figure 26 is perspective view of a wheel according to a tenth embodiment of the invention;

Figure 27 is a partial view of the wheel shown in Figure 26;

Figure 28 is a perspective view of a further wheel according to an eleventh
5 embodiment of the invention;

Figure 29 is a perspective view of a portion of the wheel shown in Figure 28; and

Figure 30 is a perspective view of a wheel according to a twelfth embodiment of the invention.

10 A wheel 10 according to a first embodiment of the invention is shown in Figure 1.

The wheel 10 includes a hub 12, a rim 14 and a plurality of spokes 16 arranged circumferentially around the hub 12. Each spoke 16 is fixedly connected at one end to the hub 12 so as to extend tangentially from the hub 12, and pivotably connected at its
15 other end to the rim 14 by means of a hinge assembly 18. The hub 12 defines an axis of rotation A of the wheel 10 (Figure 3).

The spokes 16 include curved profiles 24 and are arranged to define pairs of opposed spokes 16a,16b spaced circumferentially about the wheel 10, the curved profiles of the
20 opposed spokes 16a,16b being curved in opposite directions to each other, as shown in Figure 2.

Referring to Figures 3 and 4, the opposed spokes 16a,16b of each pair are connected to the hub 12 at circumferentially spaced locations, on opposite sides of a circumferential
25 hub line 20 that extends about the outer circumferential surface of the hub 12, about the axis of rotation A of the wheel 10, so as to extend tangentially from the hub 12 generally towards each other. They are connected at their other ends to the rim 14 on a circumferential rim line 22 that extends about the inner circumferential surface of the rim 13, about the axis of rotation A of the wheel 10, and is concentrically aligned with the
30 circumferential hub line 20.

The opposed spokes 16a,16b of each pair are shaped to pass each other as they extend generally towards each other from the hub 12 and thereafter follow their curved profiles 24 so as to extend back towards each other as they extend towards the rim 14 so as to
35 meet substantially end to end at a shared hinge assembly 18.

The spokes 16 are formed from laminated structures including a plurality of alternating layers of carbon fibre and epoxy resin. The layers of carbon fibre are arranged within the laminated structures so as to be aligned along the lengths of the spokes 16 and provide a uni-directional strengthening effect.

5

Each spoke 16 is shaped to vary in width W between the hub 12 and the rim 14, in a direction parallel to the axis of rotation A of the wheel 10, such that the width W is greatest through the curved profile 24 of the spoke 16.

10 In the embodiment shown in Figure 1, the pairs of opposed spokes 16a,16b are equidistantly spaced about the circumference of the wheel 10. Since all of the spokes are equal in length and define the same curved profile 24, this means the hub 12 is centrally located within the rim 14 in an unloaded or rest configuration of the wheel 10.

15 The resilient nature of the spokes 16 allows the curved profile 24 of each spoke to deform on the application of a compressive or tensile load, the curvature of the curved profile 24 of each spoke 16 increasing on the application of a compressive load and the curvature of the curved profile 24 of the spoke decreasing on the application of a tensile load. Consequently, on the application of a radial load to the hub 12, the spokes 16
20 deform as the hub 12 moves relative to the rim 14 in the direction of the radial load, the nature of the deformation of each spoke 16, i.e. elongation or compression, being determined by the direction of the applied load.

On removal of the radial load, the resilient nature of the spokes 16 means that each of
25 the spokes 16 resumes its original shape and the hub 12 is thereby returned to its unloaded or rest position, centrally located within the rim 14.

Similarly, on the application of a radial load to the rim 14 so as to cause movement of the rim 14 towards the hub 12, the spokes 16 will deform in accordance with the direction of
30 the radial load, as the rim 14 moves towards the hub 12, and will return the rim 14 to its unloaded or rest position relative to the hub 12 on removal of the load.

The arrangement of the spokes in each pair of opposed spokes 16a,16b relative to the circumferential hub and rim lines 20,22 improves the lateral stability of the wheel 10 by
35 resisting twisting movement of the hub 12 relative to the rim 14 whilst at the same time facilitating the use of a relatively narrow rim 14. This is particularly advantageous when

the size of the rim 14 is an important factor in terms of the performance of the wheel 10. The use of a relatively narrow rim 14 is important, for example, in racing bicycle wheels.

5 Crossing of the spokes in each pair of opposed spokes 16a,16b, as they extend tangentially away from the hub 12, also increases the lateral stiffness of the wheel 10.

10 The width W of the curved profile 24 of each spoke 16 also helps to improve the lateral stability of the wheel 10 by increasing the lateral stiffness of the spokes and thereby increases the ability of the spokes 16 to resist twisting of the hub 12 relative to the rim 14.

15 Arranging the spokes so as to define pairs of opposed spokes 16a,16b in which the curved profiles 24 of the spokes 16a,16b oppose each other, and connecting the opposed spokes 16a,16b of each pair to the hub 12 at circumferentially spaced locations along the circumferential hub line 20, enables the spokes to apply opposing turning forces to the hub 12 when a driving torque is applied to either the hub 12 or the rim 14. Consequently the spokes act on the hub 12 to resist rotation of the hub 12 relative to the rim 14. This is particularly advantageous in circumstances where the driving torque is applied to the hub 12 to either accelerate or decelerate rotation of the wheel 10.

20 Depending on the nature of the intended use of the wheel 10, and the size of driving torques intended to be applied to the hub 12 or rim 14, the size of the turning forces applied to the hub 12 by the spokes 16 may be increased by increasing the radial size of the hub 12 and by increasing the distance between the fixed ends of the opposed spokes 25 16a,16b of each pair.

30 Each pair of opposed spokes 16a,16b forms a spring unit arranged about the circumference of the hub 12 in co-operating pairs of spring units located on opposite sides of the hub 12. This arrangement provides a balanced response on the application of a radial load to the hub 12 or rim 14, one spring unit compressing whilst the co-operating spring unit elongates. When the wheel 10 is used on a vehicle or a bicycle, such balancing of the response to the spokes 16 to any such radial forces helps to provide a smooth ride for any occupant or rider as opposed to a bumpy ride that might otherwise result from an unbalanced arrangement of the spokes 16.

35

Consequently the resilient nature of the spokes 16, and the balanced arrangement of the pairs of opposed spokes 16a,16b, results in an enhanced suspension capability integrated within the wheel 10.

- 5 In other embodiments it is envisaged that balancing of the spring units may not be required. In such embodiments, the elastic nature of the reinforcing material, which defines the resilient nature of the spokes 16, and the connections between the spokes 16 and the hub 12 and rim 14 may be chosen to ensure that each spring unit provides a balanced response on its own. Alternatively the intended use of the wheel 10 may be
10 such that balancing of any displacement and oscillatory movement of the hub 12 relative to the rim 14 is not required. In such embodiments, the wheel 10 may include an odd number of pairs of opposed spokes 16a,16b and thus an odd number of spring units.

- The extent to which the spokes 16 provide an integrated suspension capability is
15 however determined by the elastic nature of the reinforcing material used in the laminated structure of each spoke 16. The use of carbon fibre produces a relatively elastic response. As such, whilst spokes 16 formed using carbon fibre react relatively quickly to the application of a radial load to the hub 12 or rim 14, they provide limited damping capability and are perhaps less suitable for use over bumpy terrain. This is
20 because the spokes 16 are more likely to reach their elastic limit on the application of a relatively large radial load to either the hub 12 or rim 14. This would lead to breakage of the spokes 16.

- The damping capability of the spokes 16 may be increased in other embodiments
25 through the use of a reinforcing material that is less elastic. Glass fibre is for example less elastic than carbon fibre, leading to the production of spokes 16 that react more slowly to radial forces applied to the hub 12 or rim 14 and thereby provide a greater damping effect. As such, the use of glass fibre may be considered more suitable for the use in a wheel 10 intended to be used over bumpy terrain. This is because the spokes
30 16 are less likely to reach their elastic limit on the application of a relatively large radial load to either the hub 12 or rim 14 and therefore less likely to snap.

- In yet further embodiments, depending on the elastic response required from the spokes 16, Kevlar (RTM) or hemp may be used in the laminated structure used to form the
35 spokes 16.

Regardless of the material used in the laminated structure, the width W of the curved profile 24 of each spoke 16 increases the strength of the spoke 16 in the curved profile 24. This increased strength of the portion of the spoke 16 that is required to deform during compression of the spoke 16 therefore reduces the risk of the spoke 16 snapping during compression.

The pivotable connection between each spoke 16 and the rim 14 also serves to reduce the risk of the spoke 16 snapping during compression by allowing limited movement of the spoke 16 relative to the rim 14. The pivoting movement of the spokes 16 at the rim 14 reduces the stresses applied to the spokes 16 at the connections with the rim 14 during compression of the spokes 16.

The spokes 16 are fixedly connected to the hub 12 so as to minimise flexing of the spokes 16 relative to the hub 12 and ensure that the spokes 16 are able to consistently apply the turning forces required to resist rotation of the hub 12 relative to the rim 14 on the application of a driving torque to the hub 12 or rim 14.

The strength of each spoke 16 at the connection between the spoke 16 and the hub 12 may be increased to cope with the stresses applied to the spokes 16 at the connections with the hub 12 through the use of one or more additional layers of carbon fibre in the laminated structure at the ends of the spokes 16 fixedly connected to the hub 12.

In other embodiments, depending on the size of radial forces and driving torques likely to be encountered by the wheel 10 and the amount of compression required from the spokes 16, it is envisaged the spokes 16 may be pivotably connected to the hub 12 instead of the rim 14, the spokes 16 may be fixedly connected at both ends to the hub 12 and the rim 14 or pivotably connected at both ends to the hub 12 and the rim 14.

In the wheel 10 shown in Figure 1, movement of the hub 12 relative to the rim 14 is limited by the space available between adjacent pairs of opposed spokes 16a, 16b. The elastic nature of the reinforcing material included in the laminated structure used to form the spokes 16 must be chosen to ensure that the spokes of adjacent pairs of opposed spokes 16a, 16b do not collide.

In order to reduce the risk of adjacent spokes colliding, the orientation of the curved portion 24 of each spoke 16 may be altered so that the curved profile 24 flexes outwardly from the wheel 10 during compression of the spoke 16.

A wheel 30 according to one such embodiment of the invention is shown in Figures 5 to 8.

5 The wheel 30 includes a hub 32, a rim 34 and a plurality of spokes 36 arranged circumferentially around the hub 32. Each spoke 36 is fixedly connected at one end to the hub 32 so as to extend tangentially from the hub 32 and pivotably connected at its other end to the rim 34 by means of a hinge assembly 38. The hub 32 defines an axis of rotation A of the wheel 30 (Figure 7).

10

The spokes 36 include curved profiles 44 and are arranged to define pairs of opposed spokes 36a,36b spaced circumferentially about the wheel 30, the curved profiles 44 of the opposed spokes 36a,36b being curved in opposite directions to each other, as shown in Figure 6.

15

Referring to Figure 7, the opposed spokes 36a,36b of each pair are connected to the hub 32 at circumferentially spaced locations on opposite sides of a circumferential hub line 40 that extends about the outer circumferential surface of the hub 32, about the axis of rotation A of the wheel 30, so as to extend tangentially from the hub 32, at an angle relative to the circumferential hub line 40, generally towards each other. They are connected at their other ends to the rim 34 on a circumferential rim line 42 that extends about the inner circumferential surface of the rim, about the axis of rotation A of the wheel 30, and is concentrically aligned with the circumferential hub line 40.

20

25 The opposed spokes 36a,36b of each pair are shaped to pass each other as they extend generally towards each other from the hub 32 and thereafter follow their curved profiles 44 so as to extend back towards each other as they extend towards the rim 34 so as to meet substantially end to end at a shared hinge assembly 38. The spokes 36 are connected to the rim 34 at an angle to the circumferential rim line 42.

30

The curved profile 44 of each spoke 36 includes a twist so that the connection between the spokes 36 and the hinge assembly 38 is skewed relative to the inner circumferential surface 35 of the rim 34.

35 The spokes 36 are formed from laminated structures including a plurality of alternating layers of carbon fibre and epoxy resin. The layers of carbon fibre are arranged within the

laminated structures so as to be aligned along the lengths of the spokes 36 and provide a uni-directional strengthening effect.

5 As in the embodiment shown in Figure 1, each spoke 36 is shaped to vary in width W between the hub 32 and the rim 34, in a direction parallel to the axis of rotation A of the wheel 30, such that the width W is greatest through the curved profile 44 of the spoke 36.

10 The pairs of opposed spokes 36a,36b are equidistantly spaced about the circumference of the wheel 30. Since all of the spokes are equal in length and define the same curved profile 44, this means that the hub 32 is centrally located within the rim 34 in an unloaded or rest configuration of the wheel 30.

15 Each spoke of each pair of opposed spokes 36a,36b is formed integrally with an opposed spoke of an adjacent pair of opposed spokes 36a,36b, as shown in Figure 8.

The use of integrally formed spokes 36 strengthens the wheel 30 and facilitates construction of the wheel 30 using connection portions 46 that are received in angled receiving slots 48 formed on the outer circumferential surface of the hub 32.

20 The resilient nature of the spokes 36 allows the curved profile 44 of each spoke to deform on the application of a compressive or tensile load, the curvature of the curved profile 44 of each spoke 36 increasing on the application of a compressive load and the curvature of the curved profile 44 of the spoke decreasing on the application of a tensile load. Consequently, on the application of a radial load to the hub 32, the spokes 36
25 deform as the hub 32 moves relative to the rim 34 in the direction of the radial load, the nature of the deformation of each spoke 36, i.e. elongation or compression, being determined by the direction of the applied load.

30 On removal of the radial load, the resilient nature of the spokes 36 means that each of the spokes 36 resumes its original shape and the hub 32 is thereby returned to its unloaded or rest position, centrally located within the rim 34.

35 Similarly, on the application of a radial load to the rim 34 so as to cause movement of the rim 34 towards the hub 32, the spokes 36 will deform in accordance with the direction of the radial load, as the rim 34 moves towards the hub 32, and will return the rim 34 to its unloaded or rest position relative to the hub 32 on removal of the load.

The angle of the angled connections between the spokes 36 and the hub 32 and the skewed connection between the spokes 36 and the rim 34, is chosen so that the curved profiles 44 of the spokes 36 follow their own trajectories in their own planes during deformation of the spokes 36, as opposed to deforming within the plane of the wheel 30.

5 As such, the spokes 36 do not collide during deformation. This allows a longer spoke 36 to be used than in the wheel 10 shown in Figure 1 and thus allows the response of the spokes 36 to the application of radial loads to the hub 32 or rim 34 to be altered.

10 The arrangement of the spokes in each pair of opposed spokes 36a,36b relative to the circumferential hub and rim lines 40,42 improves the lateral stability of the wheel 30 by resisting twisting movement of the hub 32 relative to the rim 34 whilst at the same time facilitating the use of a relatively narrow rim 34. As outlined with reference to the embodiment shown in Figure 1, this is particularly advantageous when the size of the rim 34 is an important factor in terms of the performance of the wheel 30. The use of a
15 relatively narrow rim 34 is important, for example, in racing bicycle wheels.

Crossing of the spokes in each pair of opposed spokes 36a,36b, as they extend tangentially away from the hub 32, also increases the lateral stiffness of the wheel 30.

20 The width W of the curved profile 44 of each spoke 36 also helps to improve the lateral stability of the wheel 30 by increasing the ability of the spokes 36 to resist twisting of the hub 32 relative to the rim 34.

Arranging the spokes so as to define pairs of opposed spokes 36a,36b in which the
25 curved profiles 44 of the spokes 36a,36b oppose each other, and connecting the opposed spokes 36a,36b of each pair to the hub 32 at circumferentially spaced locations, enables the spokes to apply opposing turning forces to the hub 32 when a driving torque is applied to either the hub 32 or the rim 34. Consequently the spokes act on the hub 32 to resist rotation of the hub 32 relative to the rim 34. This is particularly advantageous in
30 circumstances where the driving torque is applied to the hub 32 to either accelerate or decelerate rotation of the wheel 30.

Depending on the nature of the intended use of the wheel 30, and the size of driving torques intended to be applied to the hub 32 or rim 34, the size of the turning forces
35 applied to the hub 32 by the spokes 36 may be increased by increasing the radial size of the hub 32 and by increasing the distance along the circumferential hub line 40 between the fixed ends of the opposed spokes 36a,36b of each pair.

Each pair of opposed spokes 36a,36b forms a spring unit arranged about the circumference of the hub 32 in co-operating pairs of spring units located on opposite sides of the hub 32. This arrangement provides a balanced response on the application
5 of a radial load to the hub 32 or rim 24, one spring unit compressing whilst the co-operating spring unit elongates. When the wheel 30 is used on a vehicle or a bicycle, such balancing of the response to the spokes 36 to any such radial forces helps to provide a smooth ride for any occupant or rider as opposed to a bumpy ride that might otherwise result from an unbalanced arrangement of the spokes 36.

10

Consequently the resilient nature of the spokes 36, and the balanced arrangement of the pairs of opposed spokes 36a,36b, results in an enhanced suspension capability integrated within the wheel 30.

15 As outlined previously, it is envisaged that in other embodiments the spring units are not arranged about the circumference of the hub 32 to provide a balanced arrangement. In such embodiments the wheel 30 may include an odd number of pairs of opposed spokes 36a,36b and thus an odd number of spring units.

20 The extent to which the spokes 36 provide an integrated suspension capability is however determined by the elastic nature of the reinforcing material used in the laminated structure of each spoke 36. The use of carbon fibre produces a relatively elastic response. As such, whilst spokes 36 formed using carbon fibre react relatively quickly to the application of a radial load to the hub 32 or rim 34, they provide limited
25 damping capability and are perhaps less suitable for use over bumpy terrain. This is because the spokes 16 are more likely to reach their elastic limit on the application of a relatively large radial load to either the hub 32 or rim 34. This would lead to breakage of the spokes 36.

30 The damping capability of the spokes 36 may be increased in other embodiments through the use of a reinforcing material that is less elastic. Glass fibre is for example less elastic than carbon fibre, leading to the production of spokes 36 that react more slowly to radial forces applied to the hub 32 or rim 34 and thereby provide a greater damping effect. As such, the use of glass fibre may be considered more suitable for the
35 use in a wheel 30 intended to be used over bumpy terrain. This is because the spokes 36 are less likely to reach their elastic limit on the application of a relatively large radial load to either the hub 32 or rim 34 and therefore less likely to snap.

In yet further embodiments, depending on the elastic response required from the spokes 36, Kevlar (RTM) or hemp may be used in the laminated structure used to form the spokes 36.

5

Regardless of the material used in the laminated structure, the width W of the curved profile 44 of each spoke 36 increases the strength of the spoke 36 in the curved profile 44. This increased strength of the portion of the spoke 36 that is required to deform during compression of the spoke 36 therefore reduces the risk of the spoke 36 snapping during compression.

10

The pivotable connection between each spoke 36 and the rim 34 also serves to reduce the risk of the spoke 36 snapping during compression by allowing limited movement of the spoke 36 relative to the rim 34. The pivoting movement of the spokes 36 at the rim 34 reduces the stresses applied to the spokes 36 at the connections with the rim 34 during compression of the spokes 36.

15

The spokes 36 are fixedly connected to the hub 32 so as to minimise flexing of the spokes 36 relative to the hub 32 and ensure that the spokes 36 are able to consistently apply the turning forces required to resist rotation of the hub 32 relative to the rim 34 on the application of a driving torque to the hub 32 or rim 34.

20

The strength of each spoke 36 at the connection between the spoke 36 and the hub 32 may be increased to cope with the stresses applied to the spokes 36 at the connections with the hub 32 through the use of one or more additional layers of carbon fibre in the laminated structure at the ends of the spokes 36 fixedly connected to the hub 32.

25

In other embodiments, depending on the size of radial forces and driving torques likely to be encountered by the wheel 30 and the amount of compression required from the spokes 36, it is envisaged the spokes 36 may be pivotably connected to the hub 32 instead of the rim 34, the spokes 36 may be fixedly connected at both ends to the hub 32 and the rim 34 or pivotably connected at both ends to the hub 32 and the rim 34.

30

A wheel 50 according to a third embodiment of the invention is shown in Figure 9.

35

The wheel 50 includes a hub 52, a rim 54 and a plurality of spokes 56 arranged circumferentially about the hub 52. Each spoke is fixedly connected at one end to the

hub 52 so as to extend tangentially from the hub 52, and fixedly connected at its other end to the rim 54. The hub 52 defines an axis of rotation A of the wheel 50.

5 The spokes 56 include curved C-sections 64 and are arranged to define pairs of opposed spokes 56a,56b spaced circumferentially about the wheel 50, the C-sections 64 being curved in opposite directions to each other, as shown in Figure 13.

10 Referring to Figure 12, the opposed spokes 56a,56b of each pair are connected to the hub 52 at circumferentially spaced locations on opposite sides of a circumferential hub line 60 that extends about the outer circumferential surface of the hub 52, about the axis of rotation A of the wheel 50, so as to extend tangentially from the hub 52, at an angle relative to the circumferential hub line 60, generally away from each other. They are connected at their other ends to the rim 54 on a circumferential rim line 62 that extends about an inner circumferential surface of the rim, about the axis of rotation A of the wheel
15 50, and is concentrically aligned with the circumferential hub line 60.

Referring to Figures 10 and 11, opposing spokes of adjacent pairs of opposed spokes 56a,56b are shaped to extend towards each other and pass each other as they extend away from the hub 52 and thereafter follow their curved profiles 64 so as to extend back
20 towards each other as they extend towards the rim 54 so as to pass each other as they extend towards the rim 54. Crossing of opposing spokes of adjacent pairs of opposed spokes 56a,56b increases the lateral stiffness of the wheel 50.

25 The spokes of each pair of opposed spokes 56a,56b are connected to the rim 54 at circumferentially spaced locations and at an angle to the circumferential rim line 62.

30 The spokes 56 are formed from laminated structures including a plurality of alternating layers of carbon fibre and epoxy resin. The layers of carbon fibre are arranged within the laminated structures so as to be aligned along the lengths of the spokes 56 and provide a uni-directional strengthening effect.

The spokes of each pair of opposed spokes 56a,56b are formed integrally with each other to define a unitary spring unit 55, as shown in Figure 13.

35 The pairs of opposed spokes 56a,56b are equidistantly spaced about the circumference of the wheel 50. Since all of the spokes are equal in length and define the same C-

sections 64, this means the hub 52 is centrally located within the rim 54 in an unloaded or rest configuration of the wheel 50.

The resilient nature of the spokes 56 allows the C-sections 64 of each spoke to deform on the application of a compressive or tensile load, the curvature of the C-section 64 of each spoke 56 increasing on the application of a compressive load and the curvature of the C-section 64 of the spoke decreasing on the application of a tensile load. Consequently, on the application of a radial load to the hub 52, the spokes 56 deform as the hub 52 moves relative to the rim 54 in the direction of the radial load, the nature of the deformation of each spoke 56, i.e. elongation or compression, being determined by the direction of the applied load.

On removal of the radial load, the resilient nature of the spokes 56 means that each of the spokes 56 resumes its original shape and the hub 52 is thereby returned to its unloaded or rest position, centrally located within the rim 54.

Similarly, on the application of a radial load to the rim 54 so as to cause movement of the rim 54 towards the hub 52, the spokes 56 will deform in accordance with the direction of the radial load, as the rim 54 moves towards the hub 52, and will return the rim 54 to its unloaded or rest position relative to the hub 52 on removal of the load.

Arranging the spokes so as to define pairs of opposed spokes 56a,56b in which the C-sections 64 of the spokes 56a,56b oppose each other, and connecting the opposed spokes 56a,56b of each pair to the hub 52 at circumferentially spaced locations, enables the spokes to apply opposing turning forces to the hub 52 when a driving torque is applied to either the hub 52 or the rim 54. Consequently the spokes act on the hub 52 to resist rotation of the hub 52 relative to the rim 54. This is particularly advantageous in circumstances where the driving torque is applied to the hub 52 to either accelerate or decelerate rotation of the wheel 50.

As outlined above, each integrally formed pair of opposed spokes 56a,56b forms a spring unit 55 and the spring units 55 are arranged about the circumference of the hub 52 in co-operating pairs of spring units located on opposite sides of the hub 52. This arrangement provides a balanced response on the application of a radial load to the hub 52 or rim 54, one spring unit compressing whilst the co-operating spring unit elongates.

The angle of the angled connections between the spokes 56 and the hub 52 and the rim 54 is chosen so that the spring units follow their own trajectories in their own planes during deformation of the spokes 56, as opposed to deforming within the plane of the wheel 50. As such, the spokes 56 do not collide during deformation. This allows a longer C-section 64 to be used and thus allows the response of the spokes to the application of radial loads to the hub 52 or rim 54 to be tailored. This ability to alter the length of the C-sections renders the structure of the wheel 50 shown in Figure 9 suitable for use in relatively smaller wheels, such as those used on strollers, pushchairs and scooters. This is because the C-section is able to accommodate deformation of the spokes 56 within a relatively small region between the hub 52 and the rim 54.

As with the embodiments shown in Figures 1 and 5, the extent to which the spokes 56 provide an integrated suspension capability is however determined by the elastic nature of the reinforcing material used in the laminated structure of each spoke 56. The use of carbon fibre produces a relatively elastic response. As such, whilst spokes 56 formed using carbon fibre react relatively quickly to the application of a radial load to the hub 52 or rim 54, they provide limited damping capability and are perhaps less suitable for use over bumpy terrain. This is because the spokes 56 are more likely to reach their elastic limit on the application of a relatively large radial load to either the hub 52 or rim 54. This would lead to breakage of the spokes 56.

As outlined previously, it is envisaged that in other embodiments the spring units are not arranged about the circumference of the hub 52 to provide a balanced arrangement. In such embodiments the wheel 50 may include an odd number of pairs of opposed spokes 56a, 56b and an odd number of spring units.

The damping capability of the spokes 56 may be increased in other embodiments through the use of a reinforcing material that is less elastic. Glass fibre is for example less elastic than carbon fibre, leading to the production of spokes 56 that react more slowly to radial forces applied to the hub 52 or rim 54 and thereby provide a greater damping effect. As such, the use of glass fibre may be considered more suitable for the use in a wheel 50 intended to be used over bumpy terrain. This is because the spokes 56 are less likely to reach their elastic limit on the application of a relatively large radial load to either the hub 52 or rim 54 and therefore less likely to snap.

In yet further embodiments, depending on the elastic response required from the spokes 16, Kevlar (RTM) or hemp may be used in the laminated structure used to form the spokes 16.

5 A wheel 70 according to a fourth embodiment of the invention is shown in Figure 14.

The wheel 70 includes a hub 72, a rim 74 and a plurality of spokes 76 arranged circumferentially around the hub 72. Each spoke 76 is fixedly connected at one end to the hub 72 so as to extend tangentially from the hub 32. The hub 32 defines an axis of
10 rotation A of the wheel 70.

The spokes 76 include curved profiles 78 and are arranged to define pairs of opposed spokes 76a,76b spaced circumferentially about the wheel 70, the curved profiles 78 of the opposed spokes 76a,76b being curved in opposite directions to each other.

15 The spokes 76 of each pair of opposed spokes 76a,76b are formed integrally with one another to define a unitary spring unit 80, as shown in Figure 15. Each unitary spring unit 80 has a uniform width W along the length L thereof.

20 Each unitary spring unit 80 is secured to the hub 72 in a pre-tensioned manner. In particular, the end of each spoke 76 within a respective unitary spring unit 80 that is connected to the hub 72 lies in a plane that is inclined at an angle to the axis of rotation A of the hub 72, or is otherwise skewed relative to the outer circumferential surface of the hub 72. The other end of each spoke 76 that is connected to the rim 74 lies in a plane
25 which extends substantially parallel to the axis of rotation of the hub 72.

Securing each spoke 76 to the hub 72 and rim 74 in the foregoing manner imparts a twist in each unitary spring unit 80 as it extends between the hub 72 and the rim 74. In the embodiment shown the twist is used to generate the desired pre-tension in the unitary
30 spring unit 80. The pre-tension arises, for example, because the unitary spring unit 80 is manufactured with a flat profile (as illustrated in Figure 15) and is held in a twisted configuration when secured to the hub 72 (as illustrated in schematically in Figure 16), or because the unitary spring unit 80 is manufactured with a twisted profile (not shown) that is opposite to that provided when secured to the hub 72.

35 The opposed spokes 76a,76b in each unitary spring unit 80 are connected to the hub 72 at circumferentially spaced locations on opposite sides of a circumferential hub line 82

that extends about the outer circumferential surface of the hub 72, about the axis of rotation A of the wheel 70, so as to extend tangentially from the hub 72, at an angle relative to the circumferential hub line 82, generally towards each other. They are connected at their other ends to the rim 74 on a circumferential rim line 84 that extends
5 about the inner circumferential surface of the rim 74, the axis of rotation A of the wheel 70, and is concentrically aligned with the circumferential hub line 82.

The opposed spokes 76a,76b of each unitary spring unit 80 pass each other as they extend generally towards each other from the hub 72 and thereafter follow their curved
10 profiles 78 so as to extend back towards each other as they extend towards the rim 74 so as to extend uniformly into one another at the rim 74. The spokes 76 are connected to the rim 74 at an angle to the circumferential rim line 84.

The spokes 76 are formed from laminated structures including a plurality of alternating
15 layers of carbon fibre and epoxy resin. The layers of carbon fibre are arranged within the laminated structures so as to be aligned along the lengths of the spokes 76 and provide a uni-directional strengthening effect.

The unitary spring units 80 are equidistantly spaced about the circumference of the
20 wheel 70. Since all of the unitary spring units 80 are equal in length and define the same profile, this means that the hub 72 is centrally located within the rim 74 in an unloaded or rest configuration of the wheel 70.

The resilient nature of the spokes 76 in each unitary spring unit allows each spring unit
25 80 to deform on the application of a compressive or tensile load, the curvature of the curved profile 78 of each spoke 76 increasing on the application of a compressive load and the curvature of the curved profile 78 of the spoke 76 decreasing on the application of a tensile load. Consequently, on the application of a radial load to the hub 72, the spokes 76 deform as the hub 72 moves relative to the rim 74 in the direction of the radial
30 load, the nature of the deformation of each spoke 76, i.e. elongation or compression, being determined by the direction of the applied load.

On removal of the radial load, the resilient nature of the spokes 76 means that each of
the spokes 76 resumes its original shape and the hub 72 is thereby returned to its
35 unloaded or rest position, centrally located within the rim 74.

Similarly, on the application of a radial load to the rim 74 so as to cause movement of the rim 74 towards the hub 72, the spokes 76 will deform in accordance with the direction of the radial load, as the rim 74 moves towards the hub 72, and will return the rim 74 to its unloaded or rest position relative to the hub 72 on removal of the load.

5

The angle of the angled connections between the spokes 76 and the hub 72 and a skewed connection between the spokes 76 and the rim 74, is chosen so that the curved profiles 78 of the spokes 76 follow their own trajectories in their own planes during deformation of the spokes 76, as opposed to deforming within the plane of the wheel 70.

10

As such, the spokes 76 do not collide during deformation.

The pre-tensioning of each unitary spring unit 80 improves the lateral stability of the wheel 70 by resisting twisting movement of the hub 72 relative to the rim 74 whilst at the same time facilitating the use of a relatively narrow rim 74.

15

Such an improvement in the lateral stability of the wheel 70 is achieved without the need to increase the width W of each unitary spring unit 80.

20

Arranging the spokes so as to define pairs of opposed spokes 76a,76b in which the curved profiles 78 of the spokes 76a,76b oppose each other, and connecting the opposed spokes 76a,76b of each pair to the hub 72 on either side of the circumferential hub line 82, enables the spokes to apply opposing turning forces to the hub 72 when a driving torque is applied to either the hub 72 or the rim 74. Consequently the spokes act on the hub 72 to resist rotation of the hub 72 relative to the rim 74. This is particularly advantageous in circumstances where the driving torque is applied to the hub 72 to either accelerate or decelerate rotation of the wheel 70.

25

Crossing of the spokes of each opposed pair of spokes 76a,76b as they extend generally towards each other from the hub 72 is advantageous also in that it improves the lateral stiffness of the wheel 70 and helps to resist twisting and other lateral movement of the hub 72 relative to the rim 74.

30

Each pair of opposed spokes 76a,76b are integrally formed with one another to define a plurality of unitary spring units 80 that are arranged about the circumference of the hub 72 in co-operating pairs of unitary spring units 80 located on opposite sides of the hub 72. This arrangement provides a balanced response on the application of a radial load to the hub 72 or rim 74, one unitary spring unit 80 compressing whilst the co-operating

35

unitary spring unit 80 elongates. When the wheel 70 is used on a vehicle or a bicycle, such balancing of the response to the spokes 76 to any such radial forces helps to provide a smooth ride for any occupant or rider as opposed to a bumpy ride that might otherwise result from an unbalanced arrangement of the spokes 76.

5

Consequently the resilient nature of the spokes 76, and the balanced arrangement of the pairs of opposed spokes 76a,76b, results in an enhanced suspension capability integrated within the wheel 70.

10 Other embodiments of the invention may include an odd number of unitary spring units 80 while still providing a balanced response to an applied load.

As with previously described embodiments, the spokes 76 may be formed from, or include, other reinforcing materials such as glass fibre, Kevlar (RTM), and hemp.

15

Moreover, the strength of each spoke 76 at the connection between the spoke 76 and the hub 72 may be increased to cope with the stresses applied to the spokes 76 at the connections with the hub 72 through the use of one or more additional layers of carbon fibre in the laminated structure at the ends of the spokes 76 fixedly connected to the hub
20 72.

A wheel 71 according to a fifth embodiment of the invention is shown in Figure 17.

25

Wheel 71 is essentially identical to the wheel 70 described above with reference to Figures 14 to 16. The same reference numerals are therefore used to designate corresponding features.

30

Wheel 71 differs from the wheel 70 shown in Figures 14 to 16 only in that it includes three pairs of opposed spokes 76a,76b as opposed to four. Wheel 70 otherwise functions in the same manner as the wheel 70 described above with reference to Figures 14 to 16.

35

The use of three opposed pairs of spokes 76a,76b reduces the cost of manufacture of the wheel 71 when compared with the use of four opposed spokes 76a,76b. It also increases the space available within the envelope defined by the rim 74 about the hub 72 and into which the spokes may move when deformed. It therefore reduces the importance of introducing a twist into the spokes by the use of angled connections

between the spokes 76 and the hub 72 and between the spokes 76 and the rim 74. It will be appreciated however that in relatively smaller wheels, where the space available between the hub and the rim is comparably less, the introduction of a twist will remain important to reduce the risk of adjacent spokes colliding during deformation.

5

A wheel 190 according to a sixth embodiment of the invention is shown in Figures 18 and 19.

10 Wheel 190 is based on the wheel 70 shown in Figures 14 to 16, and shares a number of features with the wheel 70. Such common features are designated using the same reference numerals.

15 Wheel 190, as illustrated in Figures 18 and 19, differs from the wheel 70 shown in Figures 14 to 16 in that each spoke 76 is pivotably connected at one end to the hub 72 and extends tangentially from the hub 72.

Pivotably connecting each spoke 76 to the hub in this manner allows the use of a thicker spoke 76 which improves lateral stiffness of the wheel 190, while allowing such a thicker spoke 76 to articulate relative to the hub 72 to a similar extent as a thinner spoke 76 which is fixedly secured to the hub 72.

20

Wheel 190 otherwise functions in the same manner as the wheel 70 shown in Figures 14 to 16.

25 Figures 20 and 21 illustrate a wheel 90 according to a seventh embodiment of the invention.

30 Wheel 90 includes a hub 92, a rim 94 and a plurality of spokes 96 arranged circumferentially around the hub 92. Each spoke 96 is fixedly connected at one end to the hub 92 so as to extend tangentially from the hub 92. The hub 92 defines an axis of rotation A of the wheel 90.

35 The spokes 96 include curved profiles 98 and are arranged to define pairs of opposed spokes 96a,96b spaced circumferentially about the wheel 90, the curved profiles 98 of the opposed spokes 96a,96b being curved in opposite directions to each other.

The spokes 96 of each pair of opposed spokes 96a,96b are formed integrally with one another to define a unitary spring unit 100 which has a uniform width W along the length L thereof.

- 5 Each unitary spring unit 100 is secured to the hub 92 in a pre-tensioned manner.

The end of each spoke 96 within a respective unitary spring unit 100 that is connected to the hub 92 and the other end of each spoke 96 that is connected to the rim 94 each lie in a plane that extends substantially parallel to the axis of rotation A of the hub 92.

10

The opposed spokes 96a,96b in each unitary spring unit 100 are connected to the hub 92 at circumferentially spaced locations on opposite sides of the circumferential hub line 102 that extends about the outer circumferential surface of the hub 92, about the axis of rotation A of the wheel 90, so as to extend tangentially from the hub 92.

15

The ends connected to the hub 92 also extend at an angle relative to the circumferential hub line 102 so as to impart a twist in each unitary spring unit 100 as it extends between the hub 92 and rim 94. This twist is used, at least in part, to generate the desired pre-tension in the unitary spring unit 100. Additional pre-tension may arise, for example,
20 because the unitary spring unit 100 is manufactured completely flat and is then held in a curved and twisted configuration when secured to the hub 92.

25

In addition the ends of the opposed spoke 96a,96b in a given unitary spring unit 100 that are connected to the hub 92 are circumferentially spaced from one another about the outer circumferential surface of the hub 92, as shown in Figure 21. Such circumferential spacing of the ends allows for the use of a longer unitary spring unit 100 within a given rim 94 diameter.

30

Connecting the spokes of each pair of opposing spokes to the hub at circumferentially spaced locations also allows the use of a longer spring unit within a given rim diameter and so allows for tuning of the resistance to movement of the hub relative to the rim in a radial direction.

35

The other end of each opposed spoke 96a,96b is connected to the rim 94 on a circumferential rim line 104, that extends about the inner circumferential surface of the rim 94, about the axis of rotation A of the wheel 90, and is concentrically aligned with the circumferential hub line 102. The spokes 96 are connected to the rim 94 at an angle to

the circumferential rim line 104, the angle being greater than in the wheel 70 shown in Figures 14 to 16 to help ensure adjacent unitary spring units 100 do not collide during operation of the wheel 90, and to allow the inclusion of a wider unitary spring unit 100 if desired.

5

The spokes 96 are formed from laminated structures including a plurality of alternating layers of carbon fibre and epoxy resin. The layers of carbon fibre are arranged within the laminated structures so as to be aligned along the lengths of the spokes 96 and provide a uni-directional strengthening effect.

10

The unitary spring units 100 are equidistantly spaced about the circumference of the wheel 90. Since all of the unitary spring units 100 are equal in length and define the same profile, this means that the hub 92 is centrally located within the rim 94 in an unloaded or rest configuration of the wheel 90.

15

The resilient nature of the spokes 96 in each unitary spring unit allows each spring unit 100 to deform on the application of a compressive or tensile load, the curvature of the curved profile 98 of each spoke 96 increasing on the application of a compressive load and the curvature of the curved profile 98 of the spoke 96 decreasing on the application of a tensile load. Consequently, on the application of a radial load to the hub 92, the spokes 96 deform as the hub 92 moves relative to the rim 94 in the direction of the radial load, the nature of the deformation of each spoke 94, i.e. elongation or compression, being determined by the direction of the applied load.

20

On removal of the radial load, the resilient nature of the spokes 96 means that each of the spokes 96 resumes its original shape and the hub 92 is thereby returned to its unloaded or rest position, centrally located within the rim 94.

25

Similarly, on the application of a radial load to the rim 94 so as to cause movement of the rim 94 towards the hub 92, the spokes 96 will deform in accordance with the direction of the radial load, as the rim 94 moves towards the hub 92, and will return the rim 94 to its unloaded or rest position relative to the hub 92 on removal of the load.

30

As mentioned above, the angle of the angled connections between the spokes 96 and the hub 92 and between the spokes 96 and the rim 94, is chosen so that the curved profiles 98 of the spokes 96 follow their own trajectories in their own planes during

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deformation of the spokes 96, as opposed to deforming within the plane of the wheel 90. As such, the spokes 96 do not collide during deformation.

5 The pre-tensioning of each unitary spring unit 100 improves the lateral stability of the wheel 90 by resisting twisting movement of the hub 92 relative to the rim 94 whilst at the same time facilitating the use of a relatively narrow rim 94.

Such an improvement in the lateral stability of the wheel 90 is achieved without the need to increase the width W of each unitary spring unit 100.

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In the embodiment shown in Figures 20 and 21 opposing spokes 96a,96b of adjacent pairs of opposing spokes 96a,96b are also configured so as to cross as they extend tangentially from the hub 92. It will be appreciated that this in turn further increases the lateral stiffness of the wheel 90, thereby reducing lateral flexibility of the hub 92 relative to the rim 94.

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Arranging the spokes 96 so as to define pairs of opposed spokes 96a,96b in which the curved profiles 98 of the spokes 96a,96b oppose each other, and connecting the opposed spokes 96a,96b of each pair to the hub 92 on either side of the circumferential hub line 102, enables the spokes to apply opposing turning forces to the hub 92 when a driving torque is applied to either the hub 92 or the rim 94. Consequently the spokes act on the hub 92 to resist rotation of the hub 92 relative to the rim 94. This is particularly advantageous in circumstances where the driving torque is applied to the hub 92 to either accelerate or decelerate rotation of the wheel 90.

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The embodiment shown in Figure 20 differs from that shown in Figures 14 and 17 in that the spokes of each pair of opposed spokes 96a,96b are connected to the hub 92 at a greater circumferential spacing about the circumferential hub line 102 so as to extend generally away from each other as they extend tangentially from the hub 92, as opposed to extending generally towards each other. This arrangement further improves the ability of the spokes in each pair of opposed spokes 96a,96b to produce opposed turning forces on the application of a driving torque and resist rotational movement of the hub 92 relative to the rim 94.

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35 Each pair of opposed spokes 96a,96b are integrally formed with one another to define a plurality of unitary spring units 100 that are arranged about the circumference of the hub 92 in co-operating pairs of unitary spring units located on opposite sides of the hub 92.

This arrangement provides a balanced response on the application of a radial load to the hub 92 or rim 94, one unitary spring unit 100 compressing whilst the co-operating unitary spring unit 100 elongates. When the wheel 90 is used on a vehicle or a bicycle, such balancing of the response to the spokes 96 to any such radial forces helps to provide a smooth ride for any occupant or rider as opposed to a bumpy ride that might otherwise result from an unbalanced arrangement of the spokes 96.

Consequently the resilient nature of the spokes 96, and the balanced arrangement of the pairs of opposed spokes 96a,96b, results in an enhanced suspension capability integrated within the wheel 90.

Other embodiments of the invention may include an odd number of unitary spring units 100 while still providing a balanced response to an applied load.

As with previously described embodiments, the spokes 96 may be formed from, or include, other reinforcing materials such as glass fibre, Kevlar (RTM), and hemp.

Moreover, the strength of each spoke 96 at the connection between the spoke 96 and the hub 92 may be increased to cope with the stresses applied to the spokes 96 at the connections with the hub 92 through the use of one or more additional layers of carbon fibre in the laminated structure at the ends of the spokes 96 fixedly connected to the hub 92.

Figures 22 and 23 illustrate a wheel 160 according to an eighth embodiment of the invention. Wheel 160 is similar to the wheel 90 shown in Figures 20 and 21 and shares a number of features which are designated using the same reference numerals.

The wheel 160 shown in Figures 22 and 23 again includes a hub 92, a rim 94 and a plurality of spokes 96 arranged circumferentially around the hub 92. Each spoke 96 is fixedly connected at one end to the hub 92 so as to extend tangentially from the hub 92. The hub 92 defines an axis of rotation A of the wheel 160.

The spokes 96 each include curved profiles 98 having a constant radius of curvature and are arranged to define pairs of opposed spokes 96a,96b spaced circumferentially about the wheel 160, the curved profiles 98 of the opposed spokes 96a,96b being curved in opposite directions to each other.

The spokes 96 of each pair of opposed spokes 96a,96b are formed integrally with one another to define a unitary spring unit 100 which has a uniform width W along the length L thereof.

- 5 Each unitary spring unit 100 is secured to the hub 92 in a pre-tensioned manner.

The end of each spoke 96 within a respective unitary spring unit 100 that is connected to the hub 92 and the other end of each spoke 96 that is connected to the rim 94 each lie in a plane that extends substantially parallel to the axis of rotation A of the hub 92.

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The opposed spokes 96a,96b in each unitary spring unit 100 are connected to the hub 92 on opposite sides of the circumferential hub line 102 that extends about the outer circumferential surface of the hub 92, about the axis of rotation A of the wheel 160, so as to extend tangentially from the hub 92. Such tangential extension helps to avoid one unitary spring unit 100 colliding with another spring unit 100 during deformation of the spokes 96. It also improves the ability of the spokes 96 to absorb and withstand the turning forces generated when a driving torque is applied to the hub 92 or to the rim 94.

15

The ends of the spokes 96 connected to the hub 92 also extend at an angle relative to the circumferential hub line 102 so as to impart a twist in each unitary spring unit 100 as it extends between the hub 92 and rim 94. This twist is used, at least in part, to generate the desired pre-tension in the unitary spring unit 100. Additional pre-tension may arise, for example, because the unitary spring unit 100 is manufactured completely flat and is then held in a curved and twisted configuration when secured to the hub 92.

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One way in which the wheel 160 shown in Figures 22 and 23 differs from the wheel 90 shown in Figures 20 and 21 is that the end of each opposed spoke 96a,96b in a given unitary spring unit 100 is connected to the hub 92 so as to be aligned with one another on opposed sides of the circumferential hub line 102, i.e. the circumferential spacing between the two ends relative to the circumferential hub line 102 is at a maximum of 360° so that in effect there is no circumferential spacing between the ends of the spokes. Arranging the ends adjacent to one another in this manner allows for the use of an even longer unitary spring unit 100, for a given diameter of rim 94, than in the wheel 90 shown in Figures 20 and 21, and allows each pair of opposed spokes 96a,96b to define a circular profile.

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The other end of each opposed spoke 96a,96b is connected to the rim 94 on a circumferential rim line 104 that extends about the inner circumferential surface of the rim 94, about the axis of rotation A of the wheel 160, and concentrically aligned with the circumferential hub line 102. The spokes 96 are connected to the rim 94 at an angle to the circumferential rim line 104, the angle again being greater than the wheel 70 shown in Figures 14 to 16 to help ensure adjacent unitary spring units 100 do not collide during operation of the wheel 160, and to allow the inclusion of a wider unitary spring unit 100 if desired.

10 The spokes 96 are formed from laminated structures including a plurality of alternating layers of carbon fibre and epoxy resin. The layers of carbon fibre are arranged within the laminated structures so as to be aligned along the lengths of the spokes 96 and provide a uni-directional strengthening effect.

15 It is envisaged that in other embodiments however the spokes 96 may be formed from a plastics material to facilitate mass production, for example, of wheels suitable for use in pushchairs or strollers.

20 The unitary spring units 100 are equidistantly spaced about the circumference of the wheel 160. Since all of the unitary spring units 100 are equal in length and define the same profile, this means that the hub 92 is centrally located within the rim 94 in an unloaded or rest configuration of the wheel 160.

25 The resilient nature of the spokes 96 in each unitary spring unit allows each spring unit 100 to deform on the application of a compressive or tensile load, the curvature of the curved profile 98 of each spoke 96 increasing on the application of a compressive load and the curvature of the curved profile 98 of the spoke 96 decreasing on the application of a tensile load. Consequently, on the application of a radial load to the hub 92, the spokes 96 deform as the hub 92 moves relative to the rim 94 in the direction of the radial load, the nature of the deformation of each spoke 94, i.e. elongation or compression, being determined by the direction of the applied load.

35 On removal of the radial load, the resilient nature of the spokes 96 means that each of the spokes 96 resumes its original shape and the hub 92 is thereby returned to its unloaded or rest position, centrally located within the rim 94.

Similarly, on the application of a radial load to the rim 94 so as to cause movement of the rim 94 towards the hub 92, the spokes 96 will deform in accordance with the direction of the radial load, as the rim 94 moves towards the hub 92, and will return the rim 94 to its unloaded or rest position relative to the hub 92 on removal of the load.

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As mentioned above, the angle of the angled connections between the spokes 96 and the hub 92 and between the spokes 96 and the rim 94, is chosen so that the curved profiles 98 of the spokes 96 follow their own trajectories in their own planes during deformation of the spokes 96, as opposed to deforming within the plane of the wheel 160. As such, the spokes 96 do not collide during deformation.

10

The pre-tensioning of each unitary spring unit 100 improves the lateral stability of the wheel 160 by resisting twisting movement of the hub 92 relative to the rim 94 whilst at the same time facilitating the use of a relatively narrow rim 94.

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Such an improvement in the lateral stability of the wheel 160 is achieved without the need to increase the width W of each unitary spring unit 100.

Arranging the spokes 96 so as to define pairs of opposed spokes 96a,96b in which the curved profiles 98 of the spokes 96a,96b oppose each other, and connecting the opposed spokes 96a,96b of each pair to the hub 92 on either side of the circumferential hub line 102, enables the spokes to apply opposing turning forces to the hub 92 when a driving torque is applied to either the hub 92 or the rim 94. Consequently the spokes act on the hub 92 to resist rotation of the hub 92 relative to the rim 94. This is particularly advantageous in circumstances where the driving torque is applied to the hub 92 to either accelerate or decelerate rotation of the further wheel 160.

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As in the previous embodiment described with reference to Figures 21 and 22, the spokes of each pair of opposed spokes 96a,96b cross an opposing spoke of an adjacent pair of opposed spokes, which in turn helps to improve the lateral stiffness of the wheel 160.

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Each pair of opposed spokes 96a,96b are integrally formed with one another to define a plurality of unitary spring units 100 that are arranged about the circumference of the hub 92 in co-operating pairs of unitary spring units located on opposite sides of the hub 92. This arrangement provides a balanced response on the application of a radial load to the hub 92 or rim 94, one unitary spring unit 100 compressing whilst the co-operating unitary

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spring unit 100 elongates. When the further wheel 160 is used on a vehicle or a bicycle, such balancing of the response to the spokes 96 to any such radial forces helps to provide a smooth ride for any occupant or rider as opposed to a bumpy ride that might otherwise result from an unbalanced arrangement of the spokes 96.

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Consequently the resilient nature of the spokes 96, and the balanced arrangement of the pairs of opposed spokes 96a,96b, results in an enhanced suspension capability integrated within the further wheel 160.

10 Other embodiments of the invention may include an odd number of unitary spring units 100 while still providing a balanced response to an applied load.

As with previously described embodiments, the spokes 96 may be formed from, or include, other reinforcing materials such as glass fibre, Kevlar (RTM), and hemp.

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Moreover, the strength of each spoke 96 at the connection between the spoke 96 and the hub 92 may be increased to cope with the stresses applied to the spokes 96 at the connections with the hub 92 through the use of one or more additional layers of carbon fibre in the laminated structure at the ends of the spokes 96 fixedly connected to the hub

20 92.

A wheel 170 according to a ninth embodiment of the invention is illustrated in Figures 24 and 25. Wheel 170 has a similar configuration to the wheel 160 shown in Figures 22 and 23 described above, and like features again share the same reference numerals.

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The wheel 170 shown in Figures 24 and 25 differs from the wheel 160 shown in Figures 22 and 23 in that an end of each opposed spoke 96a,96b in a given unitary spring unit 100 is pivotally connected to the hub 92 (rather than fixedly connected as in the wheel 160 shown in Figures 22 and 23).

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Wheel 170 is otherwise essentially identical to the further wheel 160 and, as such, functions in essentially the same manner as set out hereinabove.

A wheel according to another, tenth, embodiment of the invention is designated generally by the reference numeral 110 and is shown in Figures 26 and 27.

35

The wheel 110 includes a hub 112, a rim 114 and a plurality of spokes 116 arranged circumferentially around the hub 112. Each spoke 116 is fixedly connected at one end to the hub 112 so as to extend tangentially from the hub 112. The hub 112 defines an axis of rotation A of the wheel 110.

5

The spokes 116 include curved profiles 118 and are arranged to define pairs of opposed spokes 116a, 116b spaced circumferentially about the wheel 110, the curved profiles 118 of the opposed spokes 116a, 116b being curved in opposite directions to each other.

10 The spokes 116 of each pair of opposed spokes 116a, 116b are formed integrally with one another to define a unitary spring unit 120 which has a uniform width W along the length L thereof.

Each unitary spring unit 120 is secured to the hub 112 in a pre-tensioned manner.

15

The end of each spoke 116 within a respective unitary spring unit 120 that is connected to the hub 112 lies in a plane that is inclined at an angle to the axis of rotation A of the hub, or otherwise skewed relative to the outer circumferential surface of the hub 112, while the other end of each spoke 116 that is connected to the rim 114 lies in a plane
20 that extends substantially parallel to the axis of rotation A of the hub 112.

The opposed spokes 116a, 116b in each unitary spring unit 120 are connected to the hub 112 at circumferentially spaced locations on opposite sides of a circumferential hub line 122 that extends about the outer circumferential surface of the hub 112, about axis of
25 rotation A of the wheel 110, so as to extend tangentially from the hub 112. Such tangential extension helps to avoid one unitary spring unit 120 colliding with another spring unit 120 during operation of the wheel 110.

The ends also extend at an angle relative to the circumferential hub line 122.

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In addition the ends of the opposed spokes 116a, 116b in a given unitary spring unit 120 that are connected to the hub 112 are spaced from one another about the circumference of the hub 112, as shown in Figure 27. Such spacing of the ends allows for the use of a longer unitary spring unit 120 within a given rim 114 diameter,

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The other end of each opposed spoke 116a, 116b is connected to the rim 114 on a circumferential rim line 124 that extends about the inner circumferential surface of the

rim, about the axis of rotation A of the wheel 110, and is concentrically aligned with the circumferential hub line 122. The spokes 116 are connected to the rim 114 at an angle to the circumferential rim line 124, the angle being greater than in the wheel 70 shown in Figures 14 to 16 to help ensure adjacent unitary spring units 120 do not collide during operation of the wheel 110, and allow the inclusion of a wider unitary spring unit 120 if desired.

Securing the end of each opposed spoke 116a, 116b to the hub 112 on opposite sides of the circumferential hub line 122, in a plane inclined to the axis of rotation A of the hub 112, and radially spaced from one another allows for a greater degree of twist to be imparted in each unitary spring unit 120 as it extends between the hub 112 and the rim 114 than in the wheels 70; 90 shown in Figures 14 to 16 and Figures 20 and 21 respectively.

Since the amount of twist at least in part contributes to the degree of pre-tension in each unitary spring unit 120, and hence the degree of lateral stability imparted to the wheel 110, increasing the amount of twist in the foregoing manner allows the use of a narrower (and hence lighter) unitary spring unit 120 than in each of the wheels 70; 90 while providing the same degree of resistance to an applied load.

The spokes 116 are formed from laminated structures including a plurality of alternating layers of carbon fibre and epoxy resin. The layers of carbon fibre are arranged within the laminated structures so as to be aligned along the lengths of the spokes 116 and provide a uni-directional strengthening effect.

The unitary spring units 120 are equidistantly spaced about the circumference of the wheel 110. Since all of the unitary spring units 120 are equal in length and define the same profile, this means that the hub 112 is centrally located within the rim 114 in an unloaded or rest configuration of the wheel 110.

The resilient nature of the spokes 116 in each unitary spring unit allows each spring unit 120 to deform on the application of a compressive or tensile load, the curvature of the curved profile 118 of each spoke 116 increasing on the application of a compressive load and the curvature of the curved profile 118 of the spoke 116 decreasing on the application of a tensile load. Consequently, on the application of a radial load to the hub 112, the spokes 116 deform as the hub 112 moves relative to the rim 114 in the direction

of the radial load, the nature of the deformation of each spoke 114, i.e. elongation or compression, being determined by the direction of the applied load.

5 On removal of the radial load, the resilient nature of the spokes 116 means that each of the spokes 116 resumes its original shape and the hub 112 is thereby returned to its unloaded or rest position, centrally located within the rim 114.

10 Similarly, on the application of a radial load to the rim 114 so as to cause movement of the rim 114 towards the hub 112, the spokes 116 will deform in accordance with the direction of the radial load, as the rim 114 moves towards the hub 112, and will return the rim 114 to its unloaded or rest position relative to the hub 112 on removal of the load.

15 As mentioned above, the angle of the angled connections between the spokes 116 and the hub 112 and between the spokes 116 and the rim 114, is chosen so that the curved profiles 118 of the spokes 116 follow their own trajectories in their own planes during deformation of the spokes 116, as opposed to deforming within the plane of the wheel 110. As such, the spokes 116 do not collide during deformation.

20 The pre-tensioning of each unitary spring unit 120 improves the lateral stability of the wheel 110 by resisting twisting movement of the hub 112 relative to the rim 114 whilst at the same time facilitating the use of a relatively narrow rim 114.

25 Such an improvement in the lateral stability of the wheel 110 is achieved while providing the option of decreasing the width W of each unitary spring unit 120.

30 Arranging the spokes so as to define pairs of opposed spokes 116a,116b in which the curved profiles 118 of the spokes 116a,116b oppose each other, and connecting the opposed spokes 116a,116b of each pair to the hub 112 on either side of the circumferential hub line 122, enables the spokes to apply opposing turning forces to the hub 112 when a driving torque is applied to either the hub 112 or the rim 114. Consequently the spokes act on the hub 112 to resist rotation of the hub 112 relative to the rim 114. This is particularly advantageous in circumstances where the driving torque is applied to the hub 112 to either accelerate or decelerate rotation of the wheel 110.

35 Each pair of opposed spokes 116a,116b are integrally formed with one another to define a plurality of unitary spring units 120 that are arranged about the circumference of the hub 112 in co-operating pairs of unitary spring units located on opposite sides of the hub

112. This arrangement provides a balanced response on the application of a radial load to the hub 112 or rim 114, one unitary spring unit 120 compressing whilst the co-operating unitary spring unit 120 elongates. When the wheel 110 is used on a vehicle or a bicycle, such balancing of the response to the spokes 116 to any such radial forces helps to provide a smooth ride for any occupant or rider as opposed to a bumpy ride that might otherwise result from an unbalanced arrangement of the spokes 116.

Consequently the resilient nature of the spokes 116, and the balanced arrangement of the pairs of opposed spokes 116a,116b, results in an enhanced suspension capability integrated within the wheel 110.

Other embodiments of the invention may include an odd number of unitary spring units 120 while still providing a balanced response to an applied load.

As with previously described embodiments, the spokes 116 may be formed from, or include, other reinforcing materials such as glass fibre, Kevlar (RTM), and hemp.

Moreover, the strength of each spoke 116 at the connection between the spoke 116 and the hub 112 may be increased to cope with the stresses applied to the spokes 116 at the connections with the hub 112 through the use of one or more additional layers of carbon fibre in the laminated structure at the ends of the spokes 116 fixedly connected to the hub 112.

A wheel 180 according to an eleventh embodiment of the invention is illustrated in Figures 28 and 29.

Wheel 180 is similar to the wheel 110 shown in Figures 26 and 27, and like features share the same reference numerals.

The wheel 180 shown in Figures 28 and 29 again includes a hub 112, a rim 114 and a plurality of spokes 116 arranged circumferentially around the hub 112. Each spoke 116 is fixedly connected at one end to the hub 112 and differs from the wheel 110 shown in Figures 26 and 27 in that it extends from the end of the hub 112, substantially perpendicularly relative to the outer circumferential surface of the hub 112. The hub 112 defines an axis of rotation A of the wheel 180.

The spokes 116 include curved profiles 118 and are arranged to define pairs of opposed spokes 116a,116b spaced circumferentially about the wheel 180, the curved profiles 118 of the opposed spokes 116a,116b being curved in opposite directions to each other.

- 5 The spokes 116 of each pair of opposed spokes 116a,116b are formed integrally with one another to define a unitary spring unit 120 which has a uniform width W along the length L thereof.

Each unitary spring unit 120 is secured to the hub 112 in a pre-tensioned manner.

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Wheel 180 also differs from the wheel 110 shown in Figures 26 and 27 in that the end of each spoke 116 within a respective unitary spring unit 120 that is connected to the hub 112 lies in a plane that is substantially perpendicular to the axis of rotation A of the hub. In the meantime, as with the wheel 110 shown in Figures 26 and 27, the other end of
15 each spoke 116 that is connected to the rim 114 lies in a plane that extends substantially parallel to the axis of rotation A of the hub 112.

15

The opposed spokes 116a,116b in each unitary spring unit 120 are connected to the hub 112 at spaced locations on opposite sides of the circumferential hub line 122 that
20 extends about the outer circumferential surface of the hub 112, about the axis of rotation A of the wheel 180.

20

The end of each opposed spoke 116a,116b in a given unitary spring unit 120 that are connected to the hub 112 are radially spaced from one another about the circumference
25 of the hub 112 by approximately 90°, as shown in Figure 27. Such radial spacing of the ends provides for a symmetrical arrangement of unitary spring units 120, although other radial spacings are also possible depending on the number of unitary spring units 120 to be included in the other wheel 180.

25

The other end of each opposed spoke 116a,116b is connected to the rim 114 on a circumferential rim line 124 that extends about the inner circumferential surface of the rim 113, about the axis of rotation A of the wheel 180, and concentrically aligned with the circumferential hub line 122.

30

35 Securing the end of each opposed spoke 116a,116b to the hub 112 on opposite sides of the circumferential hub line 122, so as to extend generally perpendicularly relative to the outer circumferential surface of the hub 112, and circumferentially spaced from one

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another allows for a desired degree of twist to be imparted in each unitary spring unit 120 as it extends between the hub 112 and the rim 114.

5 The spokes 116 are formed from laminated structures including a plurality of alternating layers of carbon fibre and epoxy resin. The layers of carbon fibre are arranged within the laminated structures so as to be aligned along the lengths of the spokes 116 and provide a uni-directional strengthening effect.

10 The unitary spring units 120 are equidistantly spaced about the circumference of the wheel 180. Since all of the unitary spring units 120 are equal in length and define the same profile, this means that the hub 112 is centrally located within the rim 114 in an unloaded or rest configuration of the wheel 180.

15 The resilient nature of the spokes 116 in each unitary spring unit allows each spring unit 120 to deform on the application of a compressive or tensile load, the curvature of the curved profile 118 of each spoke 116 increasing on the application of a compressive load and the curvature of the curved profile 118 of the spoke 116 decreasing on the application of a tensile load. Consequently, on the application of a radial load to the hub 112, the spokes 116 deform as the hub 112 moves relative to the rim 114 in the direction
20 of the radial load, the nature of the deformation of each spoke 114, i.e. elongation or compression, being determined by the direction of the applied load.

On removal of the radial load, the resilient nature of the spokes 116 means that each of the spokes 116 resumes its original shape and the hub 112 is thereby returned to its
25 unloaded or rest position, centrally located within the rim 114.

Similarly, on the application of a radial load to the rim 114 so as to cause movement of the rim 114 towards the hub 112, the spokes 116 will deform in accordance with the direction of the radial load, as the rim 114 moves towards the hub 112, and will return the
30 rim 114 to its unloaded or rest position relative to the hub 112 on removal of the load.

The connections between the spokes 116 and the hub 112 and between the spokes 116 and the rim 114 are such that the curved profiles 118 of the spokes 116 follow their own trajectories in their own planes during deformation of the spokes 116, as opposed to
35 deforming within the plane of the wheel 180. As such, the spokes 116 do not collide during deformation.

The pre-tensioning of each unitary spring unit 120 improves the lateral stability of the wheel 180 by resisting twisting movement of the hub 112 relative to the rim 114 whilst at the same time facilitating the use of a relatively narrow rim 114.

- 5 Such an improvement in the lateral stability of the wheel 180 is achieved while providing the option of decreasing the width W of each unitary spring unit 120.

Arranging the spokes so as to define pairs of opposed spokes 116a,116b in which the curved profiles 118 of the spokes 116a,116b oppose each other, and connecting the
10 opposed spokes 116a,116b of each pair to the hub 112 on either side of the circumferential hub line 122, enables the spokes to apply opposing turning forces to the hub 112 when a driving torque is applied to either the hub 112 or the rim 114. Consequently the spokes act on the hub 112 to resist rotation of the hub 112 relative to the rim 114. This is particularly advantageous in circumstances where the driving torque
15 is applied to the hub 112 to either accelerate or decelerate rotation of the wheel 180.

Each pair of opposed spokes 116a,116b are integrally formed with one another to define a plurality of unitary spring units 120 that are arranged about the circumference of the hub 112 in co-operating pairs of unitary spring units located on opposite sides of the hub
20 112. This arrangement provides a balanced response on the application of a radial load to the hub 112 or rim 114, one unitary spring unit 120 compressing whilst the co-operating unitary spring unit 120 elongates. When the wheel 180 is used on a vehicle or a bicycle, such balancing of the response to the spokes 116 to any such radial forces helps to provide a smooth ride for any occupant or rider as opposed to a bumpy ride that
25 might otherwise result from an unbalanced arrangement of the spokes 116.

Consequently the resilient nature of the spokes 116, and the balanced arrangement of the pairs of opposed spokes 116a,116b, results in an enhanced suspension capability integrated within the wheel 180.

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Other embodiments of the invention may include an odd number of unitary spring units 120 while still providing a balanced response to an applied load.

As with previously described embodiments, the spokes 116 may be formed from, or
35 include, other reinforcing materials such as glass fibre, Kevlar (RTM), and hemp.

Moreover, the strength of each spoke 116 at the connection between the spoke 116 and the hub 112 may be increased to cope with the stresses applied to the spokes 116 at the connections with the hub 112 through the use of one or more additional layers of carbon fibre in the laminated structure at the ends of the spokes 116 fixedly connected to the
5 hub 112.

A wheel 130 according to a twelfth embodiment of the invention is shown in Figure 30.

The wheel 130 includes a hub 132, a rim 134 and a plurality of spokes 136 arranged
10 circumferentially around the hub 132. Each spoke 136 is fixedly connected at one end to the hub 132 so as to extend tangentially from the hub 132. The hub 132 defines an axis of rotation A of the wheel 130.

The spokes 136 include curved profiles 138 and are arranged to define pairs of opposed
15 spokes 136a, 136b spaced circumferentially about the wheel 130, the curved profiles 138 of the opposed spokes 136a, 136b being curved in opposite directions to each other.

The spokes 136 of each pair of opposed spokes 136a, 136b are formed integrally with one another to define a unitary spring unit 140 which has a uniform width W along the
20 length L thereof. The unitary spring units 140 are, in turn, integrally formed with one another to define an endless unitary spring assembly 146.

The unitary spring assembly 146 is secured to the hub 132 in a pre-tensioned manner by imparting a twist in each unitary spring unit 140 as it extends between the hub 132 and
25 the rim 134. A series of slots 148 are provided in the hub 132 each of which receives the end of an opposed spoke 136a, 136b in adjacent unitary spring units 140.

In this manner the end of each spoke 136 within a respective unitary spring unit 140 that is connected to the hub 132 lies in a plane that is inclined at an angle to the axis of
30 rotation A of the hub and, in particular, inclined almost perpendicularly to the axis of rotation A.

The angle of inclination is chosen such that the ends extend at an angle relative to a circumferential hub line 142 that extends about the outer circumferential surface of the
35 hub 132, about the axis of rotation A of the wheel 130, and thereby allow adjacent unitary spring units 140 to pass over one another as they extend away from the hub 132.

The other end of each spoke 136 that is connected to the rim 134 lies in a plane that extends substantially parallel to the axis of rotation A of the wheel 130 and is connected to the rim 134 on a circumferential rim line 144 that extends about the inner circumferential surface of the rim 134, about the axis of rotation A of the wheel 130, and concentrically aligned with the circumferential hub line 142. The spokes 136 are connected to the rim 134 at an angle to the circumferential rim line 144 to accommodate securing of the spokes 136 to the hub 132 in the aforementioned manner while maintaining a desired degree of twist in each unitary spring unit 140.

The twist at least in part contributes to the degree of pre-tension in each unitary spring unit 140, and hence the degree of lateral stability imparted to the wheel 130.

The spokes 136 are formed from laminated structures including a plurality of alternating layers of carbon fibre and epoxy resin. The layers of carbon fibre are arranged within the laminated structures so as to be aligned along the lengths of the spokes 136 and provide a uni-directional strengthening effect.

The unitary spring units 140 are equidistantly spaced about the circumference of the wheel 130. Since all of the unitary spring units 140 are equal in length and define the same profile, this means that the hub 132 is centrally located within the rim 134 in an unloaded or rest configuration of the wheel 130.

The resilient nature of the spokes 136 in each unitary spring unit allows each spring unit 140 to deform on the application of a compressive or tensile load, the curvature of the curved profile 138 of each spoke 136 increasing on the application of a compressive load and the curvature of the curved profile 138 of the spoke 136 decreasing on the application of a tensile load. Consequently, on the application of a radial load to the hub 132, the spokes 136 deform as the hub 132 moves relative to the rim 134 in the direction of the radial load, the nature of the deformation of each spoke 134, i.e. elongation or compression, being determined by the direction of the applied load.

On removal of the radial load, the resilient nature of the spokes 136 means that each of the spokes 136 resumes its original shape and the hub 132 is thereby returned to its unloaded or rest position, centrally located within the rim 134.

Similarly, on the application of a radial load to the rim 134 so as to cause movement of the rim 134 towards the hub 132, the spokes 136 will deform in accordance with the

direction of the radial load, as the rim 134 moves towards the hub 132, and will return the rim 134 to its unloaded or rest position relative to the hub 132 on removal of the load.

5 As mentioned above, the angle of the angled connections between the spokes 136 and the hub 132 and between the spokes 136 and the rim 134, is chosen so that the curved profiles 138 of the spokes 136 following their own trajectories in their own planes during deformation of the spokes 136, as opposed to deforming within the plane of the wheel 130. As such, the spokes 136 do not collide during deformation.

10 Arranging the spokes so as to define pairs of opposed spokes 136a,136b in which the curved profiles 138 of the spokes 136a,136b oppose each other enables the spokes to apply opposing turning forces to the hub 132 when a driving torque is applied to either the hub 132 or the rim 134. Consequently the spokes act on the hub 132 to resist rotation of the hub 132 relative to the rim 134. This is particularly advantageous in
15 circumstances where the driving torque is applied to the hub 132 to either accelerate or decelerate rotation of the wheel 130.

Each pair of opposed spokes 136a,136b are integrally formed with one another to define a plurality of unitary spring units 140 that are themselves integrally formed with one
20 another to define a unitary spring assembly 146. The unitary spring units 140 are arranged about the circumference of the hub 132 in co-operating pairs of unitary spring units located on opposite sides of the hub 132. This arrangement provides a balanced response on the application of a radial load to the hub 132 or rim 134, one unitary spring unit 140 compressing whilst the co-operating unitary spring unit 140 elongates. When the
25 wheel 130 is used on a vehicle or a bicycle, such balancing of the response to the spokes 136 to any such radial forces helps to provide a smooth ride for any occupant or rider as opposed to a bumpy ride that might otherwise result from an unbalanced arrangement of the spokes 136.

30 Consequently the resilient nature of the spokes 136, and the balanced arrangement of the pairs of opposed spokes 136a,136b, results in an enhanced suspension capability integrated within the wheel 130.

Other embodiments of the invention may include an odd number of unitary spring units
35 140 which are integrally formed with one another while still providing a balanced response to an applied load.

As with previously described embodiments, the spokes 136 may be formed from, or include, other reinforcing materials such as glass fibre, Kevlar (RTM), and hemp.

- Moreover, the strength of each spoke 136 at the connection between the spoke 136 and the hub 132 may be increased to cope with the stresses applied to the spokes 136 at the connections with the hub 132 through the use of one or more additional layers of carbon fibre in the laminated structure at the ends of the spokes 136 fixedly connected to the hub 132.
- 5

CLAIMS

1. A wheel comprising a hub, a rim and a plurality of resilient spokes arranged to define pairs of opposed spokes spaced circumferentially around the wheel, the hub defining an axis of rotation of the wheel and each spoke being connected at or towards one end to the hub and at or towards its other end to the rim, wherein the spokes of each pair of opposed spokes are connected to the hub on opposite sides of a circumferential hub line that extends about an outer circumferential surface of the hub, and each spoke being connected to the rim on a circumferential rim line that extends about an inner circumferential surface of the rim and is concentrically aligned with the circumferential hub line, the spokes of each pair of opposed spokes being shaped to follow curved profiles extending towards each other as they extend towards the rim.
2. A wheel according to Claim 1 wherein the spokes of each pair of opposed spokes are connected to the hub at circumferentially spaced locations along the length of the circumferential hub line.
3. A wheel according to Claim 1 or Claim 2 wherein the spokes of each pair of opposed spokes are connected at or towards one end to the hub so as to extend tangentially from the outer circumferential surface of the hub.
4. A wheel according to any preceding claim wherein the spokes of each pair of opposed spokes extend from the hub generally towards each other, the spokes of each pair of opposed spokes being shaped to pass each other and thereafter follow curved profiles extending back towards each other as they extend towards the rim.
5. A wheel according to any one of Claims 1 to 3 wherein each spoke of each pair of opposed spokes extends from the hub generally towards an opposed spoke of an immediately adjacent pair of opposed spokes, the spoke being shaped to pass the opposed spoke of the immediately adjacent pair of opposed spokes and thereafter follow a curved profile so that the spokes of each pair of opposed spokes extend towards each other as they extend towards the rim.
6. A wheel according to any preceding claim wherein the spokes of each pair of opposed spokes meet substantially end to end at the rim.

7. A wheel according to any preceding claim wherein each spoke is shaped to vary in width between the hub and the rim, in a direction parallel to the axis of rotation of the wheel, such that the width is greatest through the curved profile of the spoke.

5 8. A wheel according to any preceding claim wherein each spoke defines a C-shaped profile along at least part of its length between the hub and the rim.

9. A wheel according to any one of Claims 1 to 7 wherein each spoke defines a curved profile along its entire length, the curved profile having a constant radius of curvature along its length which is equal to the radial distance between the outer circumferential surface of the hub and the inner circumferential surface of the rim.

10. A wheel according to any preceding claim wherein the spokes of each pair of opposed spokes are formed integrally with one another to define a unitary spring unit.

15 11. A wheel according to Claim 10 wherein each unitary spring unit is connected between the hub and the rim in a pre-tensioned condition.

12. A wheel according to Claim 10 or Claim 11 wherein each unitary spring unit is shaped to define a uniform width along its length.

13. A wheel according to any preceding claim wherein each spoke is connected to the hub so as to extend from the hub at an angle relative to the circumferential hub line.

25 14. A wheel according to any preceding claim wherein each spoke is connected to the rim so as to extend from the rim at an angle relative to the circumferential rim line.

15. A wheel according to any preceding claim wherein the profile of each spoke is twisted so that the connection between the spoke and the hub is skewed relative to the outer circumferential surface of the hub.

16. A wheel according to any preceding claim wherein the profile of each spoke is twisted so that the connection between the spoke and the rim is skewed relative to the inner circumferential surface of the rim.

35 17. A wheel according to any preceding claim wherein each spoke is pivotably connected to the hub and/or the rim.

18. A wheel according to any preceding claim wherein each spoke is formed from a laminated structure including two or more alternate layers of reinforcing material and epoxy resin.

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19. A wheel according to Claim 16 wherein the reinforcing material is chosen from glass fibre, carbon fibre, Kevlar (RTM) and hemp.

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20. A wheel according to Claim 18 or Claim 19 wherein the or each layer of reinforcing material is arranged within the laminated structure so as to follow the shape of the spoke.

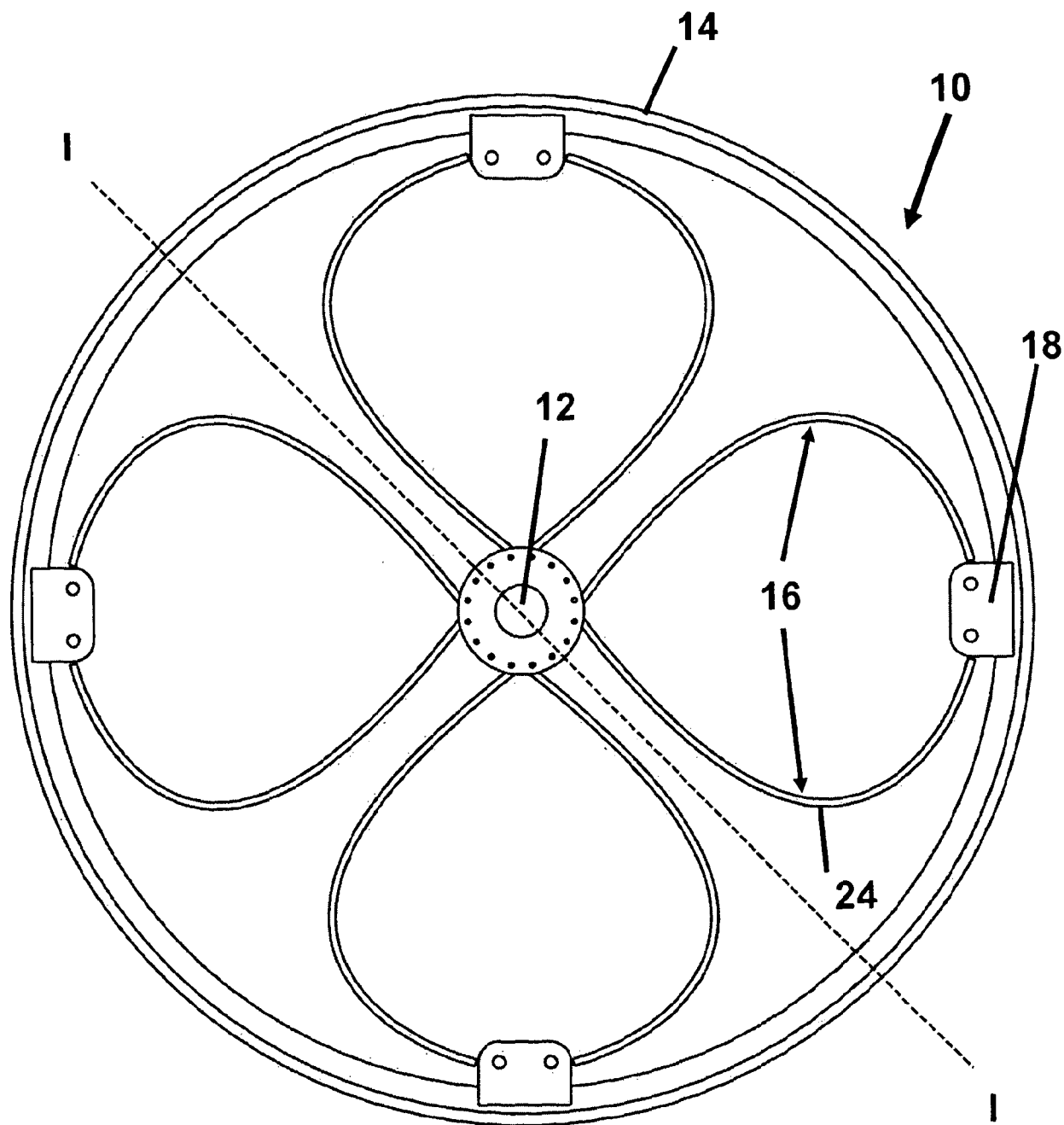
15

21. A wheel according to any preceding claim wherein each pair of opposed spoke defines a spring unit and the spring units are arranged circumferentially about the hub to define co-operating pairs of opposed spring units such that movement of the hub towards the rim in a radial direction of one of the spring units of a co-operating pair of spring units causes compression of the spokes of the one spring unit and extension of the spokes of the other spring unit of the co-operating pairs of spring units.

20

22. A wheel according to any preceding claim wherein the plurality of spokes are formed integrally with one another to define a unitary spring assembly.

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**Figure 1**

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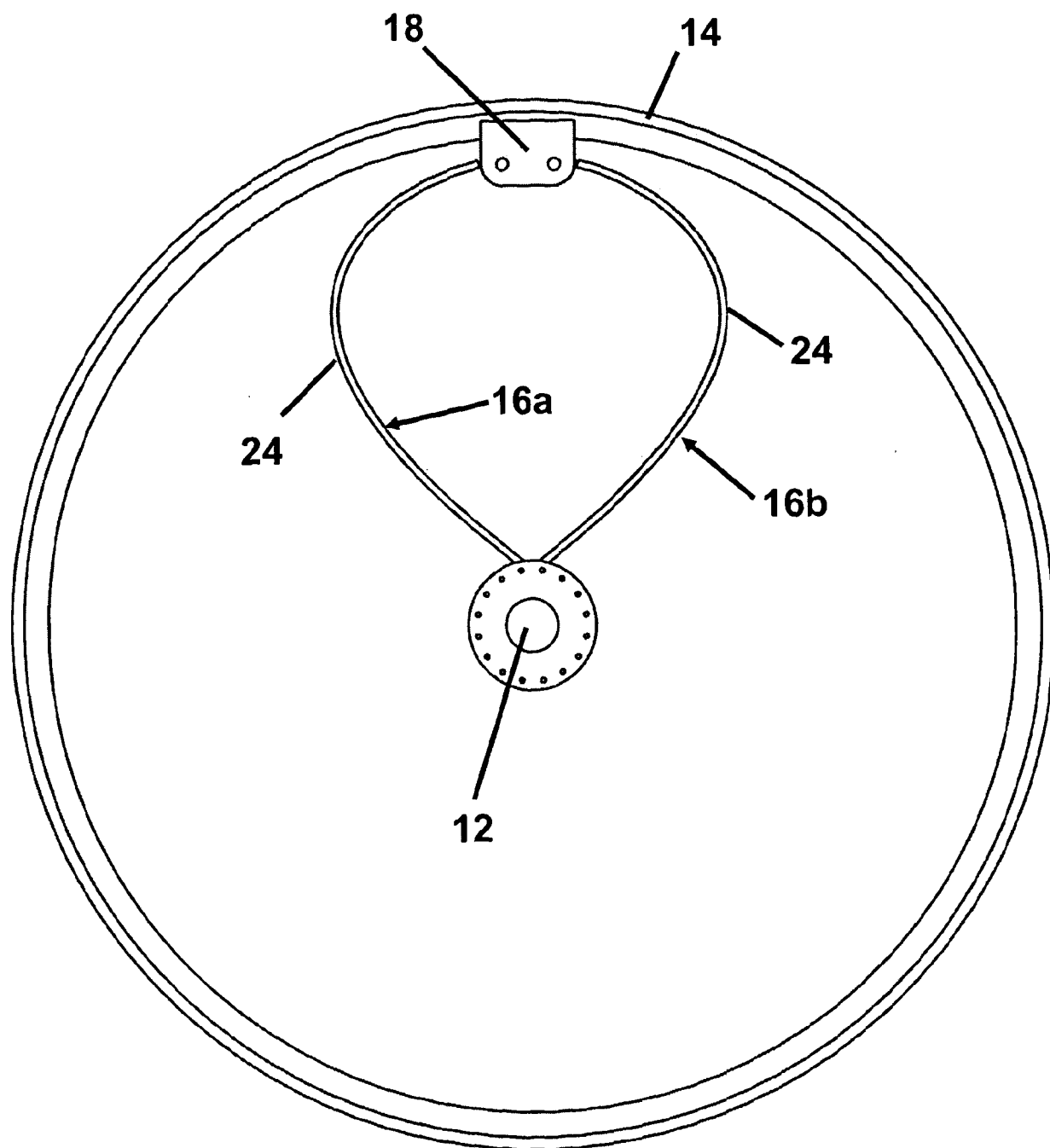
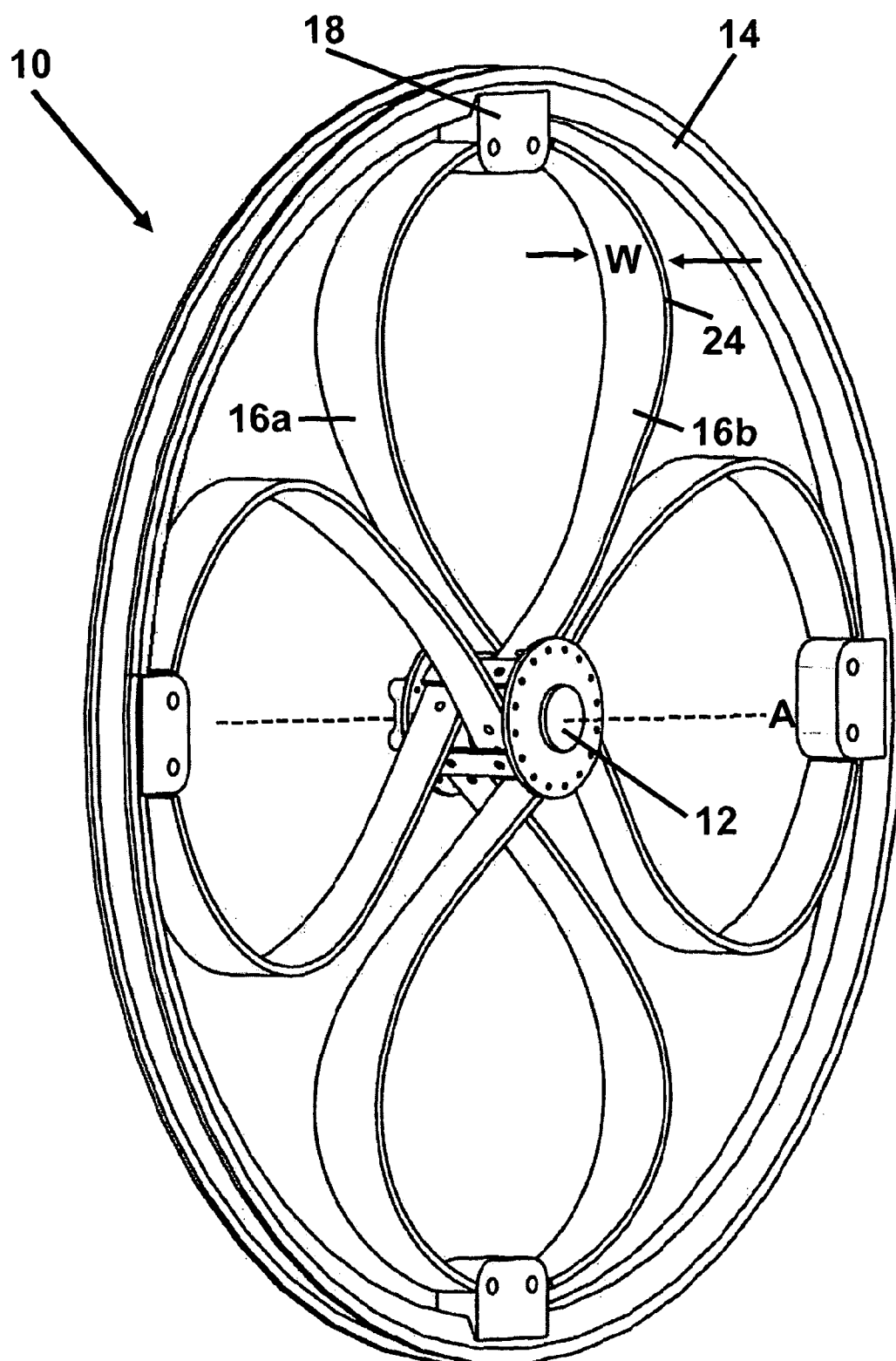


Figure 2

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**Figure 3**

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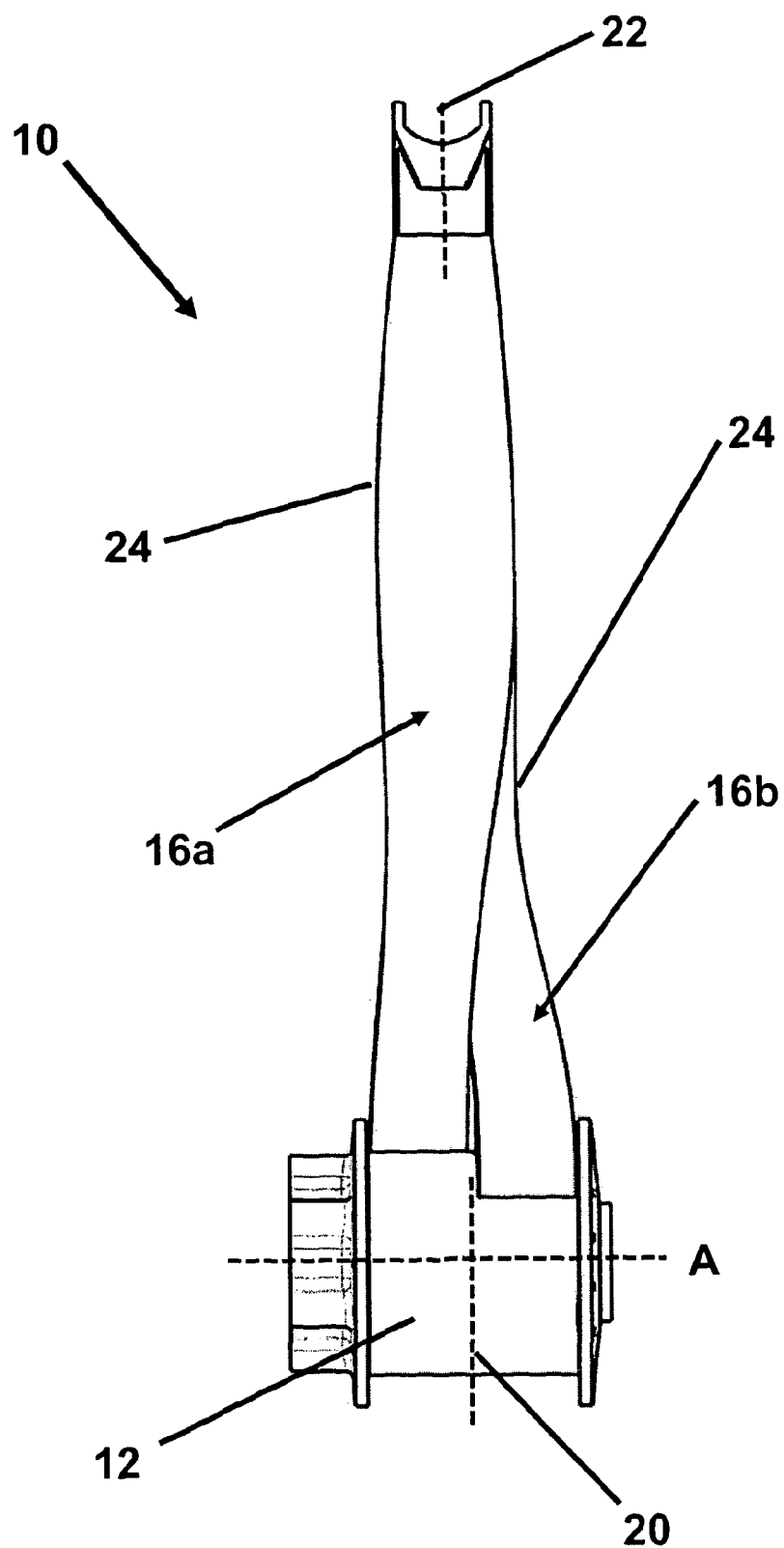


Figure 4

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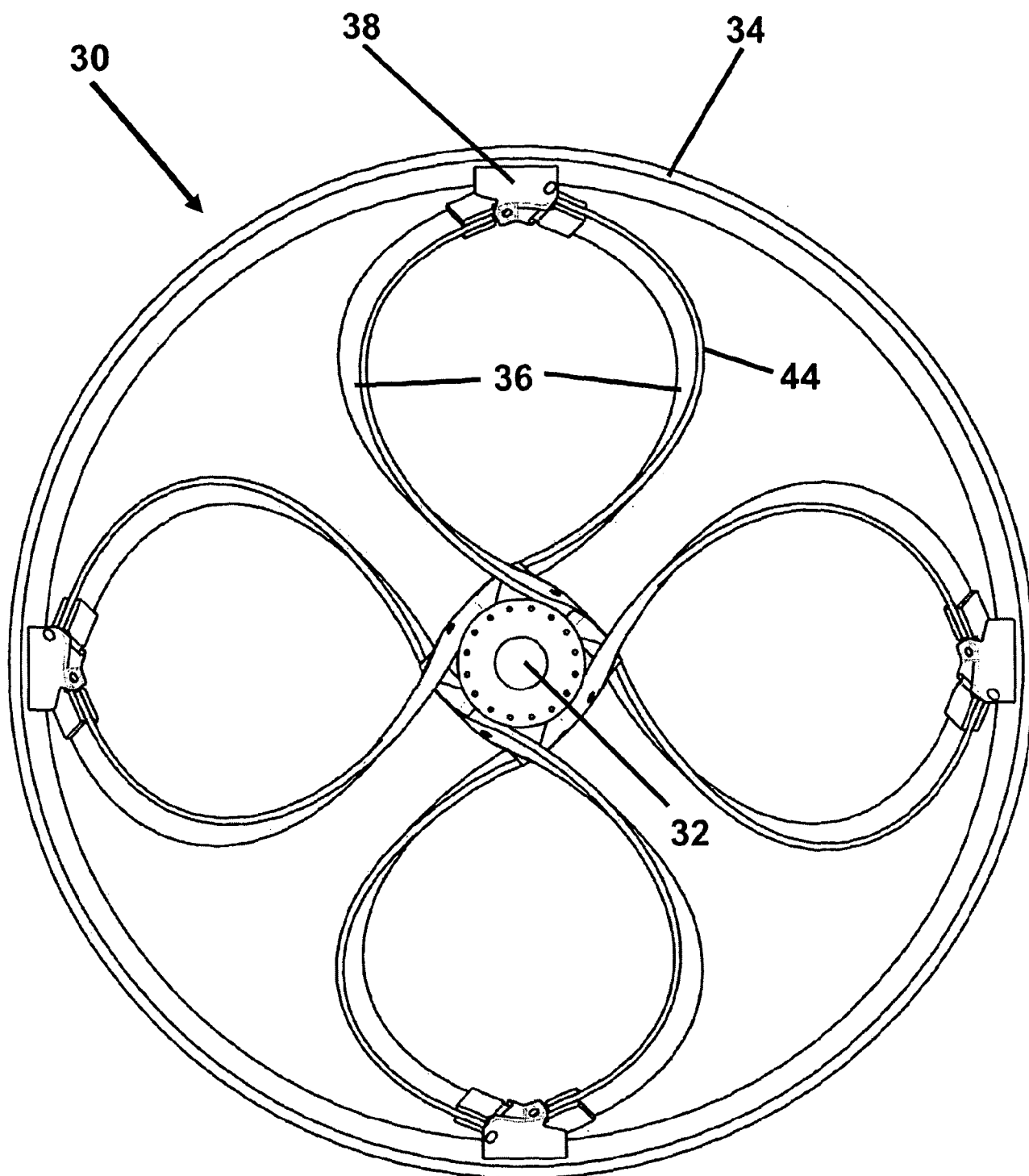


Figure 5

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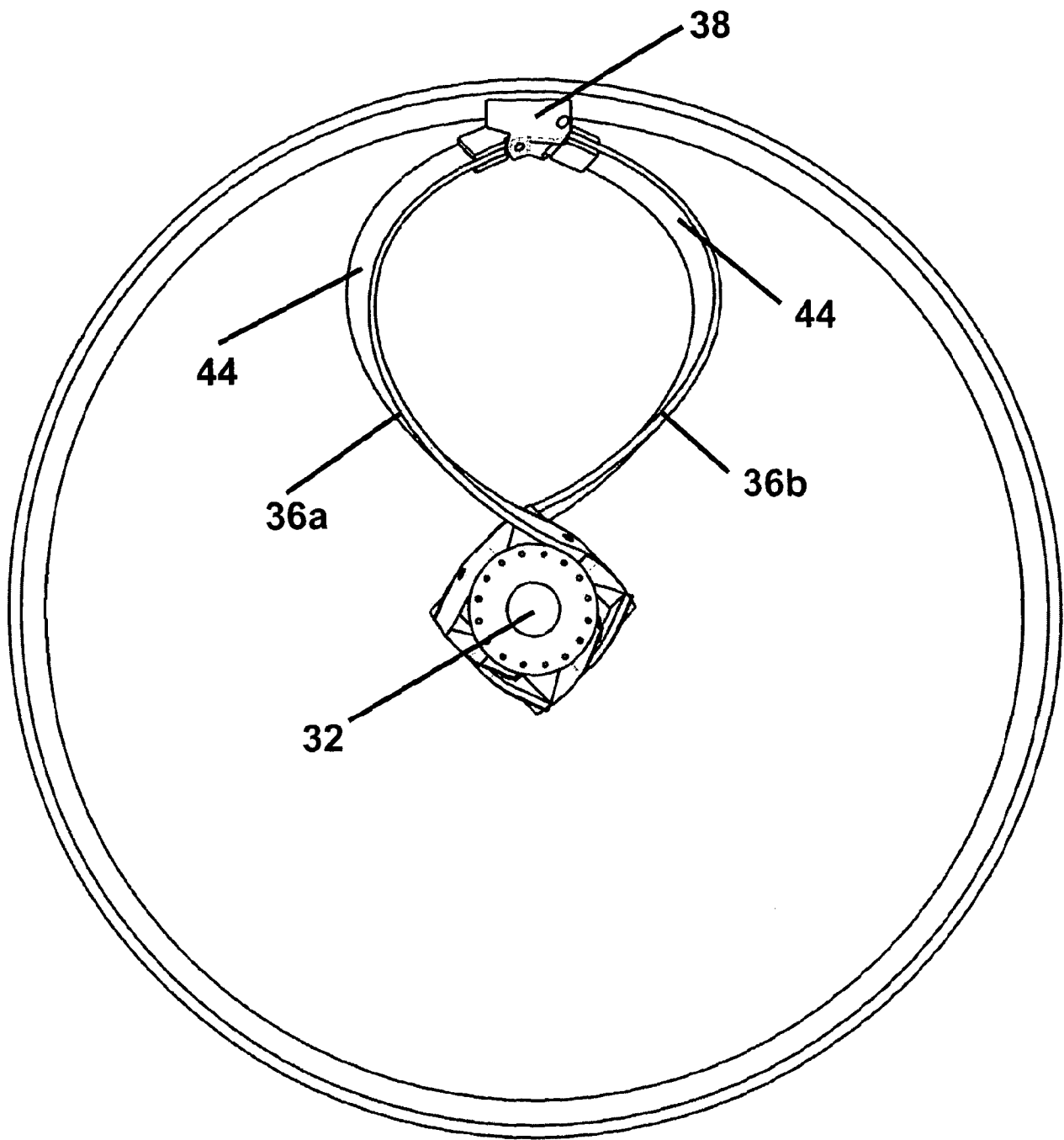


Figure 6

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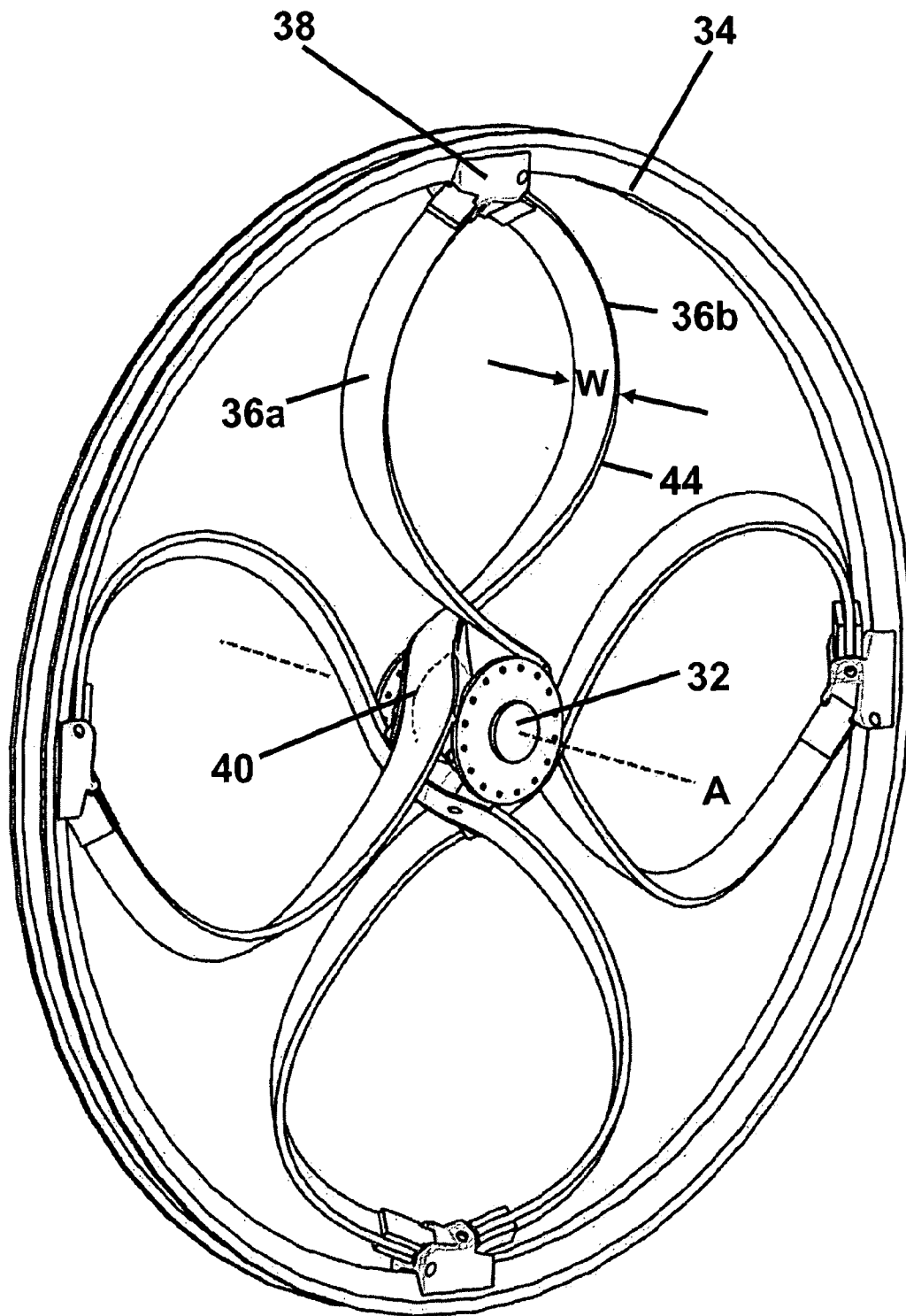


Figure 7

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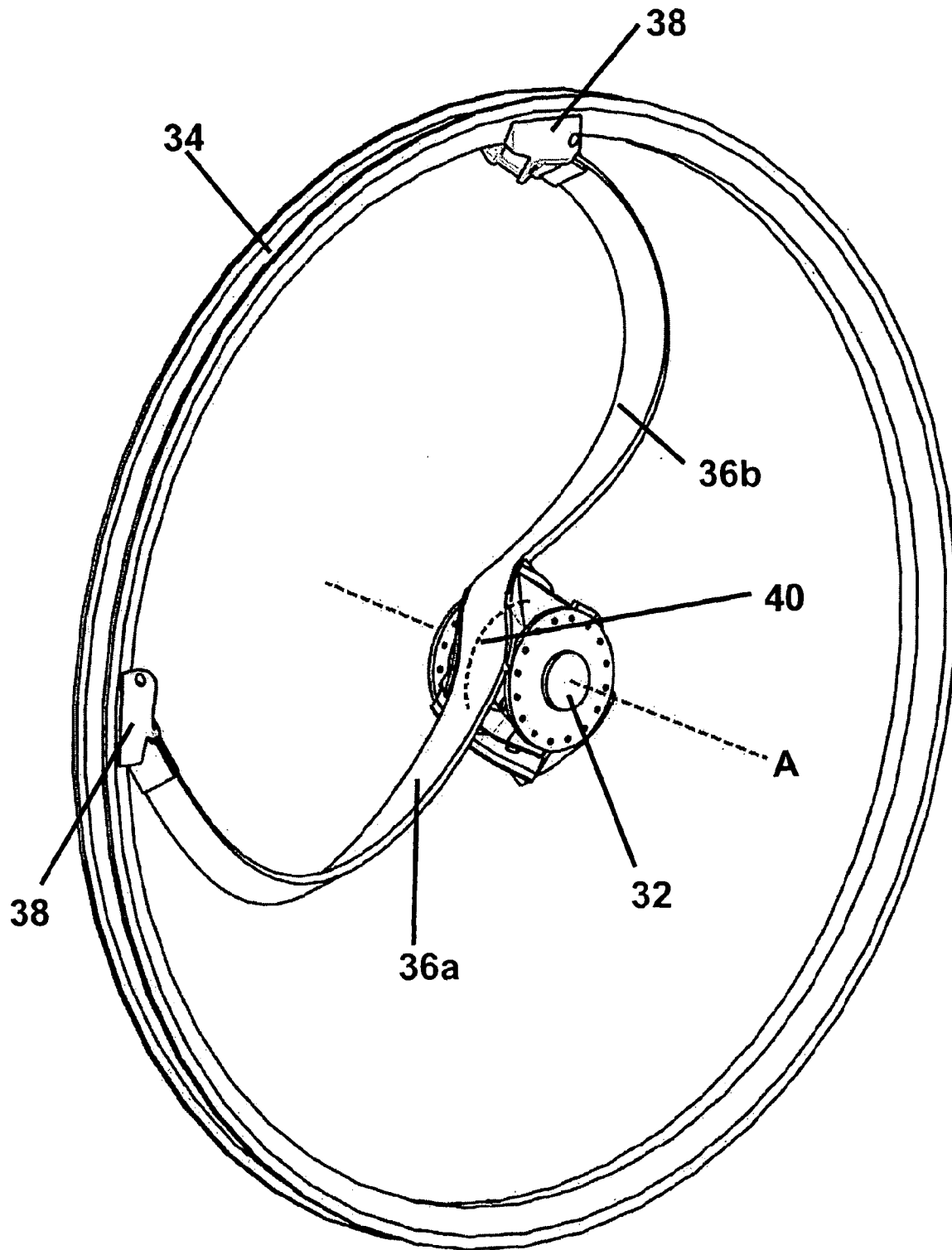


Figure 8

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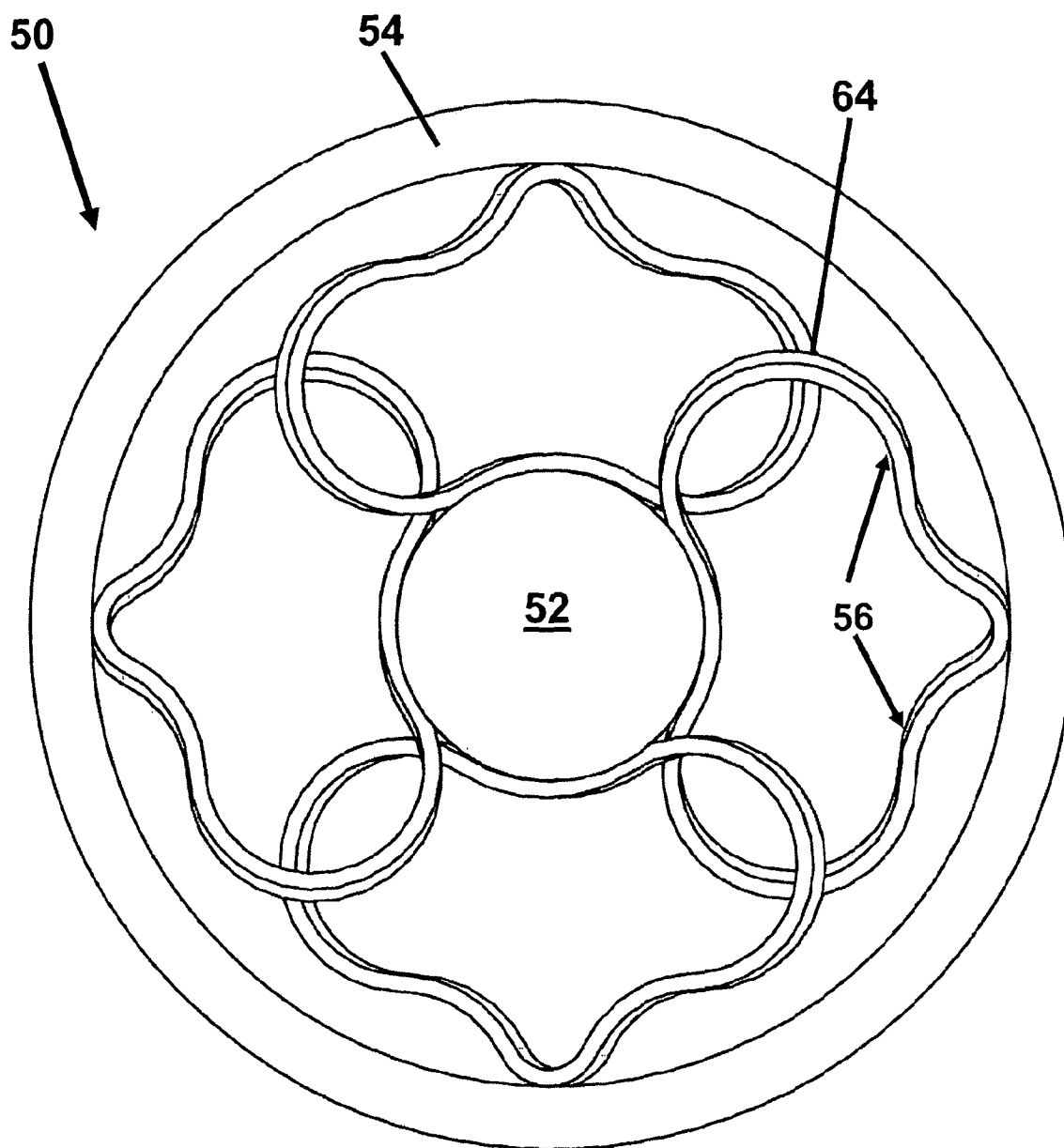


Figure 9

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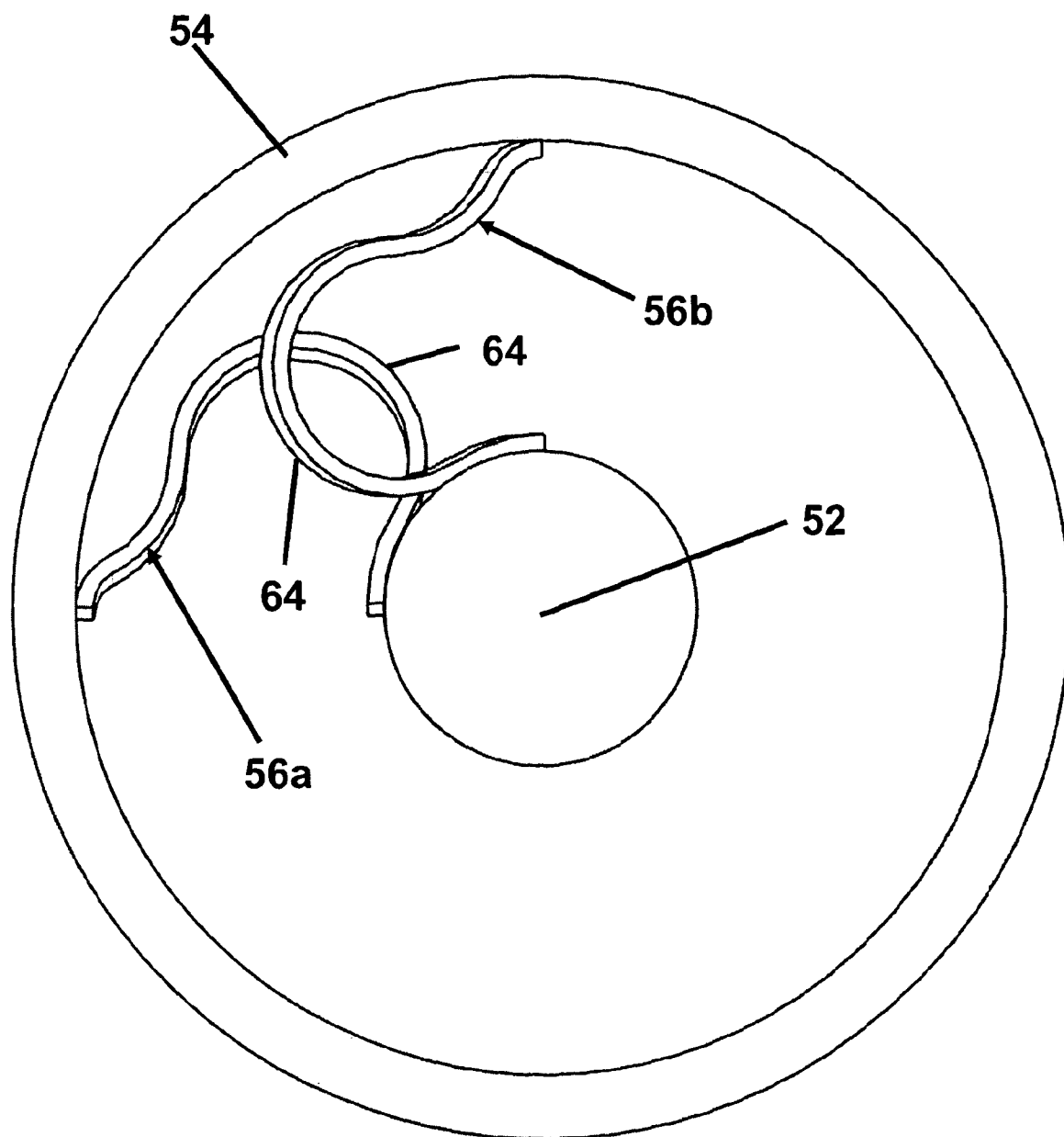


Figure 10

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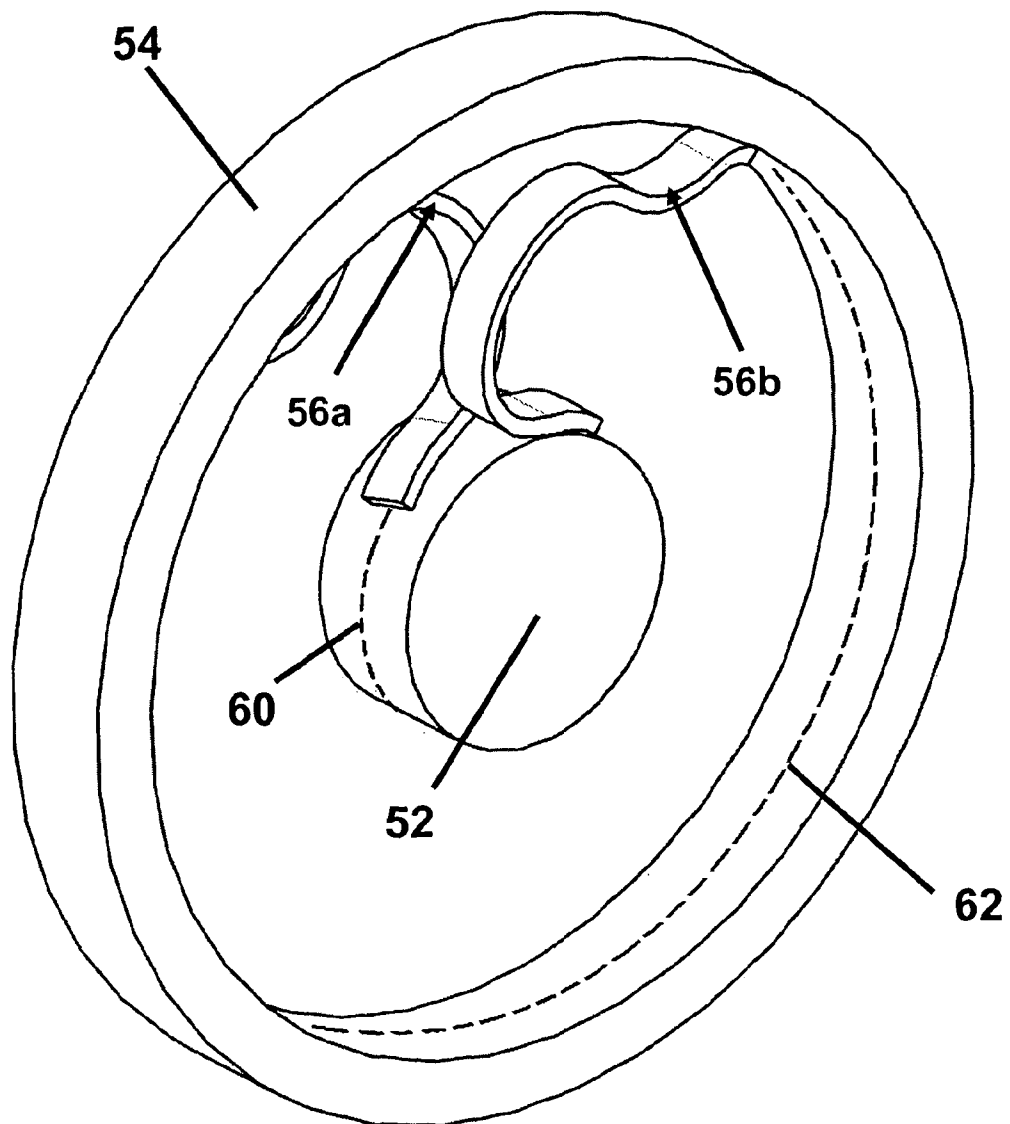
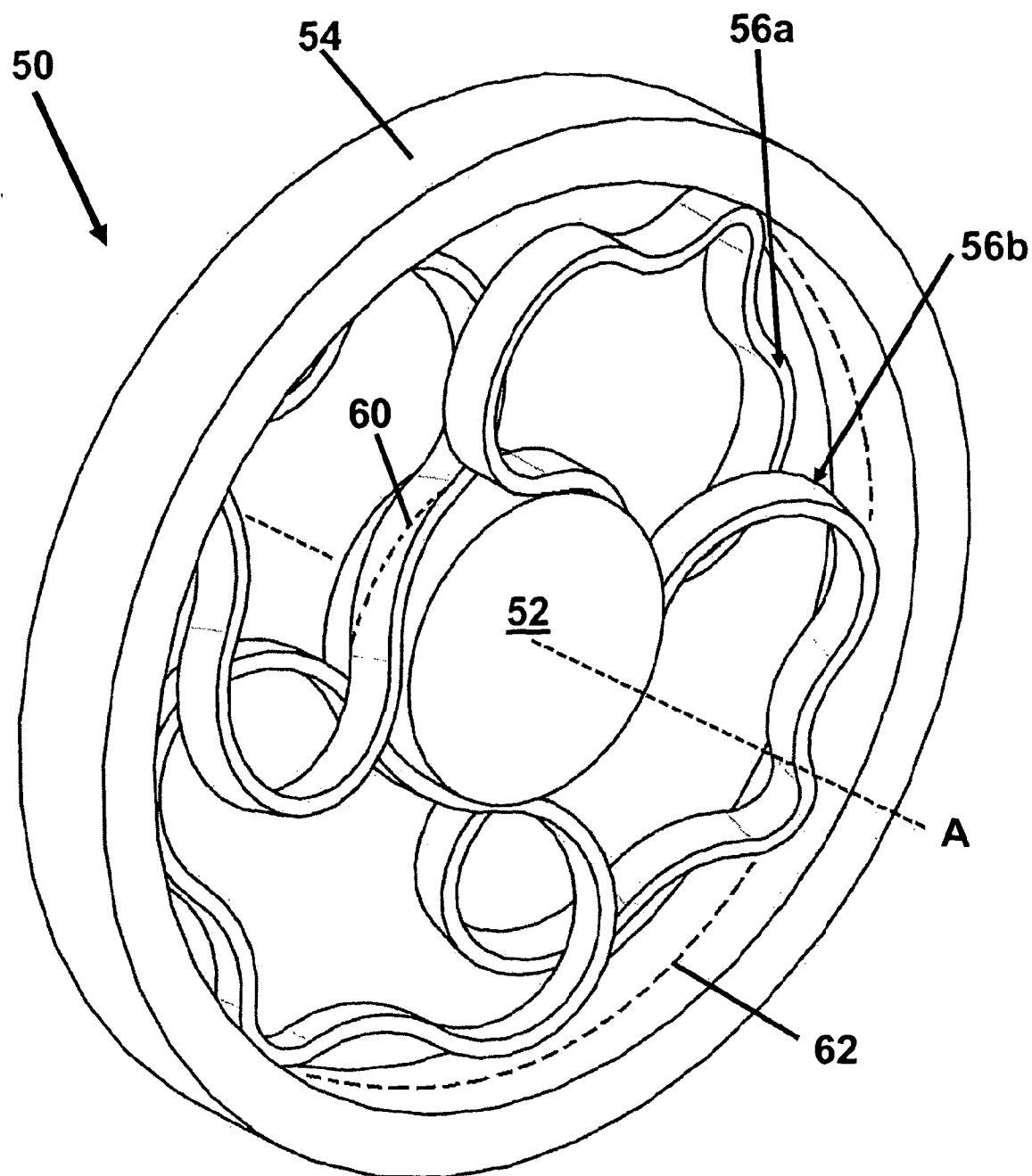


Figure 11

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**Figure 12**

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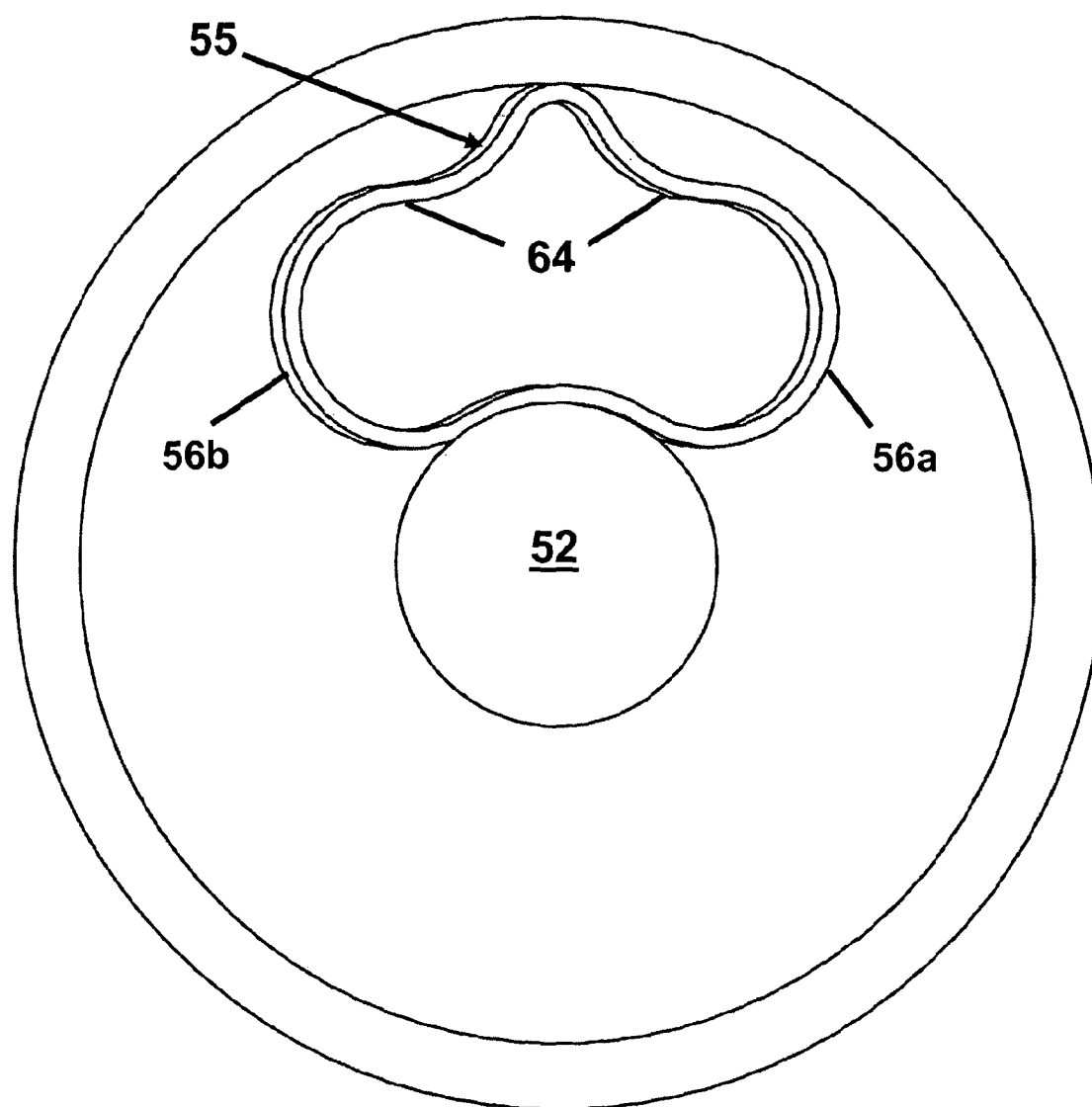


Figure 13

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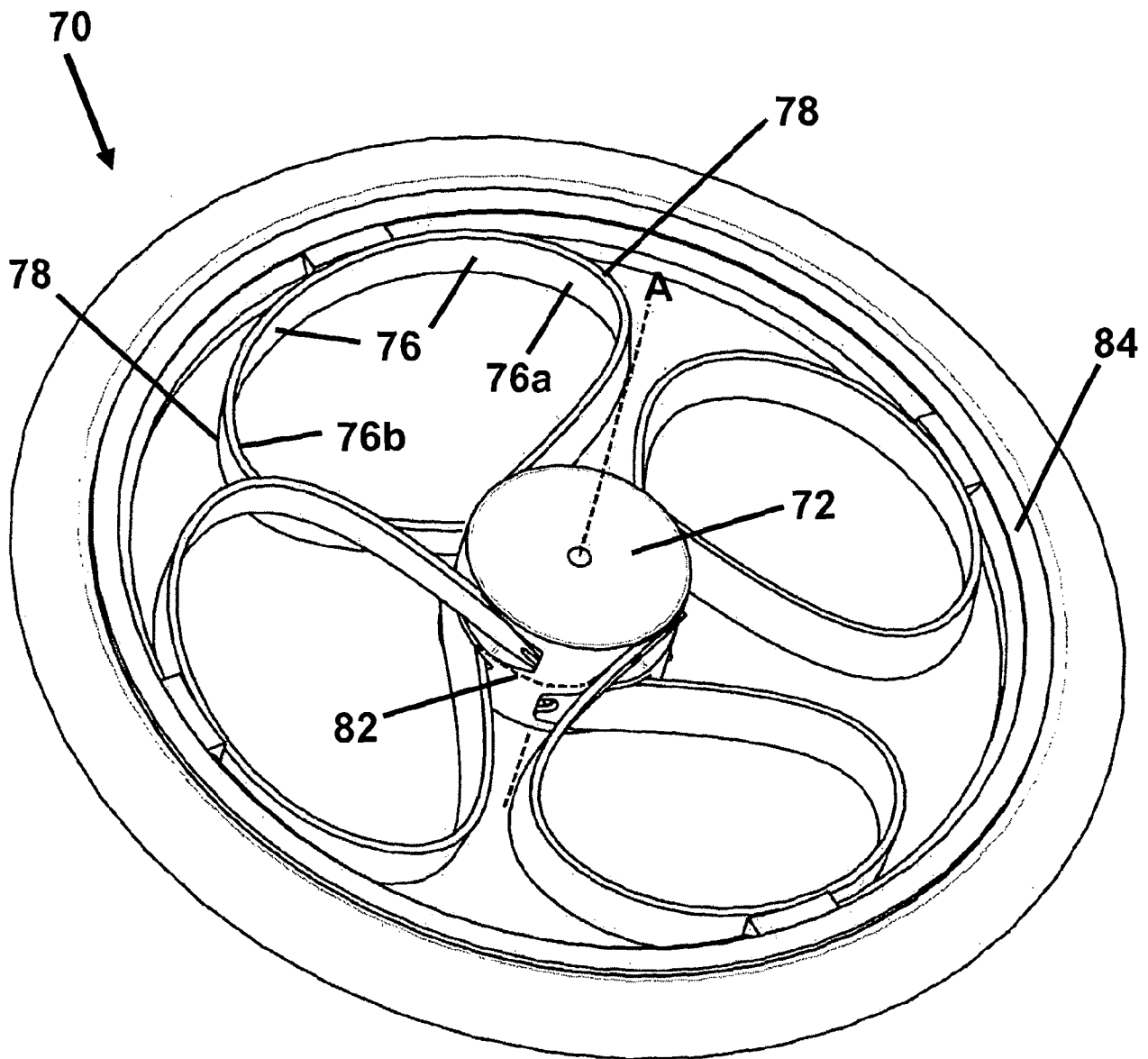


Figure 14

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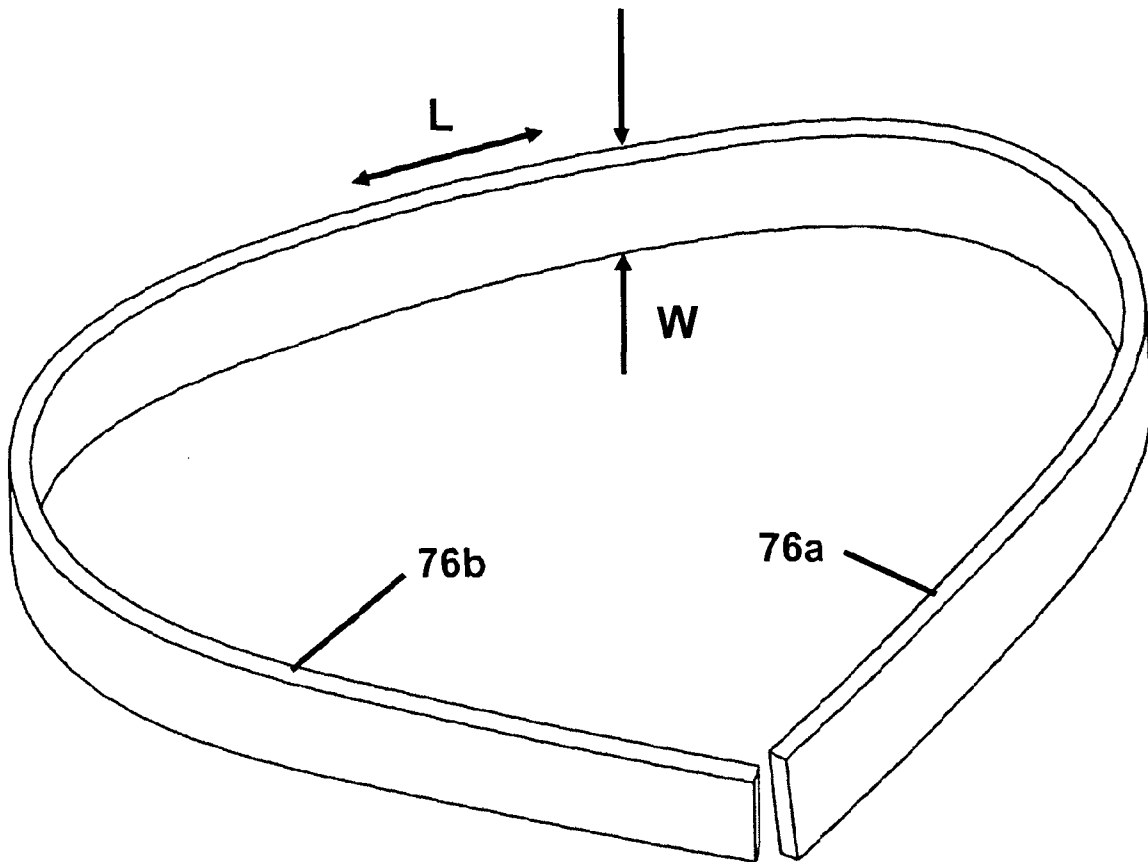


Figure 15

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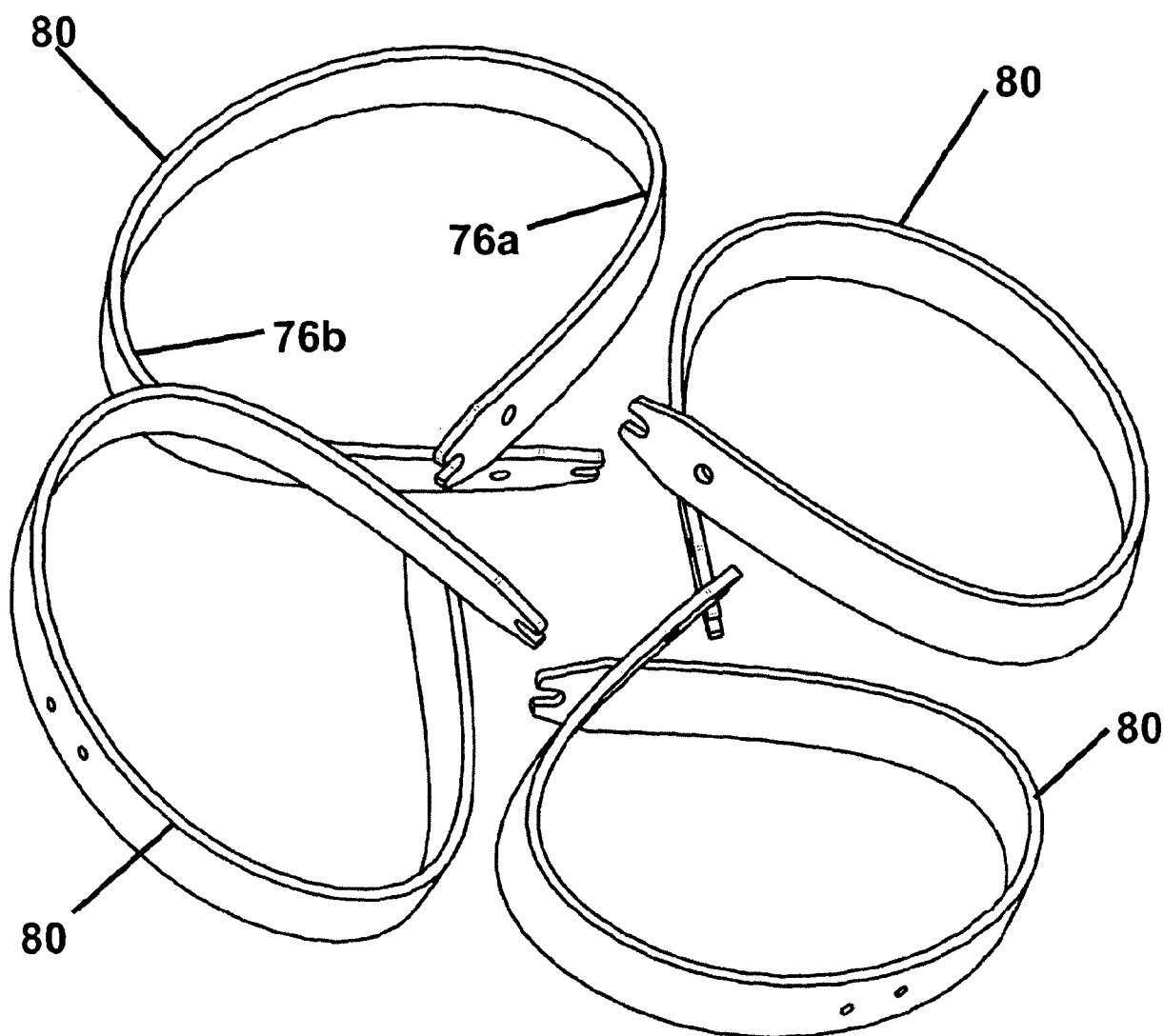
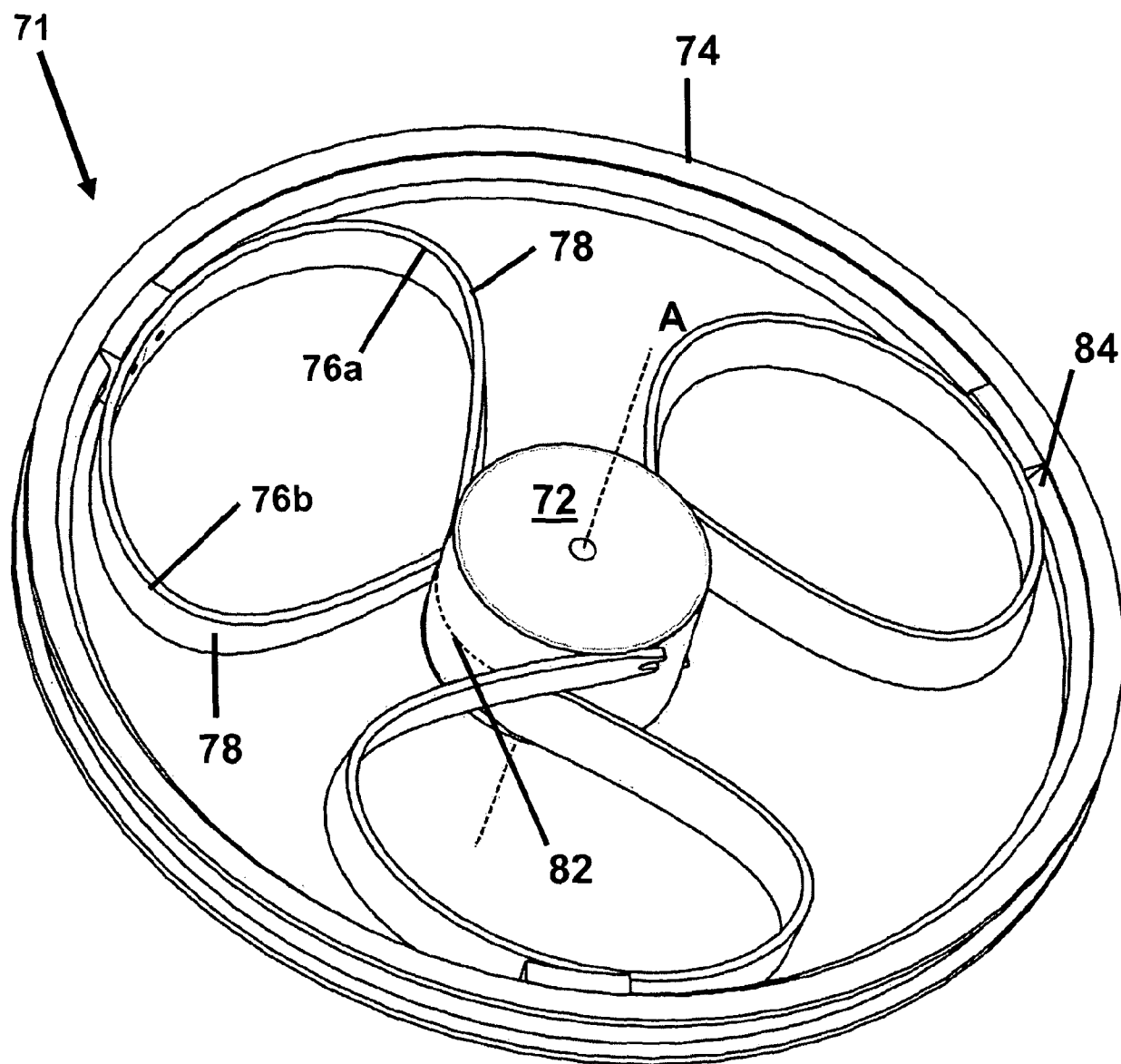


Figure 16

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**Figure 17**

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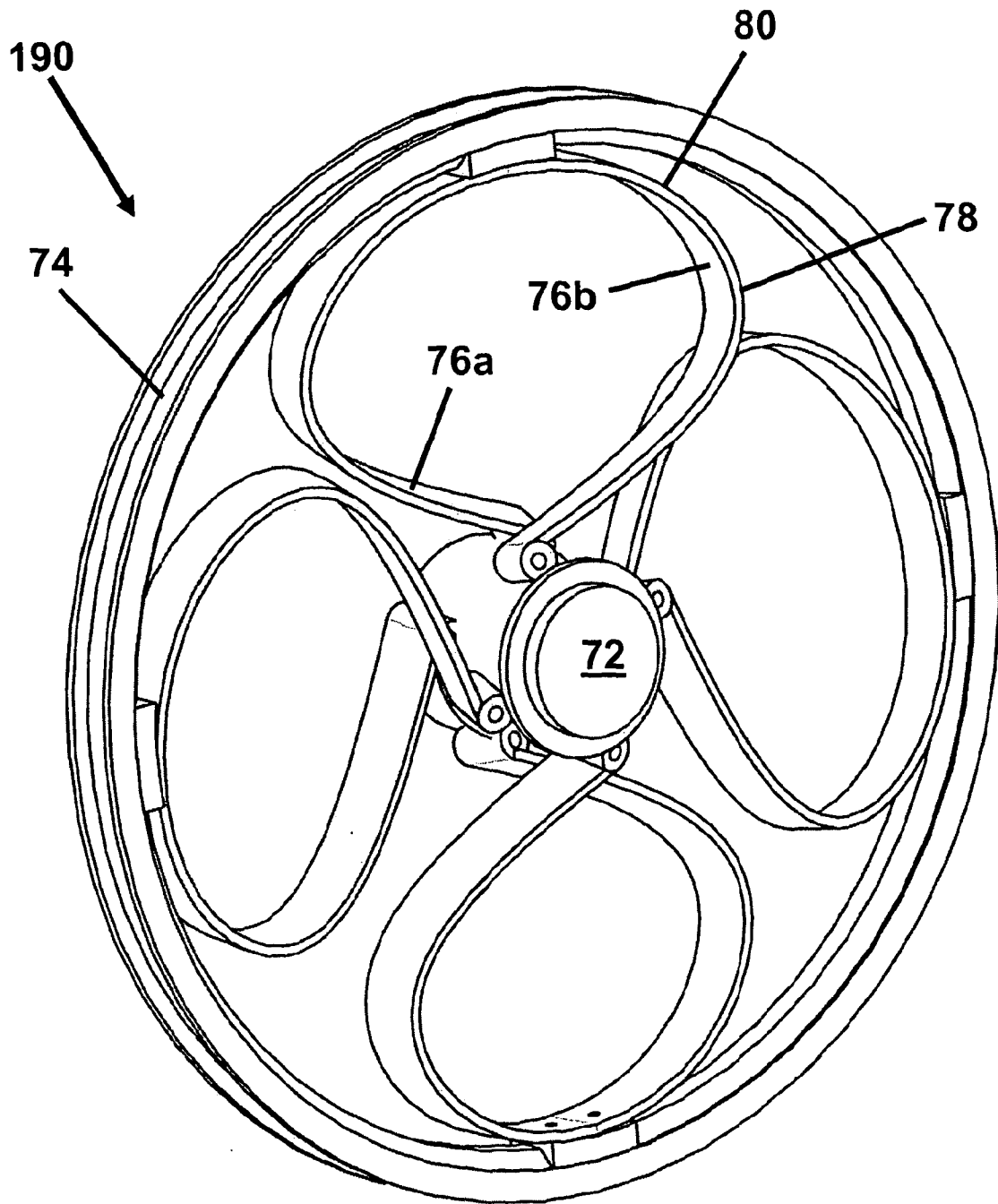


Figure 18

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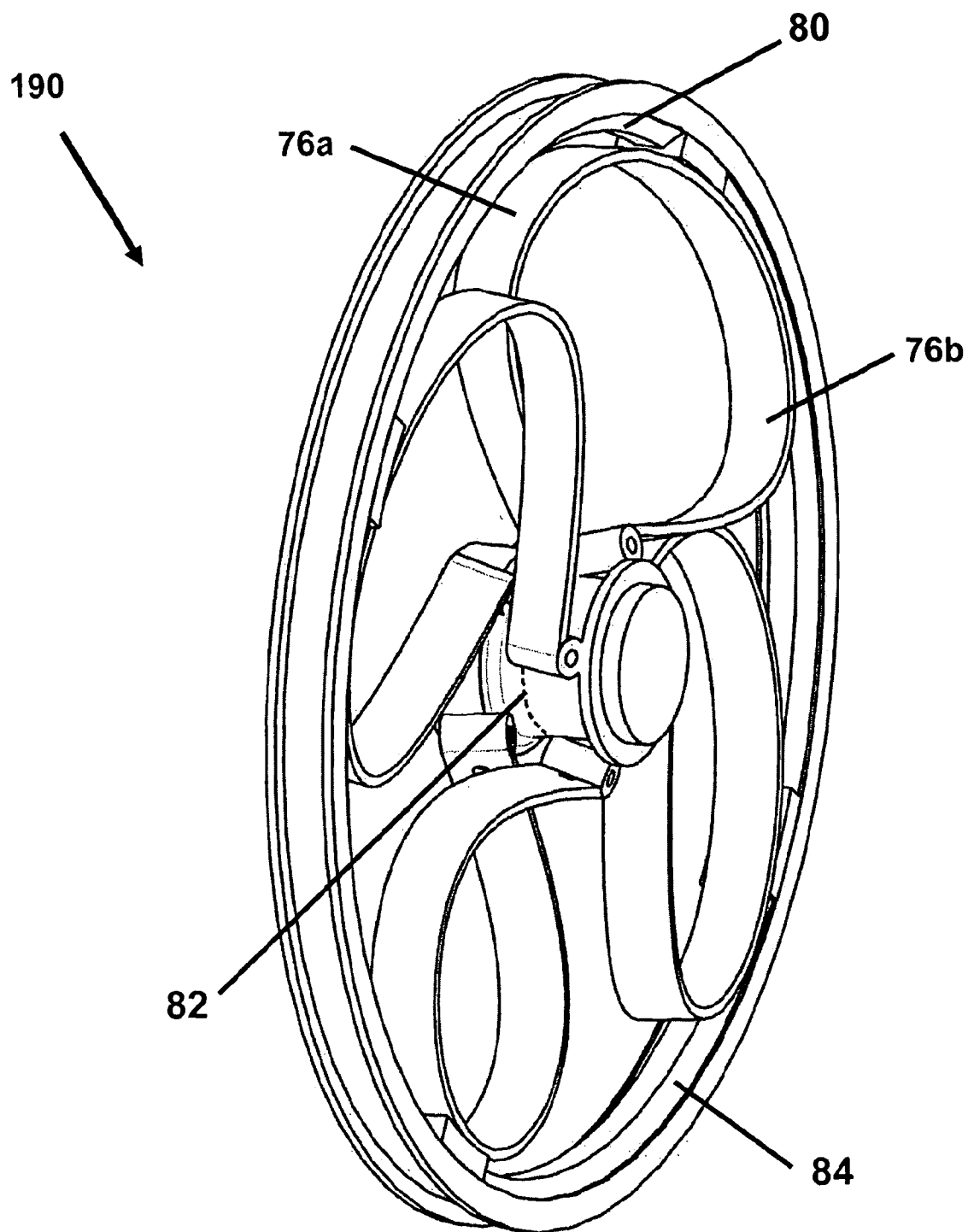


Figure 19

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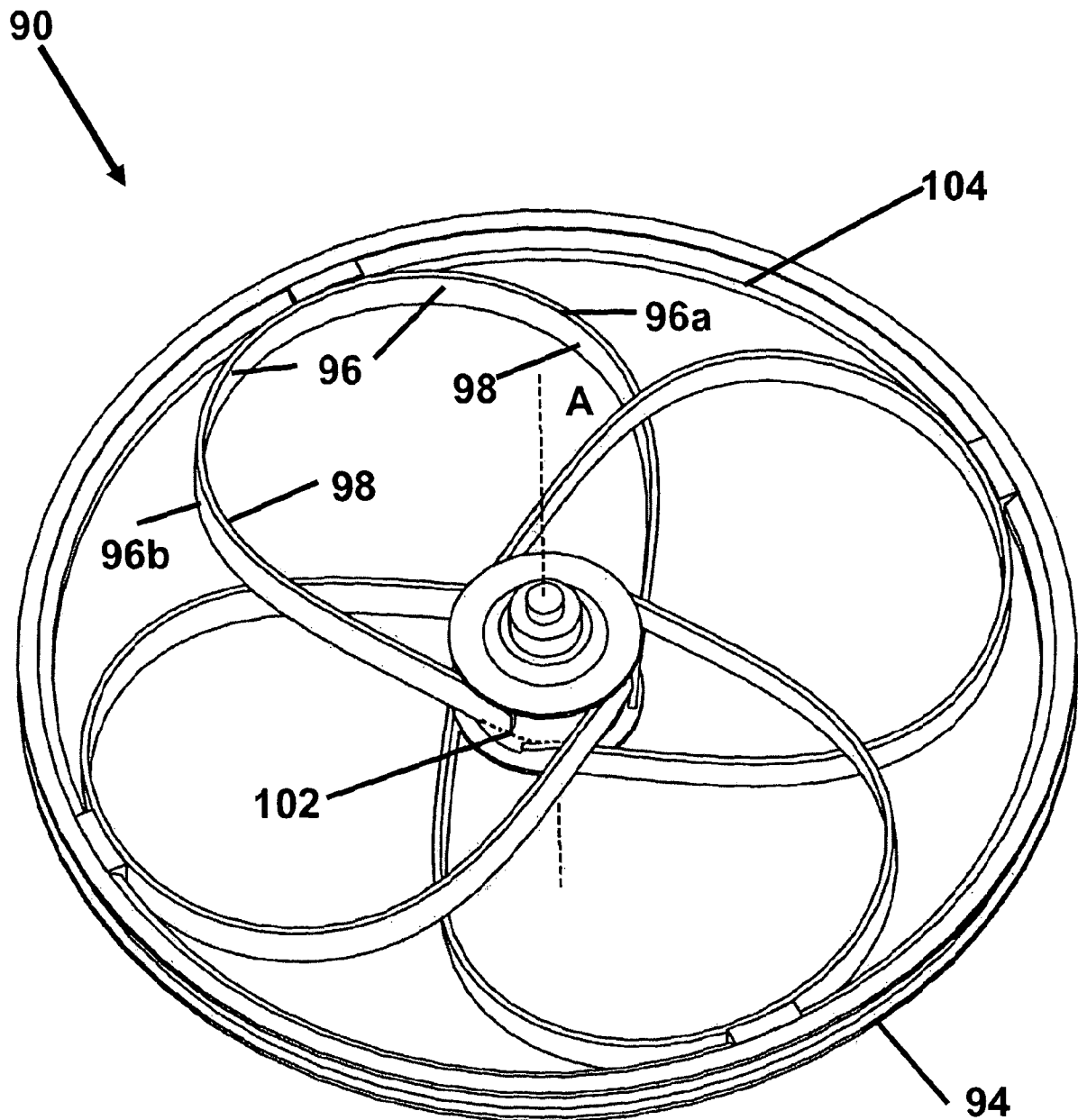
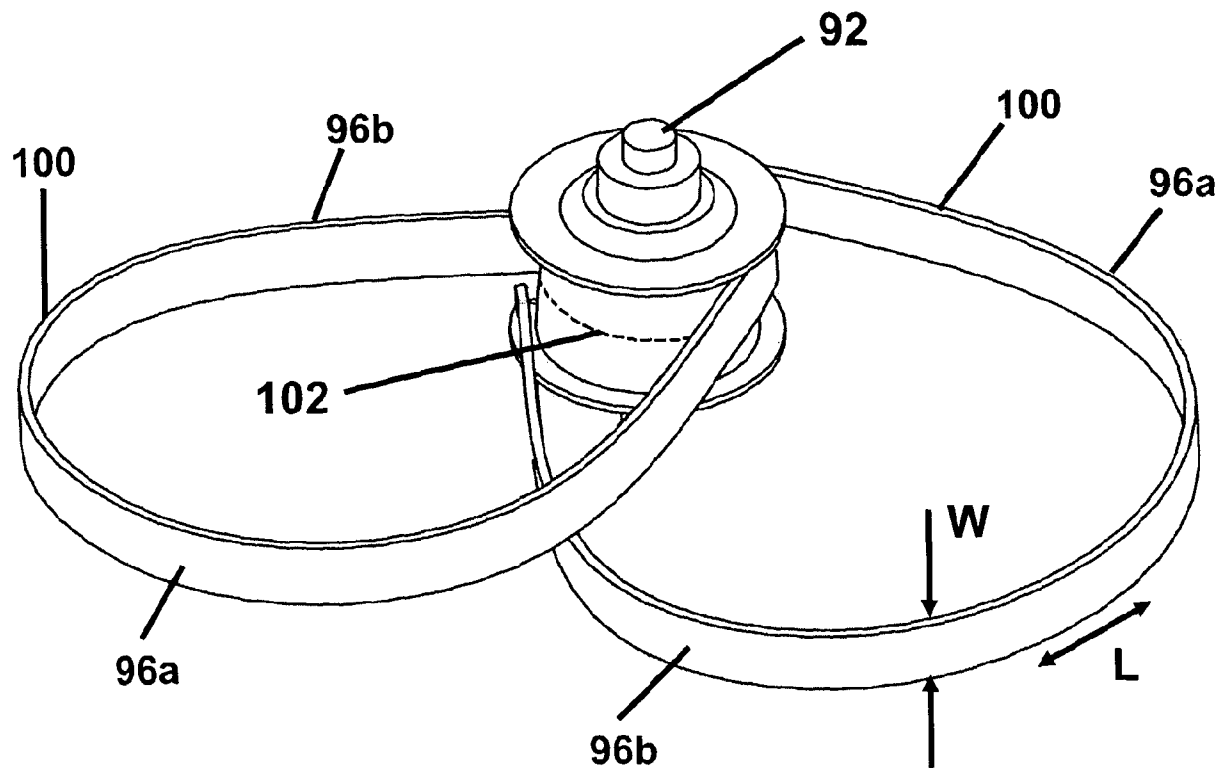


Figure 20

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**Figure 21**

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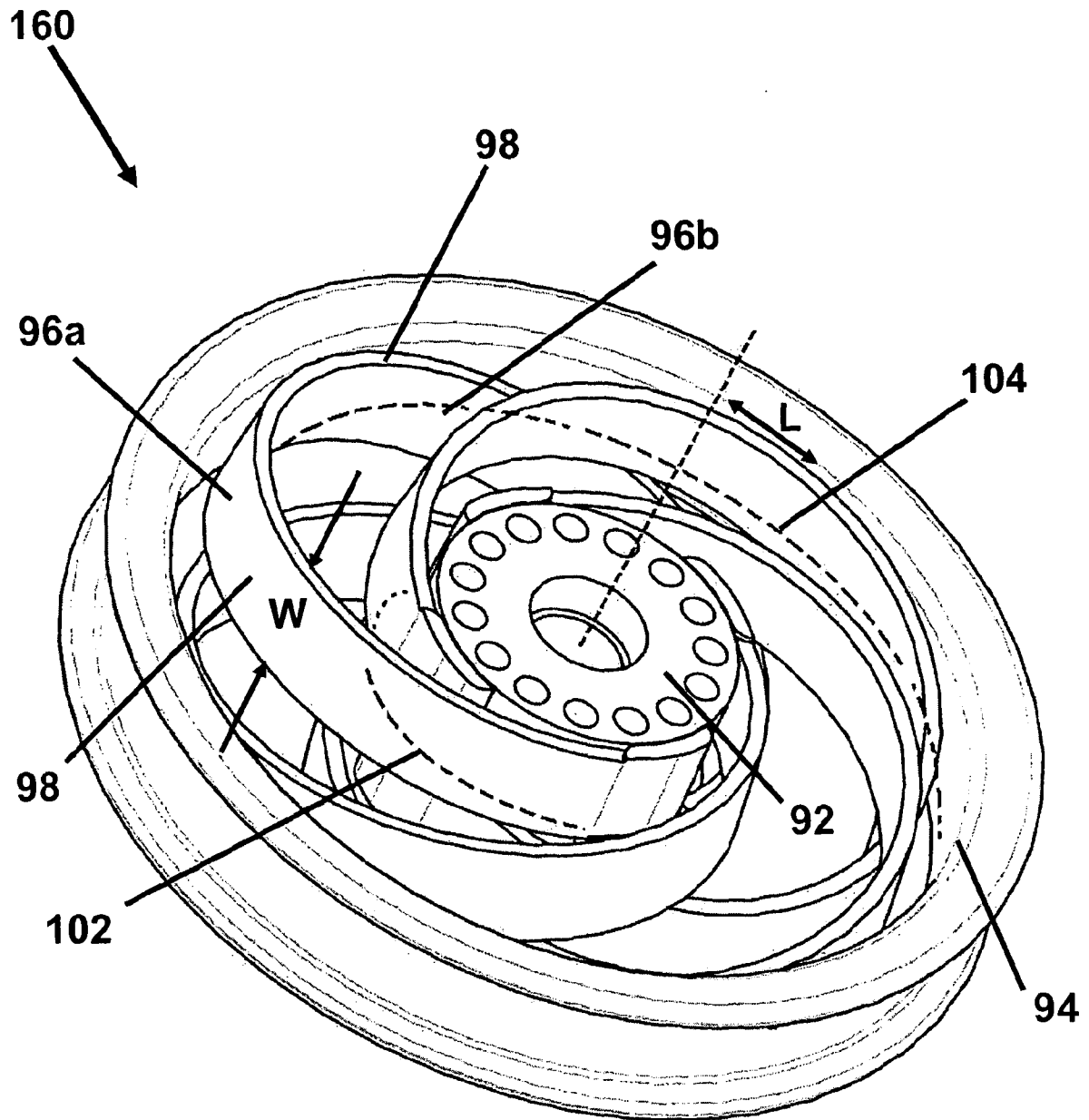


Figure 22

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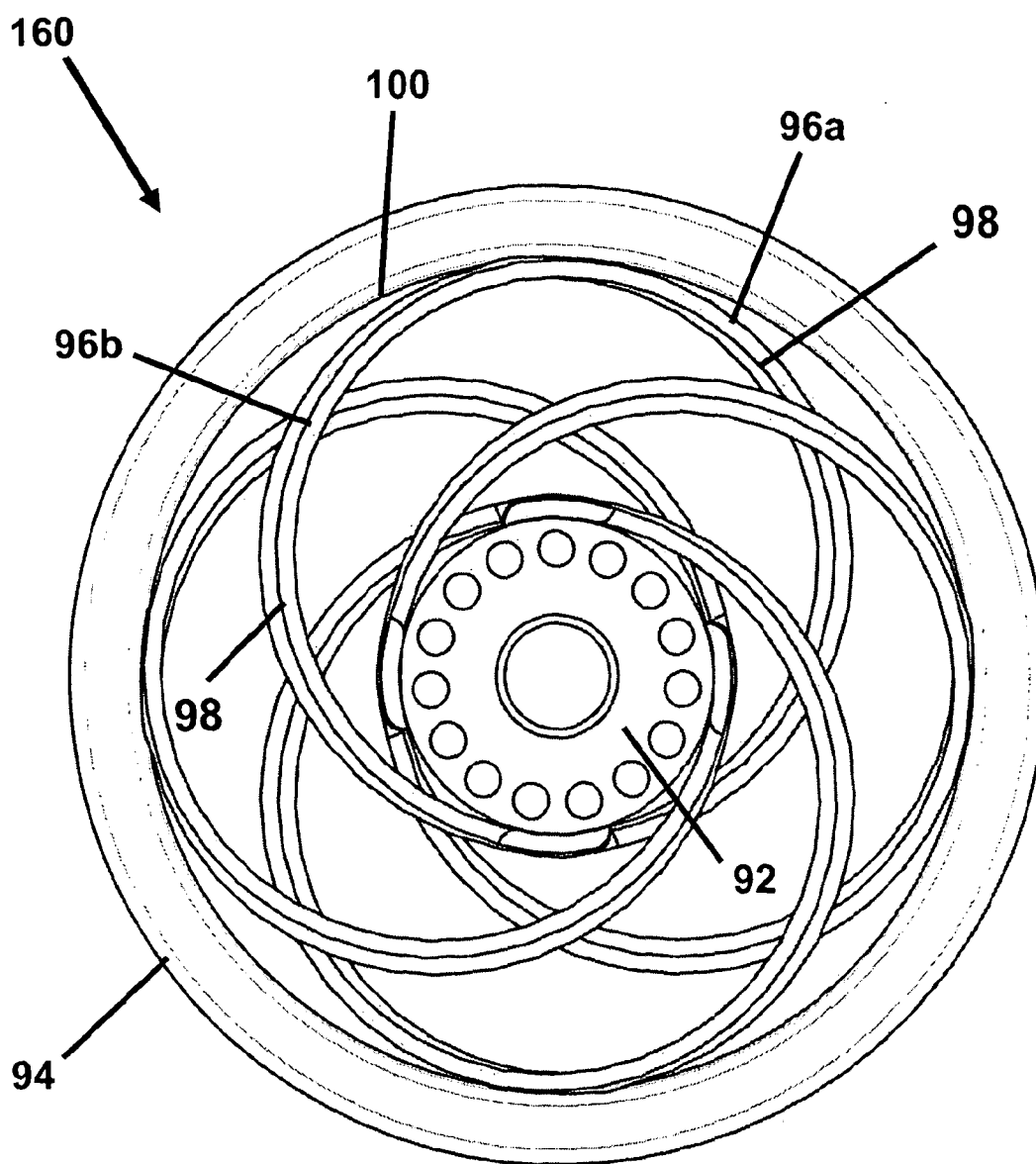


Figure 23

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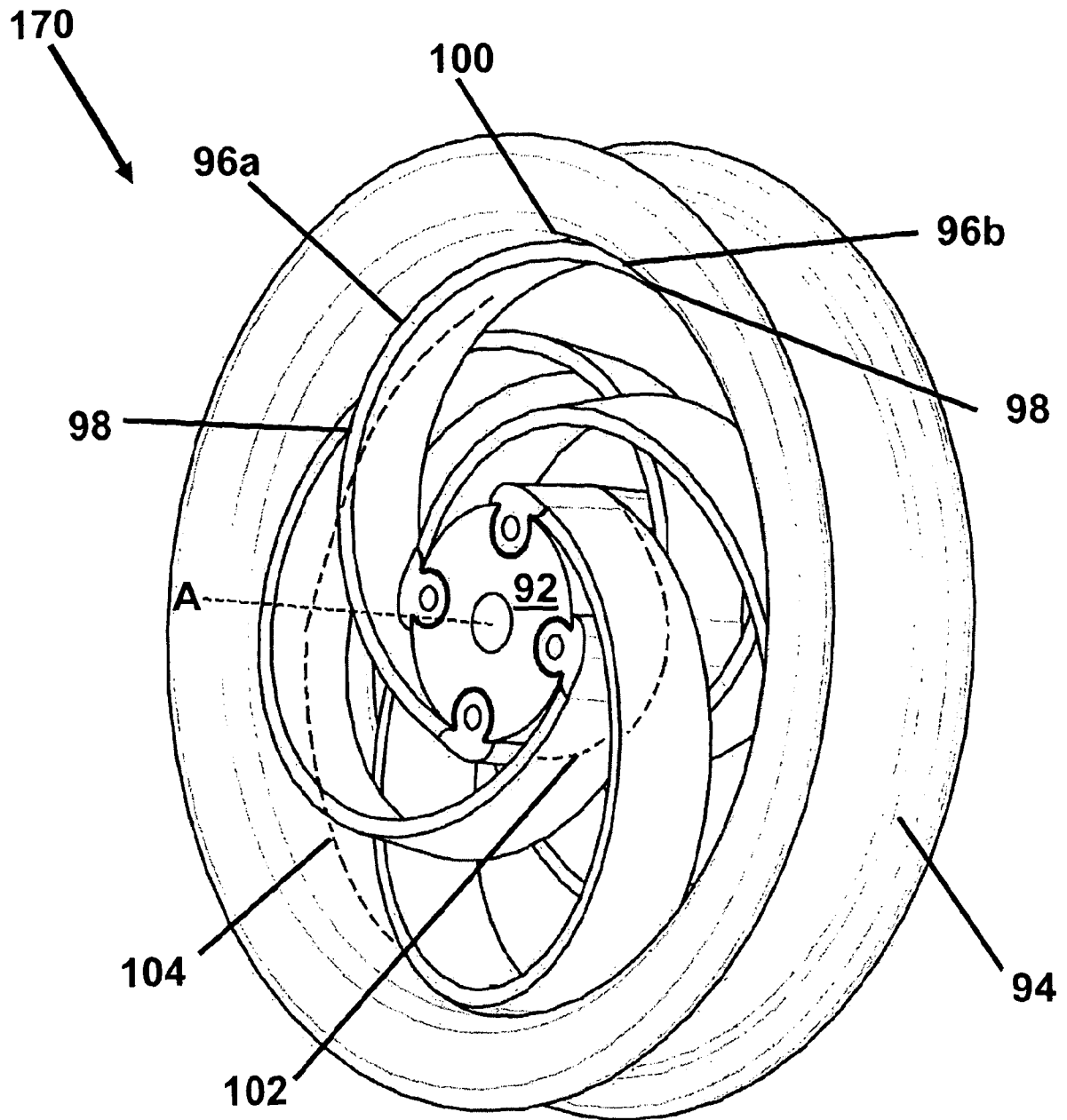


Figure 24

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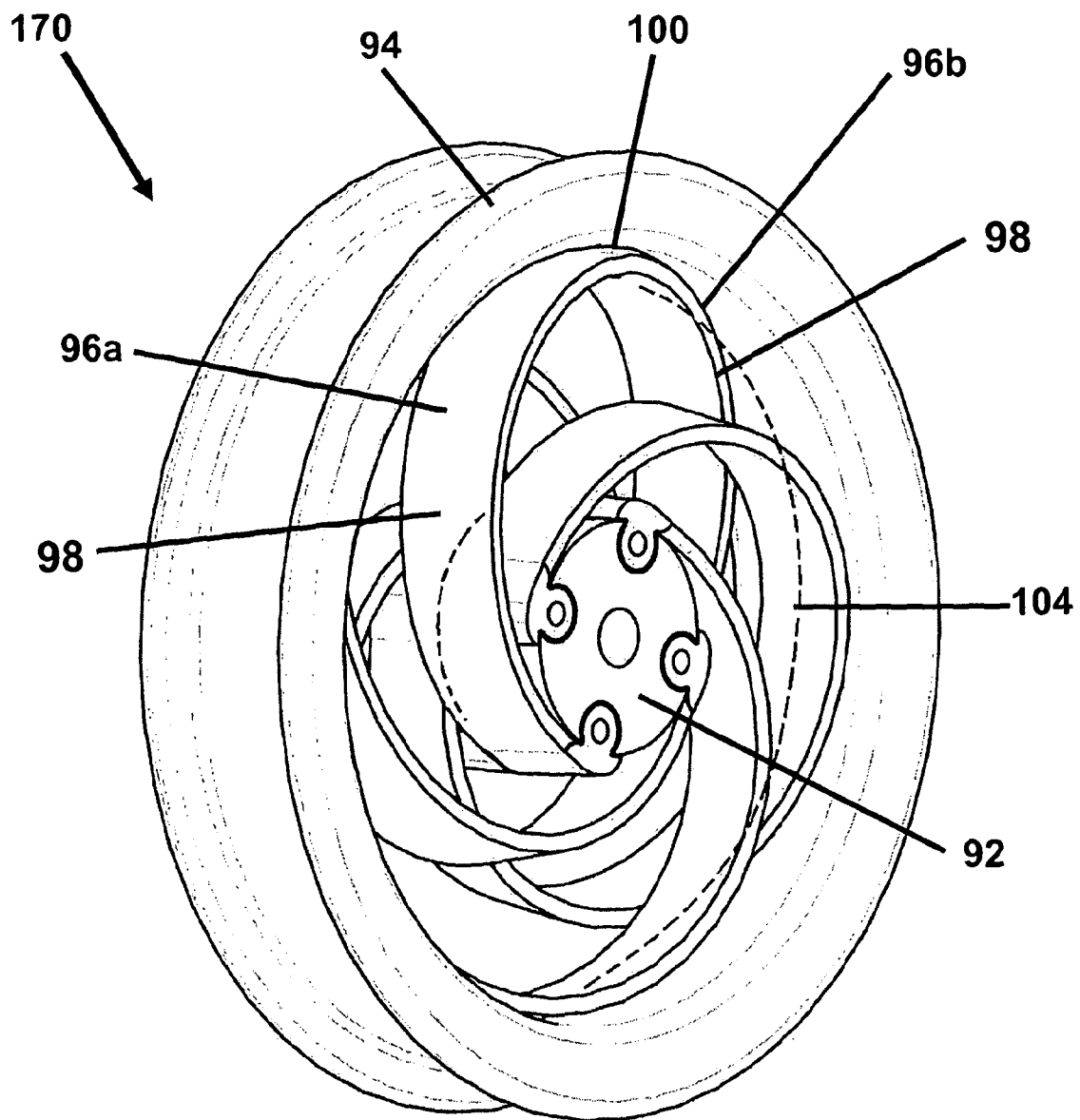
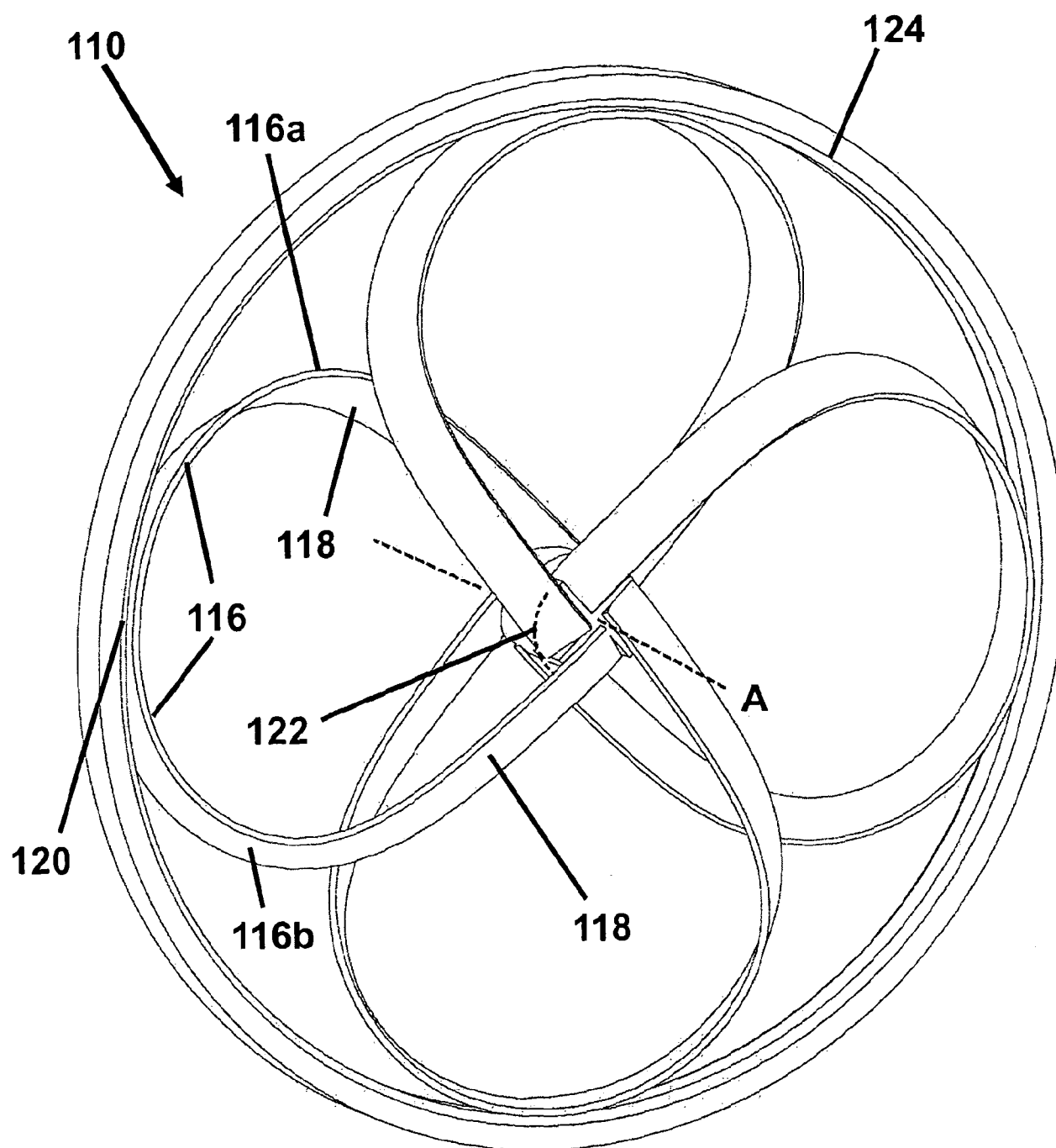


Figure 25

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**Figure 26**

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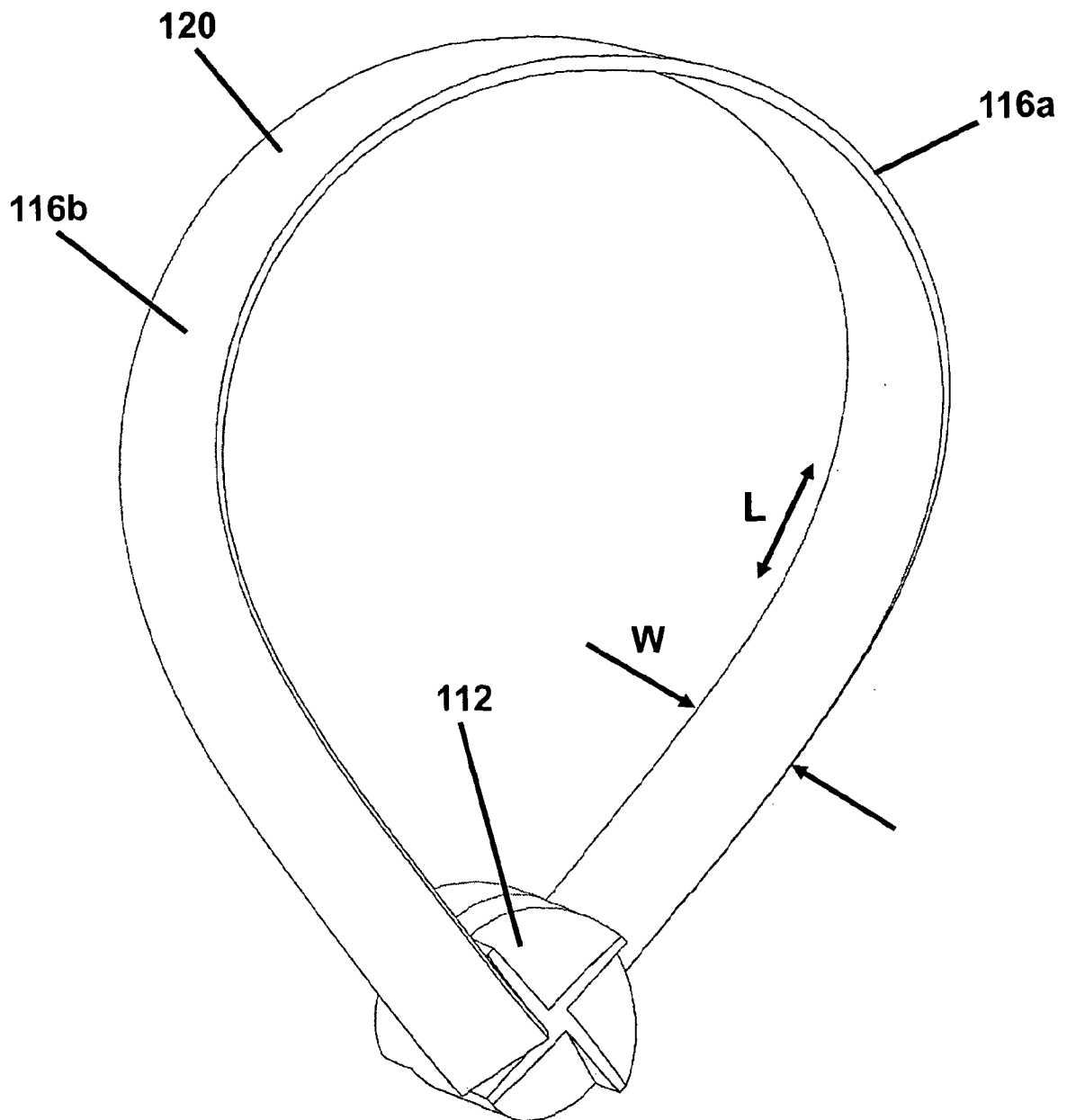


Figure 27

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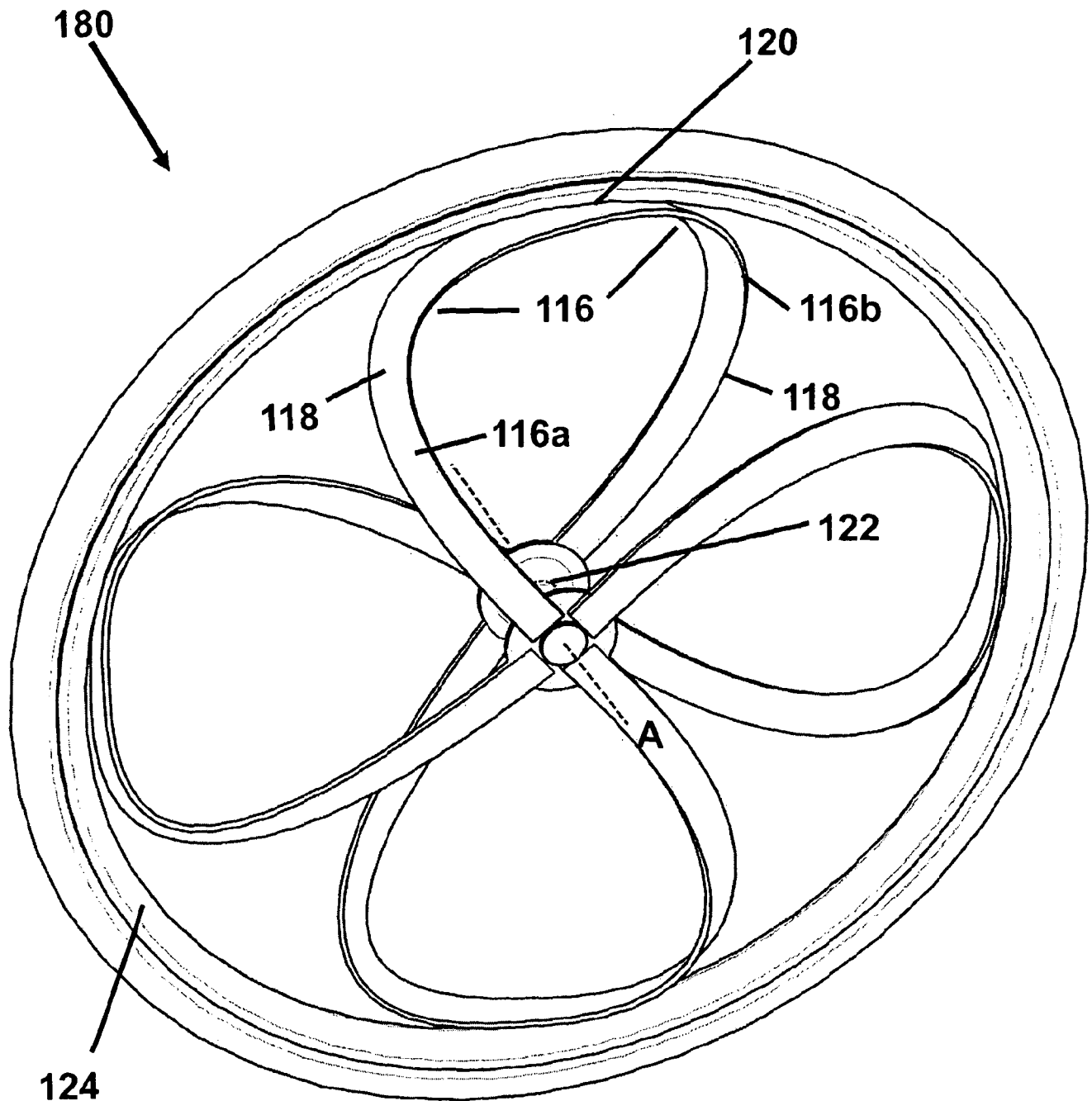


Figure 28

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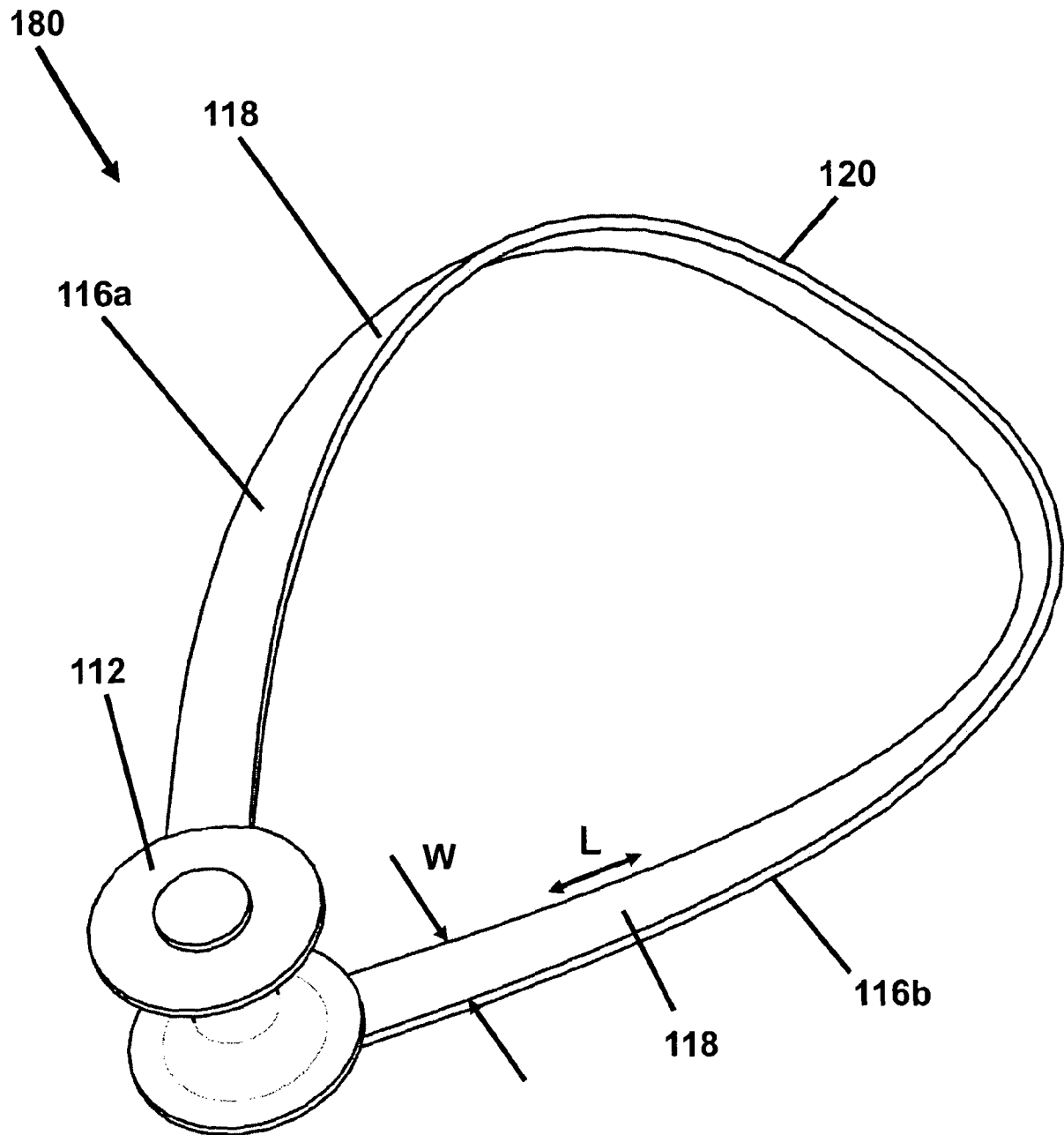


Figure 29

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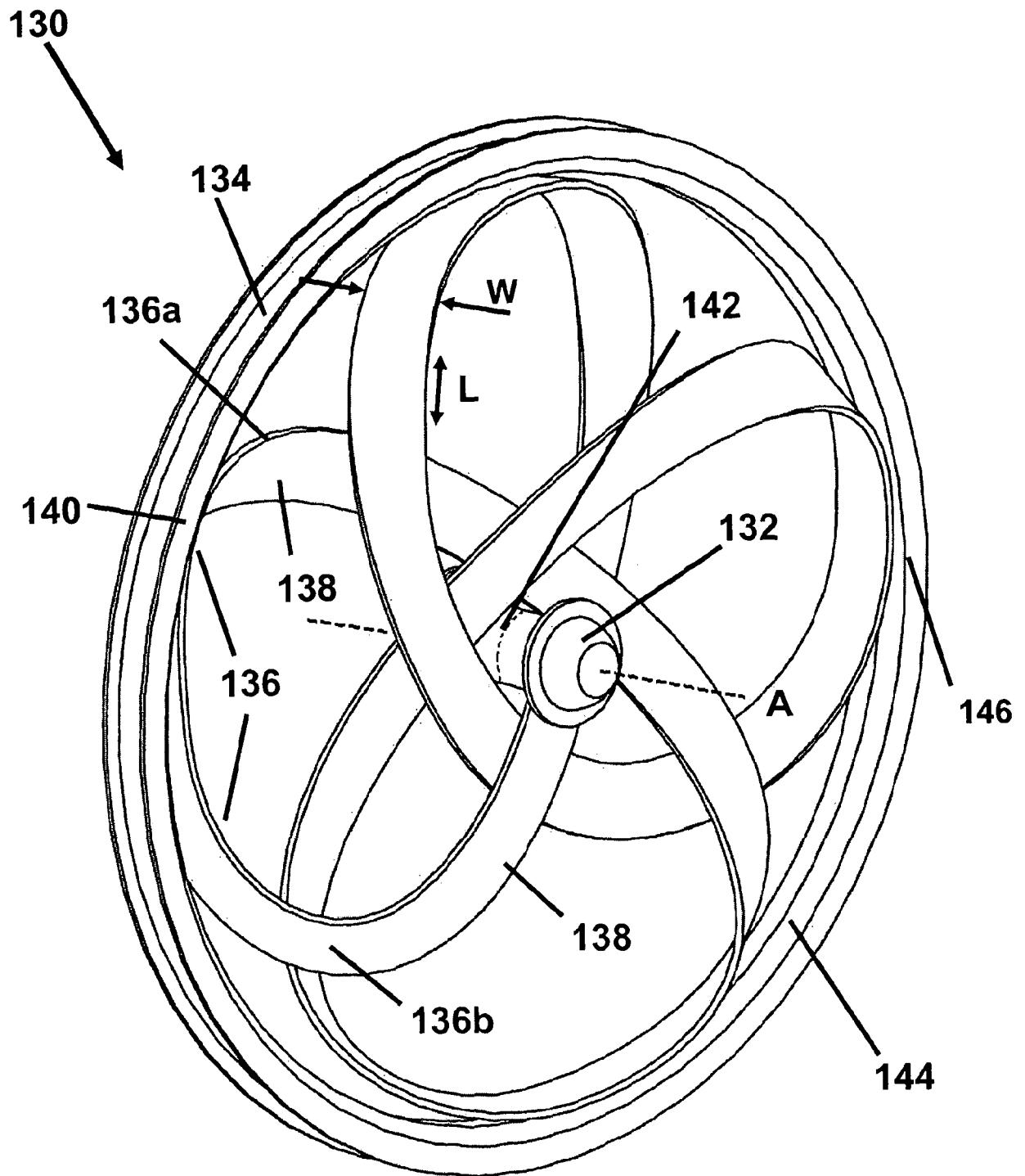


Figure 30

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2011/001165

A. CLASSIFICATION OF SUBJECT MATTER
INV. B60B9/04 B60B9/26
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B60B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	abstract; figures 1-5	5,7,9, 18-20
X	----- GB 20855 A A.D. 1911 (BLAKOE ROBERT [GB]) 23 September 1912 (1912-09-23) abstract; figures 1, 2	1-4,8, 10-17, 21,22
X	----- GB 29515 A A.D. 1913 (BRISTOW FREDERICK WILLIAM [US]) 5 February 1914 (1914-02-05) abstract; figures 1, 2	1,2,8,17
X	----- GB 12621 A A.D. 1912 (MELHUISH ALBERT EDWARD [GB]) 22 August 1912 (1912-08-22) abstract; figures 1-4 ----- -/-	1

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search

25 November 2011

Date of mailing of the international search report

05/12/2011

Name and mailing address of the ISA/

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Authorized officer

Schreck, Mathias

INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2011/001165

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 1 378 377 A2 (TECHNOLOGY INVEST LTD [IE]) 7 January 2004 (2004-01-07) paragraph [0027] - paragraph [0032]; figures 1-5 -----	18-20
Y	US 2002/003374 A1 (BRAUNSCHWEILER HANS GEORGE [CH]) 10 January 2002 (2002-01-10) paragraph [0071]; figure 4 -----	5
A		11
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2011/001165

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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