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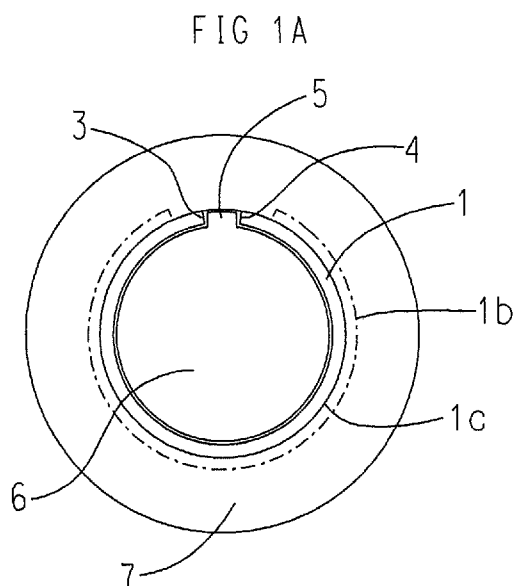
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(57) Abstract: There is provided an energy absorber comprising a first component such as a drum (7) having an axial bore and mounted for rotation about a second component such as a shaft (6). A resilient element such as a ring (1) is disposed between the first and second components and its periphery can be energised to apply a radial force with one of the components to effect frictional engagement in rotation. The resilient element has a positive interconnect (5) with the other of the two components. When a torque applied between the two components exceeds a predetermined magnitude, the frictional engagement is overcome and the first and second components are able to rotate relative to one another.



An energy absorber and safety device

The present invention relates to an energy absorber for use in fall arrest systems.

Fall arrest systems are utilised by personnel working at height primarily to prevent injury in the event of a fall. If a person falls, the fall arrest system arrests the fall in a controlled manner to bring the person to rest quickly and safely.

Fall arrest systems take many forms to suit various working at height applications and environments. They are also known as height safety systems, safety at height systems and fall prevention systems and encompass some rescue from height systems particularly where there is a fall arrest function. They all generally involve the fall arrest system being attached to one or more secure anchorages at height on a structure such as a building or tower. Personnel working at height typically wear a harness attached to a lanyard, lifeline or other safety line that can then be attached to the fall arrest system so in the event that a person falls, the person is brought to rest within a safe distance from the ground or any obstructions in the fall path.

An important requirement for a fall arrest system is that it should be able to manage the physical consequences of arresting a fall to ensure that load is kept within safe limits on the system itself, its installation and anchorages and particularly on personnel using the system. When a person is arrested from a fall, the magnitude of the fall energy is typically the product of the gravitational force applied by the faller and the vertical distance the faller falls before reaching a standstill. This energy is then largely absorbed by components of the fall system extending under load. If the extensions are insufficient, load in the fall arrest system tends to be too high. Therefore, in order to ensure that loads are kept within safe limits, fall arrest systems often employ energy absorbers that absorb fall energy by providing controlled resisted extension when load on the energy absorber exceeds a predetermined safe limit. Ideally, the energy absorber will effectively limit load by ensuring that the resistance when extending does not exceed the predetermined limit. The energy absorber will then continue to extend until sufficient energy has been absorbed for the load to reduce below the predetermined limit.

Whilst energy absorbers in fall arrest systems are important to limit loading within predetermined safe levels, it is also important that they perform consistently and ideally limit load at a constant level close to the predetermined safe level when extending. If they start to extend at loads significantly below safe levels, they extend further than necessary adding to the input fall energy because of a person falling moving through a great vertical distance. This in turn requires the energy absorber to extend further adding again to the input fall energy, potentially resulting in the faller being arrested significantly later than predicted and

risking collision with obstacles in the fall path or running out of ground clearance. Also, if the energy absorber fails to extend when loading exceeds the predetermined magnitude, load on the fall arrest system and the person falling could reach damaging levels.

A simple and common fall arrest system energy absorber such as shown in WO95/01815 is often combined with a lanyard to provide controlled extension by means of sewn webbing that rips to allow the webbing length to extend under a predetermined load. US2003111310 shows an energy absorber that deploys at a near constant deployment force using plastic deformation of metal to limit loading. This energy absorber is often used in series with a fall arrest system cable. For example, it may be attached to the end of a length of cable and attached at the top of the tower to limit loading on the cable below it or it may be used in a horizontal cable system to limit loading. EP1282460 discloses an energy absorber anchor post which is typically attached to the surface of a structure, such as a roof, as an anchor to support and connect to a fall arrest cable system or as a safe anchor for someone working at height to attach to. In a first orientation, the energy absorbing anchor stands upright to hold its connection with cable clear of the structure surface. Users attach to the cable and can move safely along it within a limited distance from the cable depending on the length of their cable attachments. In the event of a user falling such that load on the energy absorbing anchor exceeds a predetermined maximum level, the energy absorbing anchor deploys and starts to extend away from its fixings to the structure whilst remaining securely attached to them, allowing it to change its orientation towards the applied load. Resistance to deployment of the energy absorber is provided by utilising plastic deformation of metal which has been found to be exceptionally reliable for achieving a near constant resisting force. Deployment of the absorber continues until the applied fall load becomes less than the load resisting deployment of the absorber thereby limiting loading on the anchor, its installation and fixings and also on the associated fall arrest system. Also, because the load limiting can be predicted reliably, it becomes possible to install the energy absorbing anchor onto more fragile structures including directly onto roofing sheet instead of attaching to the more substantial underlying structure such as a purlin. WO2005079922 shows a similar energy absorber anchor post which uses friction to resist its deployment.

A common fall arrest system device that utilises energy absorption is known as a fall arrest block. It may be used as a fall arrest system attached to a secure anchorage on a structure or it may be a component of a fall arrest system such as being connected to a horizontal safety line. The fall arrest block provides a store of safety line secured at one end to a drum and wound onto the drum and the other end of the safety line being attached to a person's harness. A speed responsive mechanism is arranged to inhibit the drum rotation above a predetermined rotational speed. In a fall event, an energy absorber is arranged to

be deployed if a load above a predetermined threshold is encountered when the speed responsive mechanism is deployed. It is common for a fall arrest block to include a function for retracting safety line back onto the drum with the assistance of a spring mechanism similar to a clock spring. This type of fall arrest block is often referred to a retractable safety line or lanyard.

EP2771076 discloses an energy absorber for use with fall arrest systems that resists deployment of line in order to absorb energy. This invention employs a tolerance ring that is widely used to connect inner and outer components together without the need for accurate fitment tolerances. In the invention, the tolerance ring is fitted to provide an interference fit between a drum and a shaft, the drum being mounted for rotation about the shaft. When configured as an energy absorber, a safety line is typically attached at one end to the drum and wound onto the drum, the other end of the safety line being attached to a load. When the load exceeds a predetermined magnitude, such as when arresting a fall, the resulting torque on the drum overcomes the interference fit between the shaft and the drum allowing the drum to rotate with respect to the shaft and to deploy safety line thereby absorbing energy.

Whilst a tolerance ring is well suited to fitting inner and outer components together without a need for accurate tolerances, there are significant challenges when it is adapted for use with a fall arrest system energy absorber. Firstly, the mechanism for providing the interference fit between the shaft and the drum is reliant on the deflection of small corrugations around the outer circumference of the ring where small changes in their deflection will result in relatively large variations in the strength of the interference fit. If the interference fit is too strong, it will be difficult to overcome and therefore risk load on the safety line exceeding safe predetermined levels when arresting a fall. Conversely, if the interference fit is too weak, the energy absorber could deploy too much safety line, allowing a faller to fall too far and possibly run out of ground clearance. A further risk with weak interference is that the energy absorber could use up its capacity by deploying all the available safety line from the drum, resulting in the faller and the fall arrest system being exposed to unlimited load. Therefore, it is critical to maintain precise dimensional tolerances in the manufacture of the drum, shaft and the tolerance ring making the energy absorber difficult and costly to produce. Furthermore, with repeated use, any wear between the ring, drum and shaft would be likely to weaken the interference fit significantly.

Secondly, the tolerance ring is manufactured from small gauge metal sheet in order to enable the small elastic corrugated projections around its circumference to achieve the required degree of deflection. Much of the fall energy absorbed and resisted by the tolerance ring interference fit will be converted to heat and tend to be confined within the small

corrugations on the tolerance ring rather than being effectively dissipated elsewhere. This is largely because of the lack of mass in the tolerance ring itself. Significant heating of the tolerance ring could change the elastic properties of the tolerance ring material and therefore change the resistance of its interference fit. Generally, significant local heating would tend to weaken the interference fit.

Thirdly, the tolerance ring is difficult to assemble and also particularly difficult to replace because of the need to separate the interference fits between the tolerance ring, drum and shaft. When replacing a tolerance ring it is challenging to avoid damaging components, particularly the surfaces of the drum bore and the shaft and also the delicately constructed tolerance ring itself. This makes it difficult to maintain the precise and critical fitment tolerances required for the energy absorber to function safely.

Fourthly, the tolerance ring is difficult to customise easily to provide different strengths of interference fit because of its complexity and design for mass production. Since there are a large variety of the fall arrest system products and applications, it is an important requirement to be able to provide a variety of energy absorbers of different sizes that begin to extend under different predetermined loads.

An improved arrangement has now been devised.

According to the present invention there is provided an energy absorber for use in a fall arrest system encompassing any height safety system having a fall arrest function, the energy absorber comprising a first component having an axially extending bore and being mounted for rotation about a second component which extends into said bore, and a resilient element disposed radially between the first and second components, the resilient element having a periphery that can be energised to expand or contract elastically to apply a radial force between the resilient element and one of the first and second components to effect frictional engagement therebetween in the circumferential direction of rotation and having a positive interconnect between the resilient element and the other of the first and second components in order to prevent or limit their relative rotation, wherein, if a torque is applied between the first and second components that exceeds a predetermined magnitude, such as when arresting a fall, the resistance provided by the frictional engagement is overcome and the first and second components are able to rotate relative to one another thereby absorbing energy.

The resilient element is preferably in the form of an open or closed elastic ring that can be energised by reducing or expanding its periphery with respect to its free unconstrained shape. In order to effect frictional engagement with the first component, the periphery of the elastic ring is forcibly reduced to fit into the bore of the first component, the bore being smaller than the free unconstrained periphery of the ring. The ring is then

elastically energised to apply a radial force between the ring and the bore. Conversely, in order to effect frictional engagement with the second component, the periphery of the elastic ring is forcibly expanded to fit onto the second component, the second component having a larger periphery than the free unconstrained periphery of the ring, thereby elastically energising the ring to apply a radial force between the ring and the second component. The frictional resistance between the ring and the one of the first and the second component is largely determined by the magnitude of the radial force and the coefficient of friction between the contacting surfaces. Assembly of the ring with respect to either of the first or second components is typically achieved by forcibly reducing or enlarging the periphery of the ring beyond its fit in the bore of the first component or onto the second component so that it can be held and placed in its assembled position before releasing it to complete the assembly.

The positive interconnect between the ring and the other of the first and the second components is preferably provided by the ring interconnecting with one or more projections on or channels in the other of the first and second components. It is beneficial for the one or more projections or channels to be aligned parallel to the rotational axis of the first and second components so that movement between the ring and the other of the first and second components is unconstrained along this alignment. This greatly simplifies assembly and disassembly of the ring and the one of the first and second components because it enables the other of the first and second components to be easily located or withdrawn along the alignment. It also simplifies the assembly process by enabling the ring to be easily assembled for frictional engagement before, and unhindered by, assembly of the other of the first and second components.

Typically, the first component may be in the form of a cylindrical drum having an axially extending bore parallel to its central axis. In a preferred embodiment the cylindrical drum is circular and the extending bore is through its central axis. Whilst the bore in many embodiments is substantially circular it may be any suitable shape to fulfil its function. The second component extending into the bore may typically be in the form of a shaft with a substantially circular cross section. However, in other embodiments, it could have a complex cross section shape particularly where the shape is associated with providing the positive interconnect with the resilient ring.

In order to apply a torque to effect relative rotation between the drum and the shaft a typical embodiment may comprise a length of flexible elongate being connected at one end to the drum and wound onto the drum such that deployment of flexible elongate is dependent on rotation of the drum with respect to a stationary shaft, the other end of the elongate being attached to and ready to receive a tensile load. If a tensile load is applied exceeding a predetermined magnitude, such as when arresting a fall, the torque on the drum

overcomes the frictional resistance provided by the frictional engagement between the ring and the one of the drum and the shaft allowing the drum to rotate and deploy elongate thereby absorbing energy.

In a further embodiment, flexible elongate wound around the drum is able to be unwound and rewound during normal use such as with a fall arrest block or retractable lifeline. The flexible elongate deployed from the drum is typically securely attached to a person working at height allowing the person to move safely away from the fall arrest block or retractable lifeline within limits determined largely by the length of flexible elongate deployable from the drum. There is also normally a flat spirally wound spring similar to a clock spring that provides elastic energy to retract the cable onto the drum as a person moves towards the fall arrest block or retractable lifeline. To prevent a person from falling there is a speed responsive engagement mechanism that may comprise ratchet teeth and one or more pawl devices that positively engage when the speed of elongate deploying from the drum exceeds a predetermined limit. A preferred arrangement is for the shaft to be mounted for rotation in a frame, the shaft and frame being attached to a fall arrest system ready to resist a tensile load applied to the flexible elongate. One of the pawl device and ratchet teeth is typically attached to the shaft and the other of the pawl device and ratchet teeth is attached to the frame so that when the speed of deployment of flexible elongate from the drum exceeds a predetermined magnitude as when arresting a fall, the pawl device and ratchet teeth engage preventing the shaft from rotation relative to the frame. The resilient element in the form of a ring is located between the drum and the shaft providing frictional engagement with the one of the drum and the shaft whilst the other of the drum and the shaft has a positive interconnect with the ring preventing their relative rotation when interconnected. On engagement of the pawl device and ratchet teeth and the application of torque on the drum exceeding a predetermined magnitude sufficient to overcome the frictional engagement between the ring and the one of the drum and the shaft, such as when arresting the fall, the drum is allowed to rotate relative to the shaft and to deploy flexible elongate from the drum thereby absorbing energy.

In some embodiments where the resilient element is an open ring, the open portion of the ring provides a useful location for effecting a positive interconnect between the ring and the other of the drum and the shaft. Alternatively, it may be beneficial for the ring to be configured to provide the interconnect at any suitable location on its inner or outer periphery.

The open ring can be configured at its positive interconnect with the other of the drum and the shaft to benefit to an extent from the capstan effect where the resistance provided by the frictional engagement with the one of the drum and the shaft can be enhanced by the extent of the arc of contact between them. The open ring may therefore be

configured to provide any suitable contact arc ranging from as little as π radians (180 degrees) to in excess of 2π radians (360 degrees) where the ring could be formed as a spiral.

In some embodiments it may be beneficial for the elastic energising of an open ring to be provided by or enhanced by an additional resilient element such as, for example, a common spirally wound spring configured in compression or tension. This could be beneficial to allow more flexibility in considering options for the design of the geometry of the ring such as to simplify its manufacture or improve functionality. In a further embodiment it may be convenient to attach the ring and additional resilient element together effectively forming a closed ring.

In other embodiments, the resilient element may be in the form of a closed ring having sufficient elastic deflection within the ring itself to allow its periphery to expand or contract elastically to provide the required frictional engagement with the one of the drum and the shaft whilst also being configured to provide a positive interconnect with the other of the drum and the shaft.

The cross-section shape, size and geometry of the resilient element in any of the above-mentioned embodiments may vary. For example, with an open ring, the bending moment, when elastically energised, will be greatest in the middle section and reducing towards either end. Therefore, it may be beneficial to configure the ring with a stiffer section in the middle and reducing towards either end in order to distribute the applied radial force evenly around the periphery of the ring.

In further embodiments there may be a plurality of rings arranged either concentrically or arranged side by side sharing the same axis.

In a further embodiment it may be beneficial to provide one or more bearings between the drum and shaft to maintain a consistent clearance for the ring location so that the frictional engagement provided by the ring is largely unaffected by mechanical interaction between the drum and shaft perpendicular to their axes of rotation. For example, bearings between the drum and shaft may be usefully positioned either side of a ring to provide support between the drum and the shaft, or alternatively, a centrally located bearing may have rings positioned either side of it.

Where frictional engagement between the ring and one of the drum or shaft is required to endure heavy use or where there may be problems associated with high starting friction such as stiction, it may be beneficial to provide a proprietary friction lining material or durable coating to one or both frictional contact surfaces between the ring and its frictional engagement with the one of the drum and the shaft. A friction lining or durable coating may

also help to provide a predictable and consistent coefficient of friction between the contact surfaces.

Any of the above embodiments may be specifically configured for relative rotation between the drum and the shaft in one of a clockwise and anticlockwise direction instead of rotation in both directions.

A particular benefit of the invention in all of the above-mentioned embodiments is that a substantial part of the body of the ring deflects elastically so that variations in elastic deflection result in relatively small differences in the radial force effecting the frictional engagement. This is similar to the properties of a low rate spring. Consequently, in contrast with the use of a tolerance ring, there is no need for tight manufacturing tolerances in producing and assembling the ring, drum and shaft.

Another benefit of the invention is that the ring generally has a substantial mass in contrast to a tolerance ring, so that any heat generated whilst absorbing energy would be readily dissipated without the ring reaching a temperature that could change its elastic properties. Also, wear between the ring and its frictional engagement with one of the drum and the shaft is minimised by having a comparatively large contact area.

A further benefit of the invention is that it is easily customised to suit a range of applications requiring different magnitudes of frictional resistance. Firstly, when using an open ring configured to benefit from the capstan effect, the contact arc between the ring and the component with which it has frictional engagement can be increased or decreased to effect more or less frictional resistance. Secondly, the difference in size between the unconstrained free ring and the assembled ring can be increased or decreased easily to change the degree of elastic energisation and therefore the applied radial force effecting frictional engagement. Thirdly, the elastic strength of the ring can be modified by changing its cross section. Fourthly, the coefficient of friction between the ring and its frictional contact with one of the shaft or the drum can be modified by choice of materials, special linings and surface coatings.

As mentioned above, the invention is straightforward to assemble and disassemble particularly in embodiments where the other of the shaft and the drum providing the interconnect with the ring, can be freely slotted into place along a path parallel to the axis of the drum and shaft.

Whilst it is preferred for the ring to be made of metal such as steel, it could be made from any suitable resilient material. Also, the ring could have any cross-sectional shape such as round, square, rectangular or complex.

The invention will now be further described by way of example only and with reference to the accompanying drawings, in which:

Figures 1, 1A and 1B show a perspective view and end views of the invention utilising an open ring in a first configuration;

Figure 1C shows utilisation of an open spirally wound ring;

Figures 2, 2A and 2B show a perspective view and end views of the invention utilising an open ring in a second configuration;

Figures 3 and 3A show end views of the invention utilising an open ring in a third configuration;

Figures 4 and 4A show end views of the invention utilising an open ring in a fourth configuration;

Figures 5 and 5A show end views of an alternative construction of the invention utilising an open ring;

Figure 6 and 6A shows end views of the invention utilising a closed ring;

Figures 6B and 6C show a plan view of the ring in a flat condition before being formed into a ring and an isometric view of the invention utilising a ring configured to be able to expand and contract elastically along its circumferential length;

Figure 7 shows an end view of the invention with supplementary or alternative energisation;

Figures 8 and 8A show a sectional end view and associated part sectional side view of the invention having support from bearings;

Figures 9 and 9A show a front elevation and associated part sectional side elevation of the invention configured as a fall arrest system energy absorber device;

Figures 9B, 9C, 9D, 9E, 9F, 9G and 9H show an isometric view, two exploded isometric views, two front elevations and two part sectional side elevations of a typical embodiment utilising some features of the embodiment in figures 9 and 9B;

Figures 9J, 9K, 9L, 9M and 9N show an isometric view, an exploded isometric view, a front elevation, a part sectional front elevation and a part sectional side elevation of an alternative embodiment of a device performing a similar user fall arrest system function as in figures 9B, 9C, 9D, 9E, 9F, 9G and 9H with the benefit of greater leverage for applying resisting torque to absorb energy;

Figures 10 and 10A show a front elevation and associated part sectional side elevation of the invention configured as an alternative fall arrest system energy absorber device;

Figures 11, 11A and 11B show a plan elevation, side elevation and sectional side elevation of the invention as a further alternative fall arrest system energy absorber device;

Figures 12, 12A and 12B show a front elevation and associated sectional detail view and part sectional side view of the invention configured as another alternative fall arrest system energy absorber device in a first orientation;

Figure 12C shows the fall arrest system energy absorber device in figure 12, 12A and 12B in a second orientation;

Figure 12D shows the fall arrest system energy absorber device in figure 12C in a third orientation;

Figure 1 shows a resilient element being an elastic ring 1 typically having a substantially tubular form with an opening shown at an opening 2 between ends 3 and 4. In figure 1A a drum 7 is a circular cylinder having a circular bore 1c aligned with its central axis. A ring 1, similar to the ring 1 in figure 1, has an unconstrained free outer periphery, shown as periphery 1b in figure 1 (and as a ghost periphery 1b in figure 1A to illustrate its constrained and unconstrained sizes), that is larger than the diameter of the bore in the drum 7. In order to fit the ring 1 into the bore in the drum 7, the periphery of the ring 1 is preferably forcibly reduced and held to fit with clearance into the bore of the drum 7 and then released when located in position. The difference between the size of the unconstrained free periphery of the ring 1 and the diameter of bore in the drum 7 effectively elastically energises the ring 1 to apply a radial force between itself and the bore in the drum 7 thereby effecting frictional engagement. A shaft 6 is a cylindrical shaft having a diameter that fits with clearance into the assembled ring 1. The shaft 6 also has a projection 5 in the form of a key spline extending along the length of shaft 6 and configured to fit with clearance between the ends 3 and 4 of the assembled ring 1 in order to provide a positive interconnect between the ring 1 and the shaft 6 preventing their relative rotation when interconnected. The shaft 6 is then assembled into the ring 1 and the drum 7 by being slotted into the inner periphery of the ring 1 whilst also aligning the projection 5 for insertion with clearance between the ends 3 and 4 of the ring 1. In a typical embodiment as an energy absorber, a torque is applied between the drum 7 and the shaft 6 that is resisted by the frictional engagement between the ring 1 and the drum 7. However, if the applied torque exceeds a predetermined maximum such as when arresting a fall, the frictional engagement between the drum 7 and the ring 1 is overcome allowing relative rotational movement between the drum 7 and the shaft 6 thereby absorbing energy.

During relative rotation between the drum 7 and the shaft 6, the interconnect between the projection 5 on the shaft 6 and one of the ends 3 and 4 of the ring 1 tends to urge the end of the ring 1 towards the bore of the drum 7 thereby enhancing the

circumferential frictional engagement between the ring 1 and the drum 7. Therefore, to some extent, the circumferential frictional engagement may be enhanced by the capstan effect as defined in Eytelwein's formula:

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

In the example in figure 1A, T₁ can be related to the load at the interconnect between the open ring 1 and the projection 5 on the shaft 6, T₂ is related to the frictional resistance between the open ring 1 and the drum 7, θ is the contact arc between the drum 7 and the ring 1 expressed in radians and μ is the coefficient of friction between the contact surfaces. Therefore, for a given elastic energisation of the ring 1 in the bore of the drum 7 the frictional resistance between them may be enhanced or reduced by increasing or reducing their contact arc. A large contact arc such as for example using a spirally wound open ring would significantly increase frictional resistance whereas a smaller contact arc would reduce the frictional resistance. In figure 1B, two projections 5 and 5c are provided in the space between the ends 3 and 4 of a ring 1 to facilitate a smaller contact arc than in the embodiment in figure 1A. This is illustrative of the potential to customise the frictional engagement to suit different applications.

In figure 1C, a ring 1 is shown as being spirally wound between its ends in order to provide a large contact arc. A drum 7 is cylindrical with a circular bore centred on its central axis. As in figures 1A and 1B, the unconstrained free outer periphery of the ring 1 is larger than the diameter of the bore in the drum 7. The outer periphery of the ring 1 is forcibly reduced and held to fit into the bore of the drum 7 and then released when located in position so that the ring 1 becomes elastically energised to have frictional engagement with the drum 7. A shaft 6 has a cylindrical portion 6a that fits with clearance inside the inner periphery of the ring 1 assembled in the drum 7. The shaft 6 has an abutment 5 protruding on its outer surface that engages positively at its end 5a with the end 3 of the ring 1 to resist relative rotation between the drum 7 and the shaft 6 when a torque is applied between them such as when the drum 7 is urged in the direction of the arrow 19 against a stationary shaft 6. If and when such an applied torque overcomes the frictional resistance between the ring 1 and the drum 7, the drum 7 is able to rotate relative to the shaft 6 and thereby absorb energy. Also, the direction of the applied torque tends to urge the ring 1 to expand towards the bore of the drum 7 thereby benefitting to an extent from the capstan effect. The end portion 6b of the shaft 6 is shown only because it may be useful to retain the ring 1 in the drum 7. Whilst the example in figure 1C shows the ring 1 being spirally wound from circular

cross section rod, the wound material could have any other suitable cross section. Also, the spiral winding allows useful flexibility in providing for different levels of frictional resistance by increasing or decreasing the number of wound turns.

Figure 2 shows a resilient element being an elastic ring 1 typically having a substantially tubular form with an opening shown at an opening 2 between ends 3 and 4, the ends 3 and 4 being both bent outwards to form projections aligned parallel to the axis of the ring 1. In figure 2A a shaft 6 is a circular cylindrical shaft. A ring 1, similar to the ring 1 in figure 2 has an unconstrained free inner periphery 1b, such as an inner periphery 1b shown in figure 2A (and as a ghost periphery in figure 2A to illustrate its constrained and unconstrained sizes), that is smaller than the diameter of the outer periphery 1c of the shaft 6. In order to fit the ring 1 onto the shaft 6, the periphery of the ring 1 is preferably forcibly increased and held to fit with clearance onto the shaft 6 and then released when located in position. The difference between the size of the unconstrained free periphery of the ring 1 and the diameter of the shaft 6 effectively elastically energises the ring 1 to apply a radial force between itself and the surface of the shaft 6 thereby effecting frictional engagement. A drum 7 is typically a circular cylindrical drum having a substantially circular bore through its central axis that fits with clearance onto the periphery of the assembled ring 1. The drum 7 also has a channel 5a extending between either end of its bore and configured to fit with clearance between either side of ends 3 and 4 of the assembled ring 1 in order to provide a positive interconnect between the ring 1 and the drum 7 and to prevent their relative rotation when interconnected. The drum 7 is then assembled onto the ring 1 and the shaft 6 by being slotted over the outer periphery of the ring 1 whilst also aligning the channel 5a for insertion either side of the ends 3 and 4 of the ring 1. In a typical embodiment for absorbing energy, a torque is applied between the drum 7 and the shaft 6 that is resisted by the frictional engagement between the ring 1 and the drum 7. However, if the applied torque exceeds a predetermined maximum such as when arresting a fall, the frictional engagement between the shaft 6 and the ring 1 is overcome allowing relative rotational movement between the drum 7 and the shaft 6 thereby absorbing energy.

During relative rotation between the drum 7 and the shaft 6, the interconnect between the channel 5a in the drum 7 and one of the ends 3 and 4 of the ring 1 tends to urge the ring 1 onto the shaft 6 thereby benefitting from the capstan effect to enhance the circumferential frictional resistance between the ring 1 and the shaft 6 with respect to the contact arc between the ring 1 and the shaft 6. Figure 2B shows an embodiment having two channels 5a and 5b in which the projected ends 3 and 4 of a ring 1 are received to facilitate a smaller circumferential contact arc than in the embodiment in figure 2A. As in figure 1B,

this is illustrative of the potential to customise the frictional engagement to suit different applications.

In other embodiments it may be desirable to minimise the capstan effect such as in the examples in figure 3 and 3A. Figure 3 shows an example that is similar to the example shown in figure 1A except that the interconnect between the ring 1 and the shaft 6 is differently configured to minimise the capstan effect. In figure 3, ends 3 and 4 of an open ring 1 are bent inwards to form a positive interconnect with a channel 5a extending along the length of a circular shaft 6, thereby preventing relative rotation between the ring 1 and the shaft 6 when interconnected. When a torque is applied between a drum 7 and the shaft 6 sufficient to allow relative movement between them, the interconnect between the ring 1 and the shaft 6 tends to urge the ring 1 away from its frictional engagement with the drum 7 rather than reinforce its contact as in figure 1B.

The example in figure 3A is similar to the example shown in figure 2A except that the interconnect between the ring 1 and the drum 7 is differently configured to minimise the capstan effect. In figure 3A, ends 3 and 4 of an open ring 1 are located either side of a projection 5 on the inside of the bore of a drum 7, the projection 5 being in the form of a key spline extending along the length of the bore and providing an interconnect between the ring 1 and the drum 7 thereby preventing relative rotation between the ring 1 and the drum 7 when interconnected. When a torque is applied between a drum 7 and the shaft 6 sufficient to allow relative movement between them, the interconnect between the ring 1 and the drum 7 tends to urge the ring 1 away from its contact with the bore of drum 7 rather than reinforce its contact as in figure 1A.

In figure 4, ring 1 is an elastic open ring typically having a substantially tubular form. As with the example in figure 1A, the ring 1 is elastically energised to provide frictional engagement with a drum 7, the drum 7 being a circular cylindrical drum with a circular bore through its central axis. On the inner periphery of the ring 1 between its open ends is a projection 5 extending along the tubular length of the ring. A shaft 6 is typically a cylindrical shaft with a channel 5a extending along its length and configured to form a positive interconnect with the projection 5 on the ring 1 preventing relative rotation between shaft 6 and ring 1 when interconnected. When a torque is applied between the drum 7 and the shaft 6 sufficient to overcome the frictional engagement between the drum 7 and the ring 1, such as when arresting a fall, drum 7 and shaft 6 are allowed to effect relative rotational movement thereby absorbing energy.

Figure 4A is an alternative version of the embodiment in figure 4 where a ring 1 is elastically energised to provide frictional engagement with a circular shaft 6. The ring 1 has a projection 5 on its outer periphery between its open ends and extending along the tubular

length of the ring 1. A drum 7 is cylindrical and circular with a circular bore through its central axis and having a channel 5a extending the length of the bore configured to form a positive interconnect with the projection 5 in the ring 1 preventing relative rotation between the drum 7 and the ring 1 when interconnected. When a torque is applied between the drum 7 and the shaft 6 sufficient to overcome the frictional engagement between the shaft 6 and the ring 1, such as when arresting a fall, drum 7 and shaft 6 are allowed to effect relative rotational movement thereby absorbing energy.

The advantage of both embodiments in figures 4 and 4A is that the frictional engagement between the ring 1 and the drum 7 in figure 4 and the shaft 6 in figure 4A benefits to an extent from the capstan effect to one side of the positive interconnect and less so on the other side, so that the positioning of the interconnect can be useful for customising and refining the frictional engagement between the ring 1 and one of the drum 7 and the shaft 6.

Figures 5 and 5A show embodiments that share similarities with the embodiment examples in figures 1A and 2A except that the rings in figures 5 and 5A have complex cross-sectional wall thicknesses. In figures 5 and 5A the resilient elements are in the form of open tubular rings as in figures 1A and 2A but with wall thicknesses that vary along the cross section of the rings. This variation can be usefully used for example when the ring is energised in order to distribute the resulting radial force evenly around the contact surface between the ring and the component with which it is frictionally engaged. In figure 5 the frictional engagement is between a ring 1 and a drum 7, similar in this respect to the example in figure 1A. Whereas in figure 5A the frictional engagement is between a ring 1 and a shaft 6, similar in this respect to the example in figure 2A. The bending moment distributed around the ring 1 when it is elastically energised is greatest furthest away from the ends of the ring, shown as ends 3 and 4, whilst reducing towards each of the ends 3 and 4. Therefore, it is sensible for the ring 1 to have its greatest wall thickness in the middle of the ring whilst reducing towards its ends. However, the ring 1 could have any complex cross section as may be required.

In figures 5 and 5A, it is beneficial for the outer circumferential surface of the drum 7 to be concentric with the axis of the frictional engagement contact between the ring 1 and one of the drum 7 and the shaft 6 in order to maintain a consistent applied torque during relative rotation between the drum 7 and the shaft 6. For example, in figure 5, the outer surface of the drum 7 is shown as being concentric with the bore of the drum 7 and the outer surface of the ring 1. Because of the interconnect between the shaft 6 and the ring 1, the shaft 6 is typically configured to fit inside the ring 1. In figure 5A, the outer surface of the

drum 7 is shown as being concentric with the shaft 6, whereas the bore of the drum 7 is typically configured to fit outside the ring 1.

Figures 6 and 6A show end views of embodiments incorporating resilient elements in the form of elastic closed rings. In figure 6 a closed ring 1 is tubular having a cross section that is partially circular but also having a radial indent configured with radial legs 3a and 4a. A drum 7 is cylindrical with a circular bore through its central axis that has a smaller periphery than the circular part of the closed ring 1. In order to elastically energise the ring 1, the periphery of the ring 1 is forcibly reduced and held by urging the legs 3a and 4a towards each other, effectively reducing the angle subtended between them. The ring 1 is then inserted into the bore of the drum 7 and released in position in order to effect frictional engagement between the ring 1 and the drum 7. A shaft 6 has a specifically configured cross-sectional shape to fit with clearance inside the assembled ring 1 whilst also having a channel 5a for effecting a positive interconnect with the legs 3a and 4a to prevent relative rotation between the ring 1 and the shaft 6 when interconnected. With the arrangement in figure 6 is that the elastic deflection in the ring 1 on assembly is mainly in the peripheral region closest to the legs 3a and 4a so that the resulting radial force applied between the ring 1 and drum 7 is unevenly distributed. Figure 6A has a closed tubular ring 1 whereby elastic deflection of the periphery of the ring 1 is provided by two radial indents, one being configured with legs 3a and 4a and the other being configured with legs 3b and 4b in order to distribute the applied radial force between the ring 1 and the drum 7 more evenly. A shaft 6 has two channels 5a and 5b for effecting a positive interconnect with the legs 3a and 4a and the legs 3b and 4b to prevent relative rotation between the ring 1 and the shaft 6 when interconnected.

Figures 6B and 6C show an embodiment incorporating a resilient element typically in the form of a closed ring whereby elastic deflection is provided at various locations on the circumference of the ring so that its circumferential length is able to expand and contract elastically. Figure 6B shows a flat strip 1 that may be rolled into a ring. The flat strip 1 is a resilient flat rectangular strip with ends 3 and 4 and having an arrangement of open slots such as slots 8a and 8b whereby the open end of each slot alternates from either side of the strip so that the length of the strip is able to extend if pulled apart between the ends 3 and 4, or contract if the ends 3 and 4 are pushed towards each other. In figure 6C a drum 7 is a circular cylinder with a circular bore along the central axis of the drum. A ring 1 is the flat strip 1 in figure 6B rolled into a tubular circular ring with the ends of the ring 1 butted together to form a closed ring. The alternating arrangement of slots such as slots 8a and 8b allows the circumferential length of the ring 1, and therefore the size of its periphery, to be able to change elastically as a result of deflection at each slot. The free unconstrained periphery

of the ring 1 is greater than the bore in the drum 7. The periphery of the ring 1 is then preferably forcibly reduced and held on assembly into the bore of the drum 7 and then released when in position in the bore resulting in the ring 1 being elastically energised to apply a radial force between the ring 1 and the bore of the drum 7. A substantially circular shaft 6 has an arrangement of projections in the form of splines such as splines 8c and 8d, that extend from one end of the shaft 6 and partly along its length to interconnect with the ring 1. In order to simplify assembly of the shaft 6 into the ring 1, the interconnect is typically between the spline projections on the shaft 6 and slots such as the slot 8b in the ring 1 that open onto one end of the ring 1. The interconnect prevents the relative rotation between the shaft 6 and the ring 1 when interconnected. The example in figure 6B shows ends 3 and 4 of the ring 1 being butted together so that change in the size of the periphery of ring 1 is determined by elastic deflection at the slots either side of the ring. In other embodiments the same effect could be achieved by the ring being an open ring whereby its open ends butt either side of an additional spline projection extending along the length of the shaft 6. Alternatively, the ends 3 and 4 could be attached together or the ring 1 could be manufactured from a tube.

Figure 7 shows an embodiment where the elastic energising of the open ring may be provided by or assisted by an additional resilient element such as, in this example, a common spirally wound spring. In figure 7, a drum 7 is a circular cylinder with a circular bore through its central axis. A ring 1 is a resilient open ring with ends 3 and 4 either side of the opening. The ends 3 and 4 are bent inwards providing a convenient location for one or more springs such as spring 9 to be disposed between them. In this example, spring 9 is a common spirally wound compression spring tending to urge ends 3 and 4 apart thereby increasing the size of the periphery of the ring 1. The free unconstrained periphery of the ring 1 incorporating the spring 9 is larger than the diameter of the bore in the drum 7. In order to assemble the ring 1 into the bore of the drum 7, the periphery of the ring 1 is preferably forcibly reduced and held during insertion into the bore in the drum 7 and then released when in the desired position in the bore of the drum 7. The ring 1 and the spring 9 are then energised in the bore of the drum 7 in order to apply a radial force between the ring 1 and its contact with the drum 7 bore to provide frictional engagement. The extent to which the ring 1 contributes to the elastic energisation can be varied. For example, the ring 1 free unconstrained periphery could be the same size or smaller than the diameter of the bore in the drum 7 prior to the addition of the spring 9 so that the elastic energisation of the ring 1 in the bore of the drum 7 is provided solely or largely by the spring 9. Alternatively, the free unconstrained periphery of the ring 1 could be larger than the diameter of the bore in the drum 7 prior to the addition of the spring 9 so that the spring 9 is assistive in elastically

energising the ring 1. For convenience, the spring 9 could be attached between the ends of the open ring 1 to form a closed ring. A projection 9 on the shaft 6 is a key form spline extending along the length of the shaft 6 allowing space for the location of the spring 9 and also providing an interconnect between the ends 3 and 4 of the ring 1 and the shaft 6 preventing their relative rotational movement when interconnected. An alternative embodiment could also be configured so that the ring 1 has frictional engagement with the shaft 6.

Figures 8 and 8A show sectional and part sectional elevations of a drum 7 supported on bearings 10a and 10b that are both mounted on a shaft 6. The bearings could be any type such as plain, roller or ball. This embodiment is shown with the resilient element in figure 1A for convenience although it could apply to any of the preceding examples. Drum 7 is a circular cylinder with a circular central bore and a shaft 6 is a circular shaft. In a preferred embodiment, the shaft 6 would be stationary with respect to the drum 7. When a torque is applied between the drum 7 and the shaft 6, resisted by the frictional engagement between the ring 1 and the drum 7, there is a component of load tending to pull the drum 7 towards the shaft 6 thereby compressing the intermediate ring 1. The bearings 10a and 10b ensure that this component of load is resisted by the bearings rather than interacting with the ring 1. Also, the bearings provide a good rotational fit between the drum 7 and the shaft 6.

Figures 9 and 9A show a front view and side sectional elevation of a fall arrest system energy absorber incorporating a resilient element such as in any of the preceding examples although for convenience the following example is shown with an open tubular elastic ring such as in Figure 1A. A frame 11 is a metal sheet formed into a U channel with a hole either side of the channel to support either end of a shaft 6 which is a tube mounted for rotation relative to the frame 11. At one end of the shaft 6 are four equally spaced projections such as a projection 12 that engage in holes in a ratchet plate 13 to prevent any relative rotation between the shaft 6 and the ratchet plate 13. The ratchet plate 13 has an outer profile with repeated ratchet teeth. A nut and bolt 15 is located on the axis of the shaft 6 and effectively secures the ratchet plate 13 to one end of the shaft 6 and an end spacer 16 to its other end. The end spacer 16 is formed from a disc with a circular shoulder to retain its position in the end of the shaft 6 and has a central hole through which the bolt 15 passes and also has an outer circumference that is greater than the outer diameter of the shaft 6 thereby limiting the movement of the shaft 6 along its axis to within a running clearance with respect to the frame 11. A spacer 17 is a tubular spacer to ensure clearance between the ratchet plate 13, the end spacer 16 and the frame 11 when nut and bolt 15 are fastened. Pawls 18a and 18b are mounted on the frame 11 and configured for rotation with respect to the frame 11. Rotation of the shaft 6 and the ratchet teeth on ratchet plate 13 about the

frame 11 in the direction of arrow 19 in figure 9 interacts with the pawls 18a and 18b such that if and when the rotation of the ratchet plate 13 reaches a predetermined magnitude of speed, one of the pawls 18a and 18b engages with one of the ratchet teeth such as the engagement of the pawl 18b shown in figure 9. A drum 7 is typically cylindrical with a central circular bore through its central axis and having flanges at either end to contain elongate wound onto the drum. Elongate 20 is a length of flexible elongate secured at one end with respect to the drum 7 and wound a number of times around the drum 7, the other end of the elongate 20 being attached to and available to receive a load applied between elongate 20 and an attachment 21. The attachment 21 is secured to the middle of the channel section of the frame 11. An open ring 1 such as is shown in figure 1A is located between the outer surface of the shaft 6 and the central bore in the drum 7. The size of the free unconstrained periphery of the ring 1 is larger than the diameter of the bore in the drum 7 such that when the ring 1 is assembled into the bore of the drum 7, the periphery of the ring 1 is preferably forcibly reduced and held to fit into the bore of the drum 7 and then released when in position thereby elastically energising the ring 1 to have frictional engagement with the drum 7. The shaft 6 has a key form spline projection extending along its length that fits between the ends of the of the ring 1 to provide an interconnect preventing the relative rotation of the ring 1 and the shaft 6 when interconnected. The attachment 21 is typically securely attached to a secure anchor or other component of a fall arrest system whilst the elongate 20 is typically attached to a person's fall arrest harness.

In use, the drum 7 and the shaft 6 rotate together as a result of their respective interaction with the open ring 1 allowing a person working at height to move with respect to the drum 7 as a result of the elongate 20 being deployed from the drum 7. Preferred embodiments would also usually incorporate a low rate spring such as a spirally wound clock type spring in order to rewind elongate 20 onto drum 7 as the person moves closer to the drum 7. In the event of the person falling, the drum 7 and the shaft 6 initially rotate together until the rotational speed of the ratchet plate 13 exceeds a predetermined magnitude causing one of the pawls 18a and 18b to engage in one of the ratchet teeth on the periphery of the ratchet plate 13 and preventing the shaft 6 from further rotation relative to the frame 11. If and when the torque applied on the drum 7 as a result of tensile loading between the elongate 20 and the attachment 21 exceeds a predetermined magnitude such as when arresting a fall, the frictional resistance between the open ring 1 and the bore of the drum 7 is overcome allowing the drum 7 to rotate with respect to the shaft 6 and to deploy the elongate 20 thereby absorbing energy. The energy absorber effectively prevents load exceeding the predetermined magnitude between the elongate 20 and the attachment 21 thereby protecting the person falling from experiencing damaging loads whilst also protecting

the fall arrest system from excessive loading and potential failure. In Figure 9A, the embodiment example is shown with bearings 10a and 10b to provide support for the drum 7 with respect to its mounting on the shaft 6 to minimise movement between the drum 7 and the shaft 6 in normal use and also to maintain the clearance between the inner radial surface of the open ring 1 and the outer surface of the shaft 6. However, the energy absorber could function satisfactorily without bearings 10a and 10b.

Figures 9B, 9C, 9D, 9E, 9F, 9G show a further embodiment of the fall arrest system shown in figures 9 and 9A with the benefit of providing a mount for a clock type spring in order to rewind the elongate 20 on to the drum 7. For convenience, a ring 1 is shown as being largely similar to the ring 1 in figures 9 and 9A. However, in some embodiments it may be beneficial for the ring 1 to retain a circular or near circular form in both its free and elastically energised states in order to simplify its free state manufacture whilst also achieving a good fit when elastically constrained in a circular bore. When the body of the ring 1 is elastically energised it is subjected to bending moments that are highest furthest from its open ends and then gradually reducing towards each end. Therefore, it may be beneficial to reduce the material in the ring to enable it to conform elastically more easily where the bending moment is low. Ideally, more material is removed from locations nearer the ends of the ring and less or no material is removed towards the mid-point of the ring between its ends. By way of example, the ring 1 in figures 9C and 9D is shown with cut outs 8a and 8b that are configured so that the amount of material removed is approximately inversely proportional to the applied bending moment, where the most material removed is closest to either end of the ring gradually reducing either side towards the middle portion of the ring where the bending moment is greatest.

A drum 7 is typically cylindrical with central circular bore centred on its central axis and having flanges at either end to contain elongate wound onto the drum. The ring 1 has a larger free unconstrained periphery than the bore in the drum 7 such that when the ring 1 is assembled into the bore of the drum 7 the periphery of the ring 1 is forcibly reduced and held to fit into the bore of the drum 7 and then released when in position thereby elastically energising the ring 1 to have frictional engagement with the drum 7 as shown in figure 9G. The shaft 6 is shown as largely tubular with four equal spaced bosses attached to the internal wall and extending along the length of the shaft 6. Each boss has a hole through its length to allow a bolt such as a bolt 15 to pass. Each bolt passes through a disc 16, the shaft 6, a disc 40 and a spacer 41 before being fastened securely to a ratchet plate 13 such that the central axes of the discs 16, 40 and 41 are aligned with the axis of the shaft 6. Ratchet plate 13 has an outer profile with repeated ratchet teeth equally disposed about a central

hole that is also aligned with the central axis of shaft 6 on assembly. The assembly of the shaft 6 to the ratchet plate 13 is then located into the ring 1 in the bore of the drum 7. The shaft 6 has a key form spline projection 5 extending along its length that fits between the ends of the ring 1 to provide a positive interconnect preventing relative rotation of the ring 1 and the shaft 6 when interconnected. Also, the outer periphery of the shaft 6 fits with clearance into the inner periphery of the ring 1.

A shaft 17 is cylindrical and located with clearance in holes sharing the same axis in the adjacent sides of a frame 11 which is typically formed from metal sheet into a U channel. Hence, the shaft 17 is able to rotate with respect to the frame 11. Preferably, both the disc 16 and the ratchet plate 13 have their central holes configured with clearance to be able to rotate about the shaft 17 and the drum 7 has a central hole 45 shown in figure 9D to locate on to the shaft 17. A pin 43 is inserted into a hole in the shaft 17 perpendicular to its cylindrical axis which also positively engages with channels such as channel 44 shown in figure 9D to provide an interconnect between the drum 7 and the shaft 17 so that they rotate together. At one end of the shaft 17 there is a slot 17a to which the inner end of a spirally wound clock spring can be attached, the other end of the clock spring being attached to the frame 11 or to an outer casing or any other component that is stationary with respect to the rotation of the drum 7.

The elongate 20 in figures 9E and 9F is a length of flexible elongate secured at one end with respect to the drum 7 and wound a number of times around the drum 7, the other end of the elongate 20 being attached to and available to receive a load applied between the elongate 20 and an attachment 21. The attachment 21 is secured to the middle portion of the frame 11 U channel.

As with the fall arrest system in figures 9 and 9A, the attachment 21 is securely attached to a secure anchor whilst the elongate 20 is typically attached to a person's fall arrest harness. In use, the drum 7 and the shaft 6 rotate together as elongate 20 is deployed from drum 7 and then rewound back on to drum 7 as a result of the action of the clock spring driving the rotation of the shaft 17 that in turn drives the rotation of the drum 7. A pawl 18, shown in figures 9E, 9F and 9G is mounted for rotation supported securely between the side of the frame 11 and a parallel mounting plate 11a, the axis of rotation being perpendicular to the planes of the supporting frame 11 and mounting plate 11a. The pawl 18 is located close to the periphery of the ratchet plate 13 and, with the aid of spring assistance, interacts with rotation of ratchet plate 13 to engage in one of its teeth when the speed of rotation of the ratchet plate 13 exceeds a predetermined magnitude such as in the event of a person falling.

In the event that a person does fall, the pawl engages in a ratchet tooth as shown in figure 9F bringing the rotation of shaft 6 to a standstill relative to the frame 11. If and when the torque applied by the elongate 20 on the drum 7 overcomes the frictional resistance between the ring 1 and the drum 7, the drum 7 will continue to rotate with respect to the shaft 6 until sufficient energy has been absorbed to reduce the torque applied on the drum 7 below the predetermined level. The disc 40 shown in figures 9C, 9D and 9G is beneficial in limiting any movement of the ring 1 along the length of the bore of the drum 7. Also, the adjacent ring 41 is a spacer to provide room for the mechanical interaction between the pawl 18 and the ratchet plate 13.

Figure 9H shows a part sectional elevation of an embodiment with the addition of bearings 10a and 10b between the drum 7 and the shaft 6 similar to the example in figure 8A. It also shows the use of seals to protect the energy absorbing mechanism from ingress of substances that may affect the coefficient of friction of the contact surfaces between the ring 1 and drum 7. The seals in this example are shown as 'O' rings seals 45 and 45a although they may be any other suitable form of seal and be placed in any suitable location to protect the contact surfaces. Seals may usefully be applied to any of the embodiments of this invention to avoid the frictional engagement mechanics from being compromised by the ingress of external substances.

Figures 9J, 9K, 9L, 9M and 9N show a further embodiment variation of the fall arrest system shown in figures 9 and 9A where a ring 1 is mounted to one side of a drum 7. In figures 9J to 9N, a ring 1 is shown as a cylindrical tubular open ring such as in figures 1 and 1A although, by way of example, the tubular/axial depth of the ring extending parallel to its axis varies gradually between the ends of the ring 1, the depth being greatest furthest from the ends of the ring and decreasing towards the ring's ends. The effect shares similarities with the removal of material at 8a and 8b in the ring 1 shown in figure 9C/9D in order to help the ring to deform elastically to retain its circular form between its free unconstrained state and when elastically energised, helping the ring to deform elastically more easily towards its ends where the bending moment is least.

A collar 50 as shown clearly in figures 9J, 9K and 9N is a closed ring supporting pawls such as pawls 18a, 18b and 18c on its outer periphery, the pawls being preferably equal spaced about the central axis of the collar 50 and with each pawl able to rotate to a limited extent about axes parallel to the axis of the collar 50. The inner periphery of the collar 50 is circular being smaller than the free unconstrained periphery of the ring 1. The periphery of the ring 1 is then forcibly reduced, fitted into the inner periphery of the collar 50 and then

released in position thereby elastically energising the ring 1 to have frictional engagement with the collar 50. A drum 7 is typically a cylindrical drum with flanges at either end to contain elongate wound onto the drum and is preferably integral with a cylindrical boss 7d which has a central bore 7e disposed on the central axis of the drum 7. To one side of the drum 7 is a circular tubular protrusion 7a with a key form spline 7b (equivalent to projection 5 in earlier embodiments) disposed along its outside surface parallel to the tubular axis of the protrusion 7a. The collar 50 together with the assembled and energised ring 1 are then located with clearance onto the protrusion 7a with the ends of the ring 1 located either side of the key form spline 7b. A dished circular disc 51 is fastened securely to the drum 7 by means of fasteners such as the bolt 52, such that the disc 51 is held on the central axis of the drum 7 and supported, to prevent its rotation relative to the drum 7, by means such as provided by bosses including a boss 7c on the protrusion 7a of the drum 7, that locate in holes such as a hole 51a on the disc 51. The disc 51 serves to retain the collar 50 and the ring 1 in place on the protrusion 7a on the drum 7.

A shaft 17 is cylindrical and located with clearance in holes sharing the same axis in the adjacent sides of a frame 11, shown in figures 9J, 9L, 9M and 9N, which is typically formed from metal sheet into a U channel. Hence, the shaft 17 is able to rotate with respect to the frame 11. The shaft 17 is also located in the bore 7e in the drum 7 and is positively connected to the drum 7 by means of a pin 55 shown in figures 9K, 9M and 9N that constrains the shaft 17 to the drum 7 both rotationally and along their shared axes. The shaft 17 also passes through a hole in the centre of the disc 51. At one end of the shaft 17 there is a slot 17a to which the inner end of a spirally wound clock spring can be attached, the other end of the clock spring being attached to the frame 11 or to an outer casing or any other component that is stationary with respect to rotation of the drum 7.

Elongate 20 shown in figures 9L and 9M is a length of flexible elongate secures at one end with respect to the drum 7 and wound a number of times around the drum 7, the other end of the elongate 20 being attached to and available to receive a load applied between the elongate 20 and an attachment 21. The attachment 21 is secured to middle portion of the frame 11 U channel.

As with the fall arrest system embodiments in figures 9 to 9G, the attachment 21 is securely attached to a secure anchor whilst the elongate 20 is typically attached to a person's fall arrest harness. In use, the drum 7 and the collar 50 rotate together with respect to the frame 11 enabling elongate 20 to be deployed from the drum 7 and then rewound back on to the drum as a result of the action of the clock spring driving the rotation of the

shaft 17 that in turn drives the rotation of the drum 7 due to the constraints applied by interaction with the pin 55.

Beneath the central portion of the U channel 11 is a reinforcing U channel 11b with the length of its U section perpendicular to that of the U channel 11 but with both U channel middle portions sharing the same plane. Preferably the two U channels are fixed together such as by welding and U channel 11b is useful to assist in resisting bending moment applied by loading on attachment 21. The pawls 18a, 18b and 18c are lightly spring-loaded and urged to rotate inwards towards the outer surface of the collar 50. However, when the speed of rotation of the drum 7 exceeds a predetermined maximum, such as when arresting a fall, the pawls 18a, 18b and 18c tend to rotate outwards away from the outer surface of the collar 50 due to centrifugal forces, until one of the pawls such as the pawl 18a, as shown in figure 9M, engages with the edge of the U channel 11b causing the rotation of the collar 50 to cease with respect to the frame 11. If and when the torque applied by the elongate 20 on the drum 7 overcomes the frictional resistance between the ring 1 and the collar 50, the drum 7 will continue to rotate with respect to the collar 50 until sufficient energy has been absorbed to reduce the torque applied on the drum 7 below the predetermined level.

Figures 10 and 10A show a front view and side part sectional elevation of a fall arrest system energy absorber incorporating a resilient element such as in any of the preceding examples although for convenience the following example is shown with an open ring such as in Figure 1A. The device in Figures 10 and 10A is typically used to limit tensile loading in a fall arrest system such as in a cable that a person working at height might be attached to directly or indirectly. A frame 11 is metal strip formed into a U channel having an attachment 21 at the centre of the channel in order to attach it at one end to a load in a fall arrest system. In this example, attachment to a fall arrest system is shown by means of swaging onto a fall arrest system cable shown as a cable 22. However, the attachment to a fall arrest system could take many different forms depending on the fall arrest system installation. A shaft 6 is tubular having projections 12a and 12b at either end that interact with the frame 11 to prevent the shaft 6 from rotation relative to the frame 11 when the shaft 6 is securely attached to frame 11 by means of a nut and bolt 15. Disc spacers 16a and 16b in figure 10 hold the shaft 6 concentric with the position of the nut and bolt 15 and a tubular spacer 17 provides compressive support to counteract tensioning of the nut and bolt 15. A drum 7 is cylindrical with flanges either end with a circular central bore and clearance between itself and either side of the frame 11. An open ring 1 is an elastic tubular open ring similar to the

example shown in figure 1A and is located between the outer radial surface of the shaft 6 and the bore in the drum 7. The free unconstrained periphery of the ring 1 is larger than the diameter of the bore in the drum 7. On assembly, the periphery of the ring 1 is forcibly reduced and held to fit with clearance into the bore of the drum 7 and released when located in the bore thereby elastically energising the ring 1 to apply a radial force between itself and the drum 7 to effect frictional engagement. The shaft 6 has a projection in the form of a key spline extending along its length to provide an interconnect between the ends of the ring 1 preventing relative engagement between the ring 1 and shaft 6 when interconnected. An elongate 20 is a length of flexible elongate that at one is secured and wound around the drum 7 such that the elongate 20 can only be deployed from the drum 7 as a result of the rotation of the drum 7. The other end of the elongate 20 leaves the drum 7 and passes through guides 23 and 24 and has an attachment eye 25 for attaching to a fall arrest system. In the event that the fall arrest system experiences a load, the load is resisted between the cable 22 and the attachment eye 25. In normal use, tensile loading between the cable 22 and the attachment 25 would be insufficient to overcome the frictional resistance between the open ring 1 and the shaft 7. However, when arresting a fall, the tensile loading would increase sharply and could exceed a predetermined limit whereby the torque transferred by the elongate 20 to the drum 7 would be sufficient to overcome the frictional engagement between the open ring 1 and the drum 7 allowing the drum 7 to rotate and deploy the flexible elongate 20 thereby absorbing energy.

Figures 11, 11A and 11B show a plan view, side view and side part sectional elevation of a fall arrest system energy absorber incorporating a resilient element such as in any of the preceding examples although for convenience this example is shown with an open ring such as in Figure 1A. This fall arrest system device is typically used as an absorber installed to limit line load on a safety line as in the preceding example shown in figures 10 and 10A whilst being well suited for use with a temporary fall arrest system because of its portability, simplicity and lightness particularly when used with high strength synthetic materials.

The frame elements 11a and 11b are typically manufactured from metal strip with through holes positioned to receive nut and bolt fastenings 15, 15a and 15b. A shaft 6 is a circular tube with projections 12a and 12b at one end and projections 12c and 12d at the other end. The frame elements 11a and 11b are positioned apart at either end of the shaft 6 such that the projections 12a, 12b, 12c and 12d at either end of the shaft 6 interact with the frame elements to prevent the rotation of the shaft 6 with respect to the frame elements. Discs 16a and 16b are circular discs with a central through hole to receive the fastening 15 and are each located in the bore of the tubular shaft 6 held apart by a tubular spacer 17

shown in figure 11B and held in place by a nut and bolt fastening 15. When the fastening 15 is located and tightened between the frame elements 11a and 11b, the shaft 6 is held between the two frames and prevented from rotation relative to the frames as a result of the projections at either end of the shaft 6 and their interaction with the frames 11a and 11b. The discs 16a and 16b are held apart by the tubular spacer 17, the discs serving to constrain the axis of the shaft 6 with the axis of the fastening 15 and its position relative to the frame elements 11a and 11b.

A drum 7 is a cylindrical drum with flanges at either end to contain flexible elongate, and with a central circular bore configured for rotation about the shaft 6. An open ring 1 similar to that in figure 1A has frictional engagement with the bore of the drum 7, as in the preceding example in figure 10 and 10A. The shaft 6 has a key form spline projection extending along its length that fits between the ends of the ring 1 to provide an interconnect between the two components to prevent their relative rotation when interconnected. A flexible elongate 20 is a length of flexible elongate shown in this example as being webbing with a flat rectangular cross section although it could be any other form of flexible elongate with any cross section. Between the ends of elongate 20, the elongate is folded back on itself about a pin 26 in figure 11B, the pin 26 being secured between the flanges of the drum 7. The flexible elongate 20 is then coiled in the same direction around the drum 7 for a number of turns with one end of the elongate 20 exiting around a tubular spacer guide 17a and the other end exiting around a tubular spacer guide 17b. The energy absorber is attached as part of a fall arrest system ready to receive a tensile load between either end of the elongate 20. In normal use, tensile loading between either end of the elongate 20 would be resisted by the frictional engagement between the drum 7 and the open ring 1. However, in a fall event such as arresting a fall, the tensile load between either end of the elongate 20 may exceed a predetermined limit and thereby apply sufficient torque on the drum 7 to overcome its frictional engagement with the open ring 1 allowing the elongate 20 to be deployed. Because the elongate 20 is double wound onto the drum 7 and deployed at either end of the device in figures 11, 11A and 11B, the extension between either end of the elongate as a result of its deployment will be approximately twice the associated arc of rotation of the drum 7. Therefore, this energy absorber embodiment would require the frictional resistive torque between the ring 1 and the drum 7 to be approximately twice the predetermined torque limit. However, a particular benefit of this fall arrest system energy absorber is that elongate 20 could be a fall arrest system safety line disposed between end anchors without the need for terminations between the energy absorber and the safety line.

Figures 12, 12A, 12B, 12C and 12D show an example of a further embodiment of a fall arrest system energy absorber incorporating a flexible element such as in any of the

preceding examples although for convenience this example is shown with an open ring such as in Figure 1A. This fall arrest system embodiment is an energy absorbing anchor for installation on a variety of structures including various types of roofing. The ability for the anchor to absorb energy also has the effect of limiting loading on its installation enabling it to be attached in many instances directly to roofing sheets rather than to underlying supports such as purlins.

The energy absorbing anchor provides a secure connection to a cable system that one or more persons working at height can be attached to by means of wearing a harness attached to a lanyard or other safety line in order to move within a safe distance of the cable. Their movement in relation to the cable is usually simplified by their lanyard being attached to a traveller device that is able to move along the cable whilst also passing over fall arrest system anchors without needing to remove the traveller device from the cable system. Many such cable systems usually include a number of energy absorbing anchors to provide location for the cable where safe access for working at height is required and also to provide a safe anchored connection to the cable in the event that a person falls. In normal use, the energy absorbing anchor is in an upright orientation, resembling a post, in order to hold the cable clear of the structure and to avoid personal cable attachments such as traveller devices from damaging the structure surface or impeding movement. However, in a fall event, the energy absorbing anchor is designed to allow it to change its upright orientation if and when fall arrest loading on it exceeds a predetermined safe level so that it can lean towards the applied load allowing its attachment to the load to move closer to the structure surface and thereby reduce bending moments on the energy absorbing anchor installation and particularly its fixings.

Figures 12, 12A and 12B show the energy absorbing anchor in an upright orientation. A plate 27 is a rectangular base plate that is typically fixed close to its periphery to the surface of a structure such as a roof. Attached to the centre of the plate 27 is a U bolt 28 that is securely connected to a sheave 29, shown in figure 12B, the sheave 29 being able to orientate about the U bolt 28 and along its length. A flexible elongate 20 is a length of flexible elongate passed around the sheave 29 in the middle of its length. Both ends of the flexible elongate 20 are then secured to and wound around a drum 7 such that elongate can only be deployed as a result of rotation of the drum 7. The drum 7 is cylindrical with a circular central bore and with flanged ends to assist in containing the flexible elongate 20. A shaft 6 is a tubular and circular shaft having four equal spaced projections at each of its ends, such as a projection 12, that engage with holes, such as a hole 30, in either side of a frame 11, the frame 11 being a U channel formed from metal plate or sheet. When the projections at either end of the shaft 6 are engaged in the holes either side of the frame 11,

the shaft 6 is prevented from rotation relative to the frame 11. In order to ensure safe securement of the shaft 6 to the frame 11, a nut and bolt fastening 15 is located to compress both sides of the frame 11 onto either end of the shaft 6, the fastening 15 being ideally located on the central axis of the shaft 6 in order to distribute compressive load evenly on either end of the shaft 6. An open ring 1 similar to that in figure 1A has frictional engagement with the bore of the drum 7, as in the preceding examples in figure 10, 10A, 11, 11A and 11B. The shaft 6 has a key form spline projection extending along its length that fits between the ends of the ring 1 to provide an interconnect between the two components to prevent their relative rotation when interconnected.

The frame 11 is attached at the centre of its U formation to an attachment eye 31. The attachment eye 31 is a closed ring for attachment also to another part of the fall arrest system such as a cable system or for direct attachment to a person or other fall arrest component or system. Loading on the energy absorbing anchor is then resisted between the eye 31 and the U bolt 28 that is attached to the base plate 27. A casing 32 is a rigid hollow cylindrical circular tube and with an incorporated or connected rigid hollow dome at one end and with its circular base at the other end bearing on the base plate 27. The circular base of the casing 32 is useful to allow the energy absorbing anchor to lean in any direction in the plane of the structure surface to which the base plate 27 is attached. The energy absorbing anchor in its upright orientation is required to resist accidental side loading on the eye 31 to avoid causing the anchor to lean prematurely from its upright position before a fall arrest event. This resistance is ideally provided by resisting extension between the eye 31 and the U bolt 28. If and when a relatively small side load is applied to the eye 31, a resisting torque is then applied between the eye 31 and the bearing of the circular edge of the casing 32 onto the base 27. Therefore, in order to maintain the upright position, it is important to resist the attachment eye 31 extending away from the U bolt 28.

One method of resisting premature separation between the attachment eye 31 and the U bolt 28 is to rely on the frictional resistance between the drum 7 and the open ring 1 to resist any deployment of the elongate 20 until side loading on the attachment eye 31 exceeds a predetermined magnitude such as when arresting a fall. However, it may be more practical to adopt a different method such as in figure 12A where two similar T shaped frangible brackets 37a and 37b made from a suitable material are connected to the U bolt 28 such as at a through hole 36 and also to the frame 11 at frangible lugs 33 and 34 engaging in holes in the frame 11, thereby bypassing the need to depend on the friction engagement between the ring 1 and the drum 7. If and when an applied load at the attachment eye 31 exceeds a predetermined magnitude, such as when arresting a fall, the resulting tensile load on the frangible brackets causes one or both the frangible lugs 33 and 34 to shear at their

connection to the frame 11 thereby allowing extension between the attachment 31 and the U bolt 28 to initiate a change of orientation of the energy absorbing anchor. Use of the frangible brackets may also be beneficial to solve any potential stiction problems at the frictional engagement between the open ring 1 and the bore of the drum 7 after prolonged periods in situ.

Figure 12C shows the energy absorbing anchor orientating towards the load applied at attachment 31 in the direction of arrow 38 as a result of the load exceeding the predetermined magnitude and deploying the elongate 20. Continued excessive applied load, such as when arresting a fall, causes further orientation of the energy absorbing anchor about its base 27 as a result of further deployment of the elongate 20.

As the application of load exceeding the predetermined magnitude at eye 31 continues such as is shown in figure 12D, deployment of the flexible elongate 20 from the drum 7 results in the energy absorbing anchor further extending between the attachment eye 31 and the base plate 27. A beneficial effect of this level of orientation is that the eye 31 moves closer to the surface of the structure enabling bending moment on the base plate 27, its fixings and attachment to a structure to be significantly reduced. The energy absorbing anchor then continues to extend between its attachment eye 31 and its base 27 until the applied load on eye 31 reduces to below the predetermined safe level after which the fall arrest event concludes.

The configuration of the flexible elongate 20 in Figures 12, 12B, 12C and 12D effectively enables the flexible elongate 20 to receive approximately half of the separation load between the eye 31 and the base plate 27 because of the doubling of the elongate 20 around the sheave 29 and on the drum 7. This is beneficial to enable the cross section of flexible elongate 20 to be relatively small for winding around drum 7 and also for configuring attachment of both ends to the drum 7 neatly and securely.

In all the above fall arrest system energy absorber embodiments it may be beneficial to enclose them, at least in part, in casings to protect the mechanical parts from adverse environmental conditions and from accidental damage. The embodiment in figures 12, 12A, 12B, 12C and 12D may be an exception to this because of its casing 32 already provided to assist in its function.

In all the above examples, the resilient element is typically made of metal such as steel or metal alloy. Alternatively, the ring could be made from any other material such as plastic, plastic composite or reinforced plastic composite, or it could be made from a ceramic, ceramic composite or reinforced ceramic composite material or combinations of any of the above mentioned materials including metal.

Use of the term 'periphery' with respect to the peripheral surface of the resilient element/ring that is energised to expand or contract elastically may or may not extend circumferentially through 360 degrees. For example, in figures 1, 1A and 1B the effective periphery extends less than 360 degrees about the central axis whereas in figure 1C it extends greater than 360 degrees when there is more than one full turn, and in figures 6B and 6C it extends 360 degrees.

All the above examples of embodiments of the invention are for illustrative purposes only both in terms of their description and accompanying drawings.

Claims

1. An energy absorber for use in a fall arrest system, the energy absorber comprising a first component having an axially extending bore and being mounted for rotation about a second component which extends into said bore, and a resilient element disposed radially between the first and second components, the resilient element having a periphery that can be energised to expand or contract elastically to apply a radial force between the resilient element and one of the first and second components to effect frictional engagement therebetween in the circumferential direction of rotation and having a positive interconnect between the resilient element and the other of the first and second components in order to prevent or limit their relative rotation, wherein, if a torque is applied between the first and second components that exceeds a predetermined magnitude, such as when arresting a fall, the resistance provided by the frictional engagement is overcome and the first and second components are able to rotate relative to one another thereby absorbing energy.
2. An energy absorber as claimed in claim 1 wherein the resilient element is in the form of an open ring having an axially extending opening between its circumferential ends.
3. An energy absorber as claimed in claim 2 wherein the positive interconnect is effected by at least one projection provided on one of the first and second components being disposed in said opening.
4. An energy absorber as claimed in claim 2 wherein at least one of the circumferential ends of the open ring projects radially and is disposed in a channel provided on one of the first and second components, thereby effecting said positive interconnect.
5. An energy absorber as claimed in claim 2 wherein the positive interconnect is effected by means of at least one projection being provided on one of the first and second components and disposed in a respective channel provided on the other of the first and second components, the at least one projection being spaced from the opening of the open ring.

6. An energy absorber as claimed in any one of claims 2 to 5 wherein an additional resilient means is provided between the two circumferential ends of the open ring.
7. An energy absorber as claimed in claim 1 wherein the resilient element is in the form of a closed ring having a radial indent disposed in a channel provided in the second component, thereby effecting said positive interconnect.
8. An energy absorber as claimed in claim 7 wherein a second radial indent and channel combination is provided radially opposite the first indent and channel combination.
9. An energy absorber as claimed in claim 7 or claim 8 wherein the or each indent has a pair of inwardly extending legs which are connected to each other at an inner location.
10. An energy absorber as claimed in claim 1 wherein the resilient element is in the form of a closed ring formed with alternating axially extending closed slots extending from opposite axial ends of the closed ring, at least some of the slots extending from one axial end forming the positive interlock with axially extending splines provided on one of the first and second components.
11. An energy absorber as claimed in any one of claims 1 to 10 wherein the radial thickness of the resilient element varies around its circumferential length.
12. An energy absorber as claimed in claim 11 wherein the radial thickness is greater at a location opposite the positive interconnect.
13. An energy absorber as claimed in any one of claims 1 to 12 wherein the axial length of the periphery of the resilient element varies around the periphery.

14. An energy absorber as claimed in claim 1 wherein the resilient element is spirally wound and extends at least 360 degrees.
15. An energy absorber as claimed in any one of claims 1 to 14 wherein the resilient element is formed from a metal such as steel.
16. An energy absorber as claimed in any one of claims 1 to 15 wherein the first component is a drum having a cylindrical external surface.
17. An energy absorber as claimed in any one of claims 1 to 16 wherein the second component is a shaft.
18. A fall arrest device incorporating an energy absorber as claimed in any one of claims 1 to 17.

FIG 1

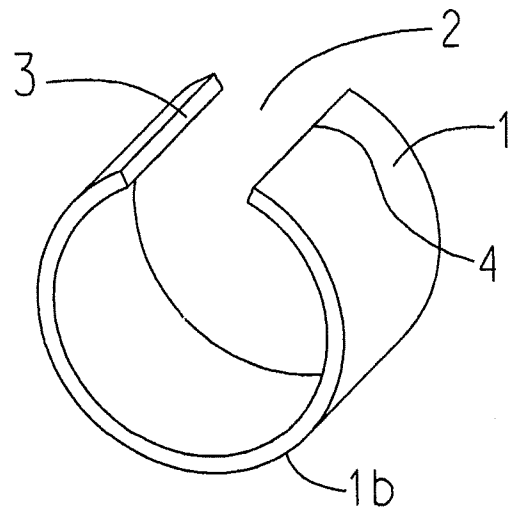


FIG 1A

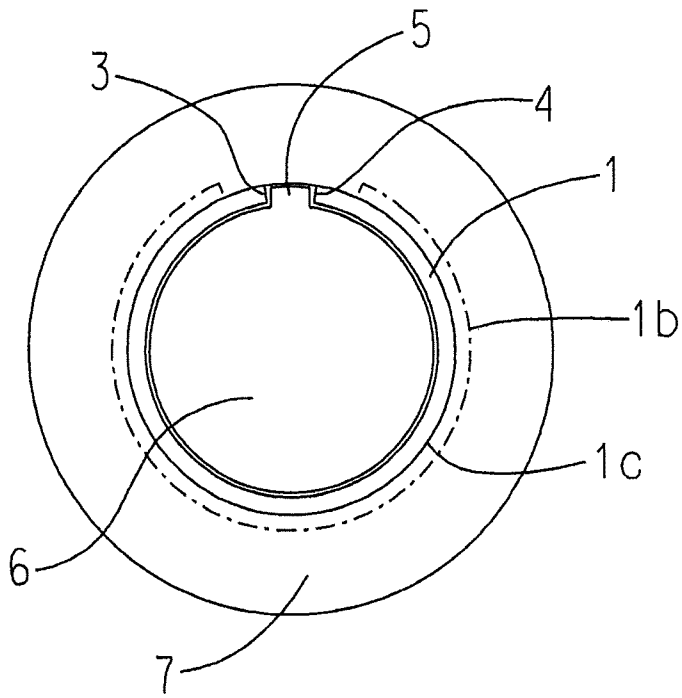


FIG 1B

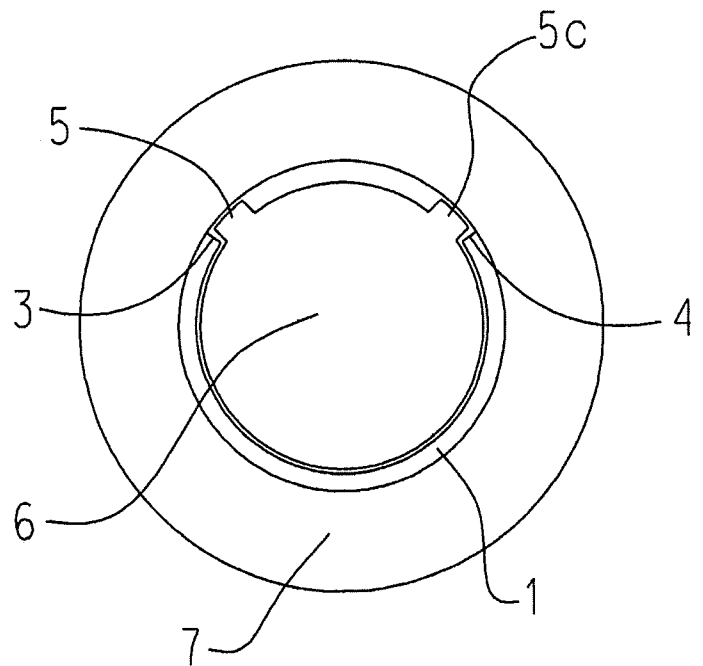
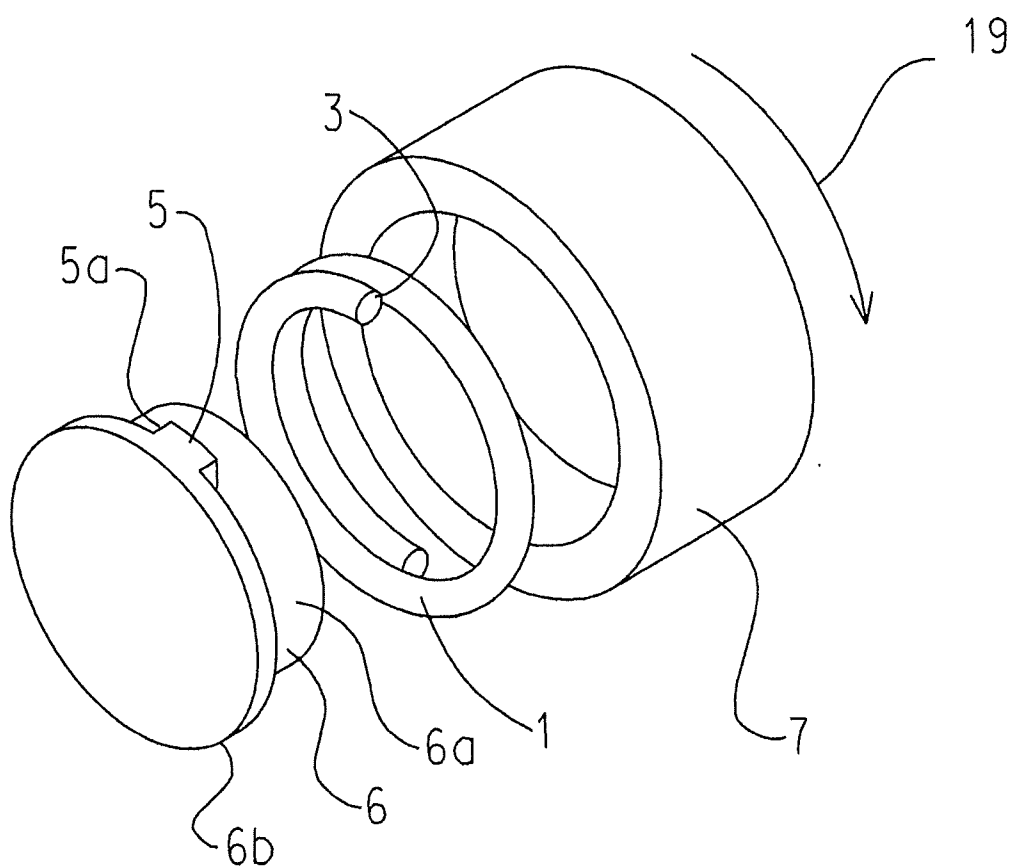


FIG 1C



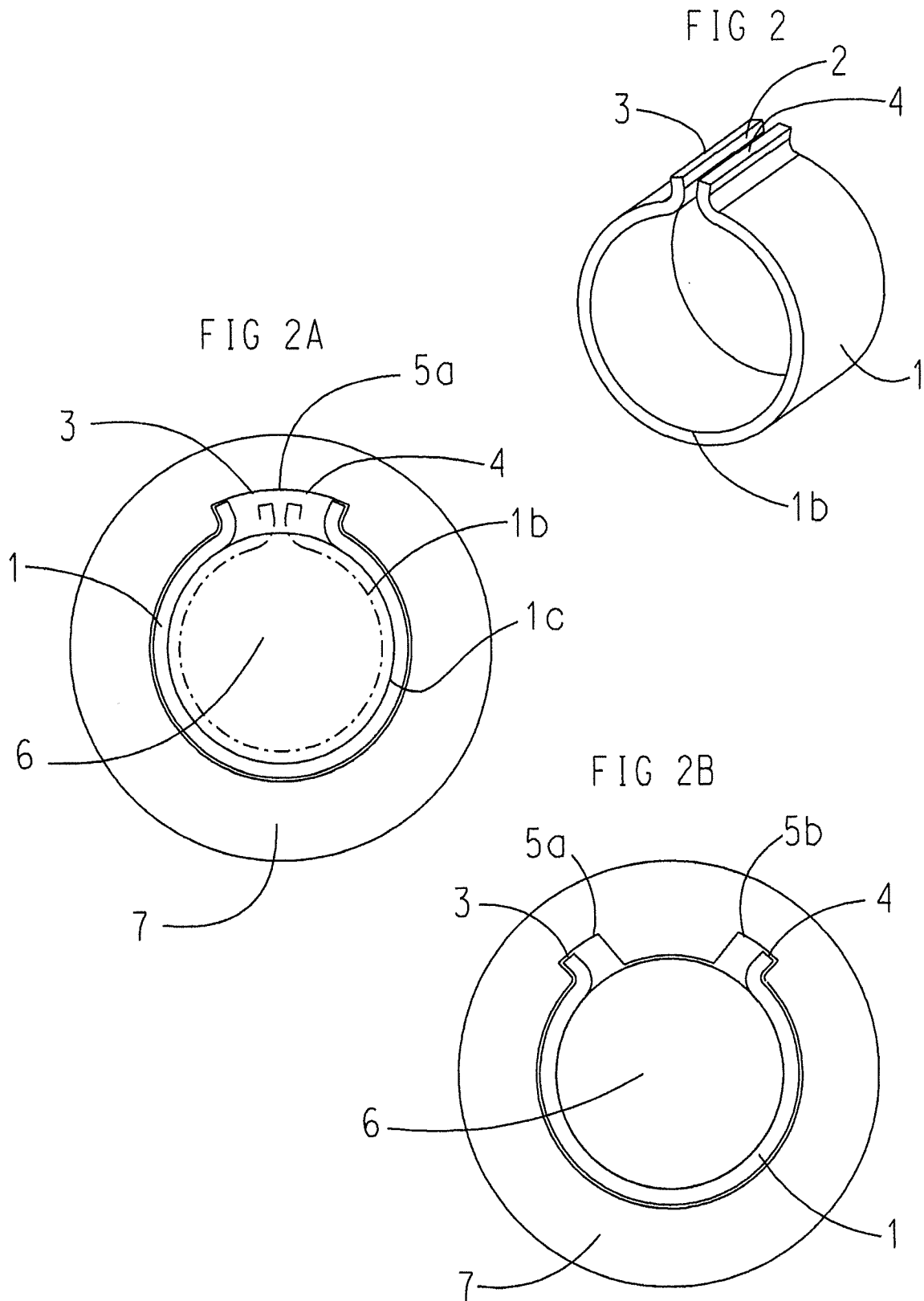


FIG 3

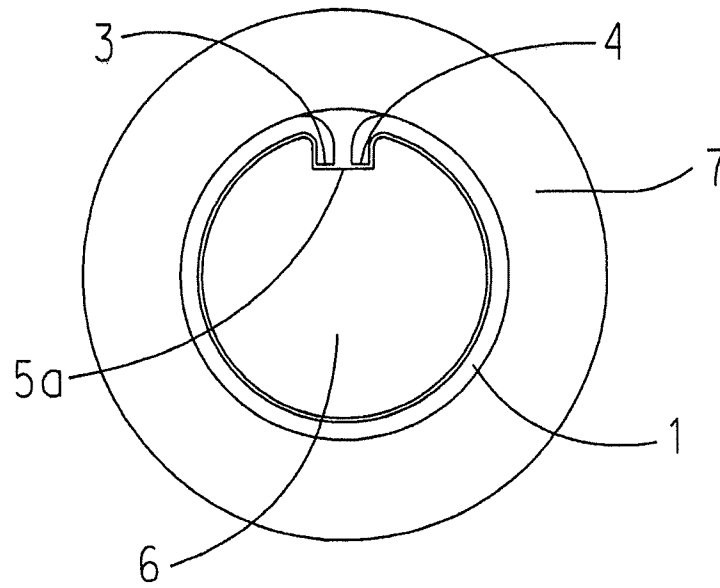


FIG 3A

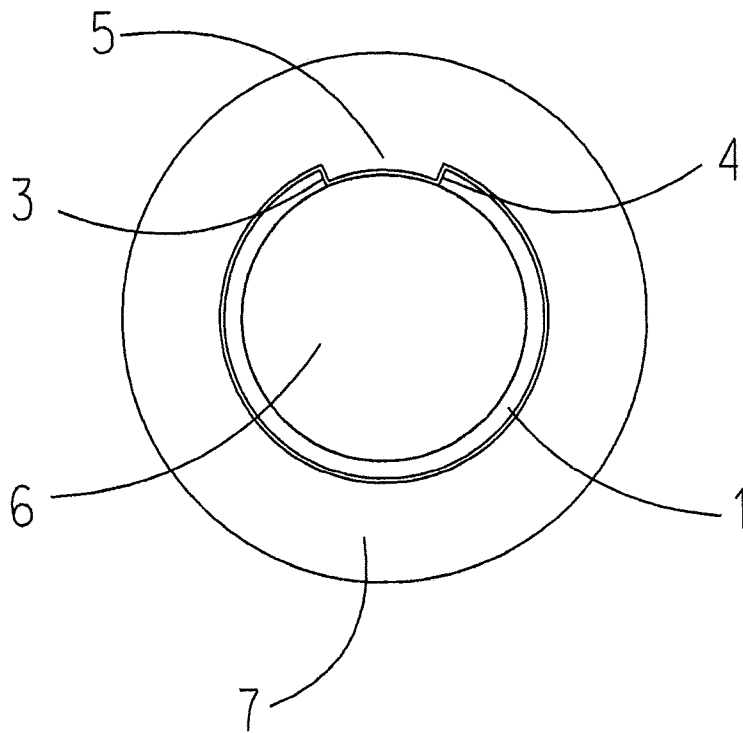


FIG 4

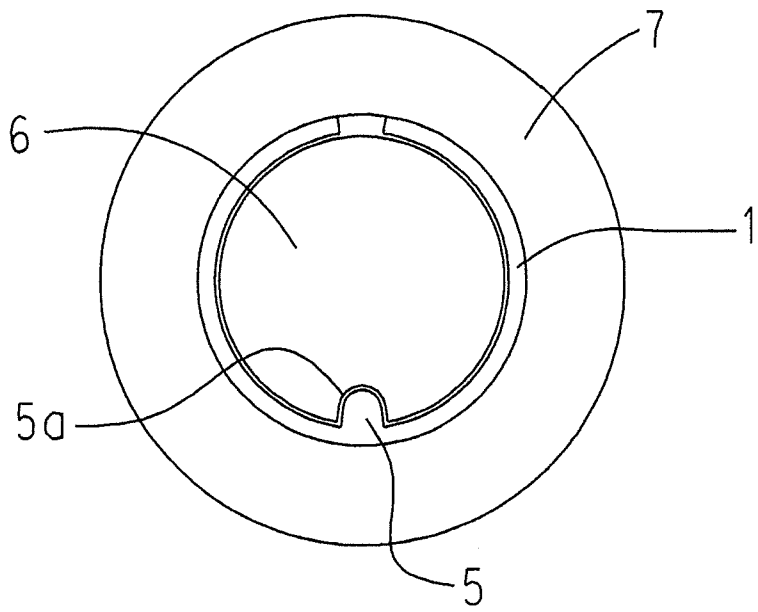


FIG 4A

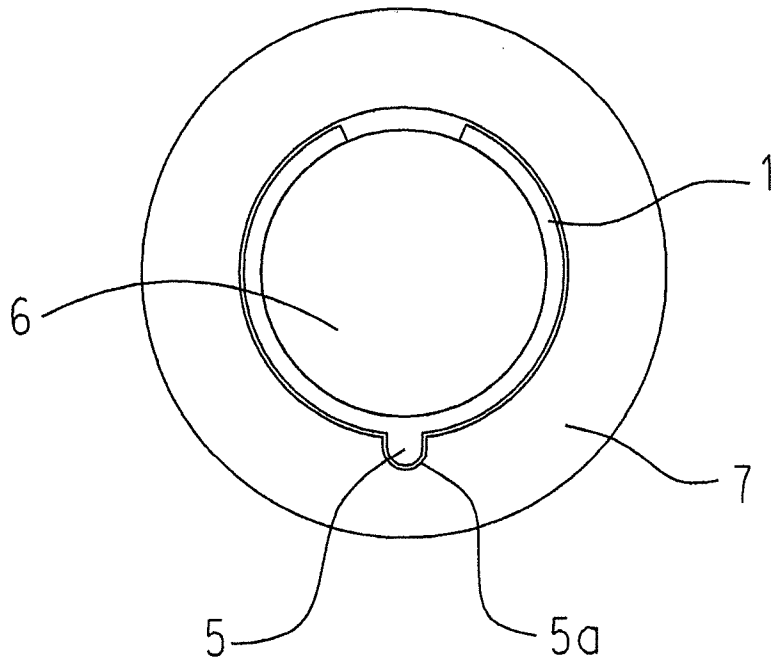


FIG 5

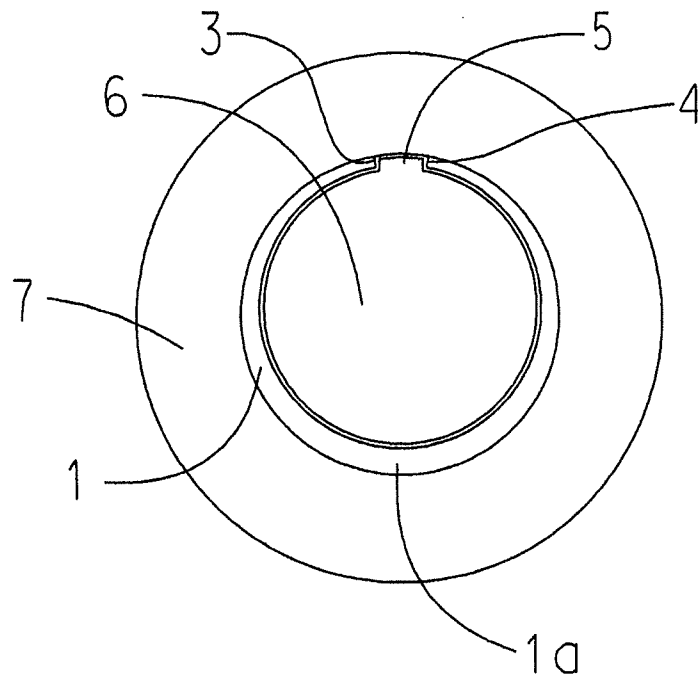


FIG 5A

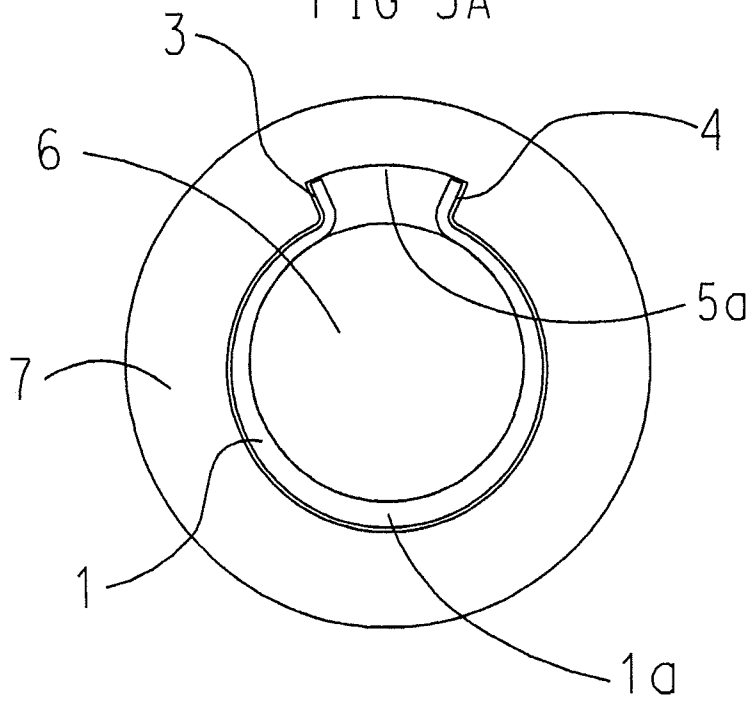


FIG 6

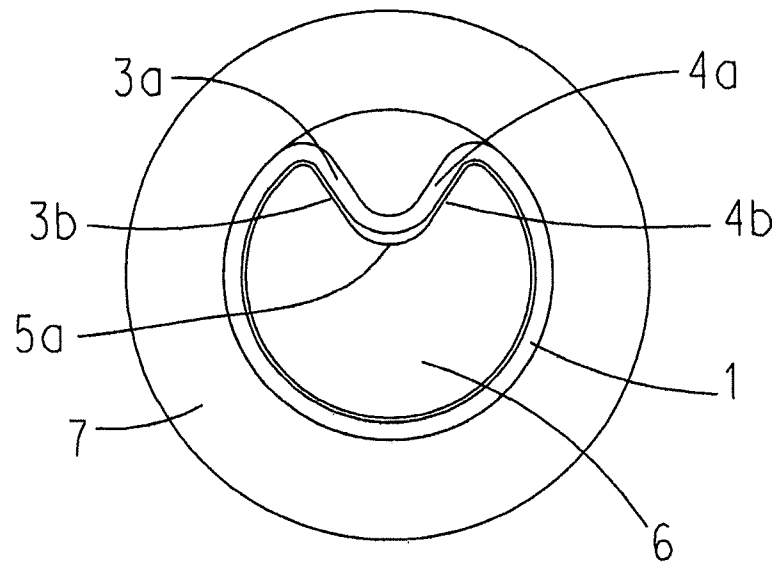


FIG 6A

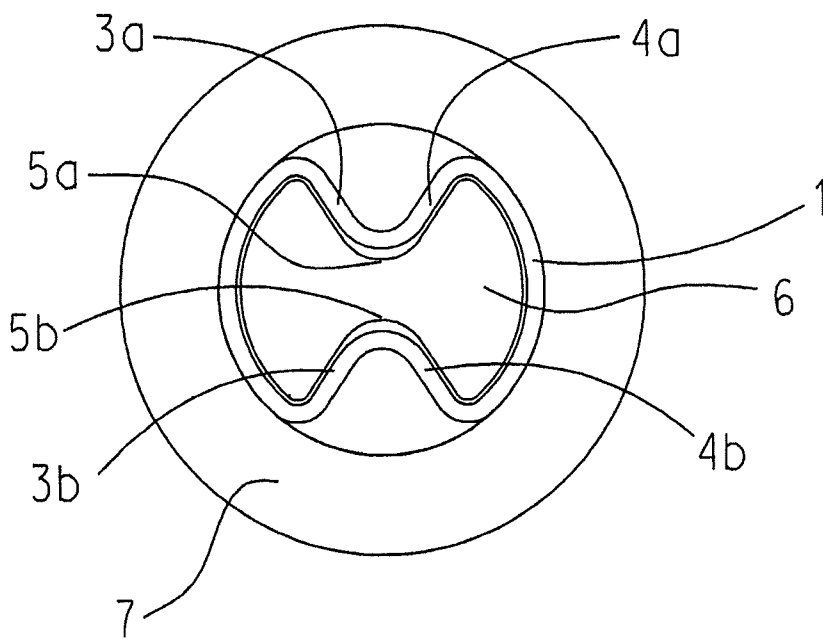


FIG 6B

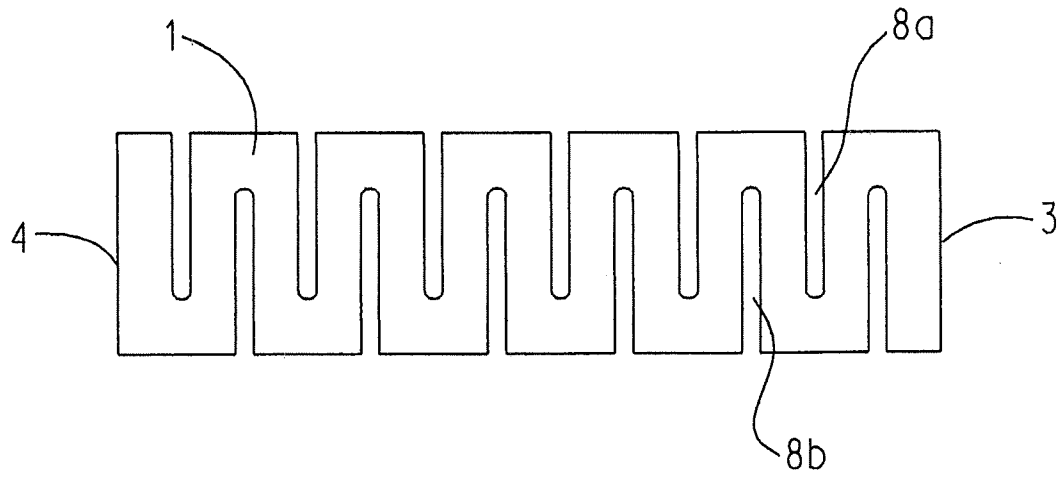


FIG 6C

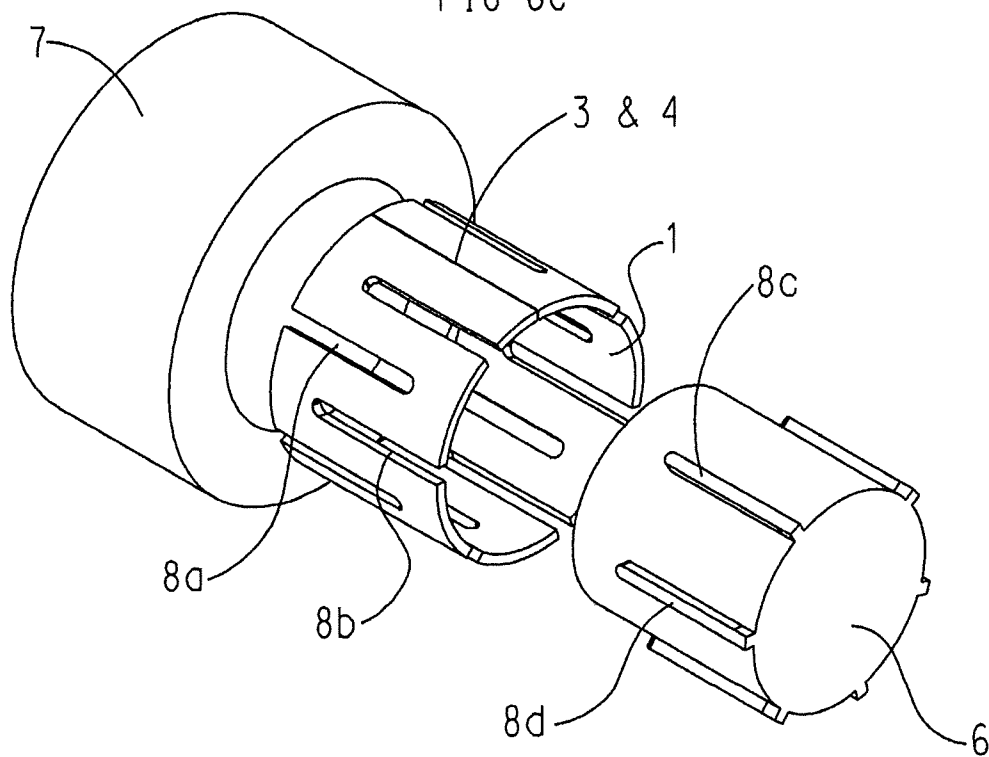


FIG 7

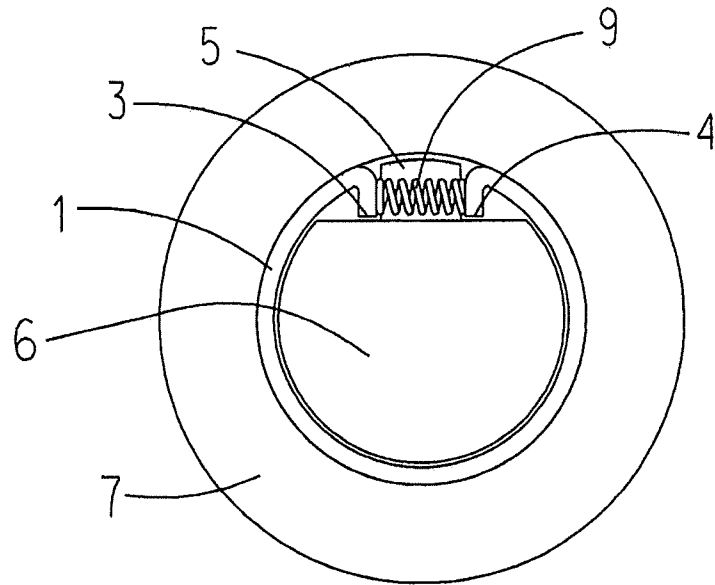


FIG 8

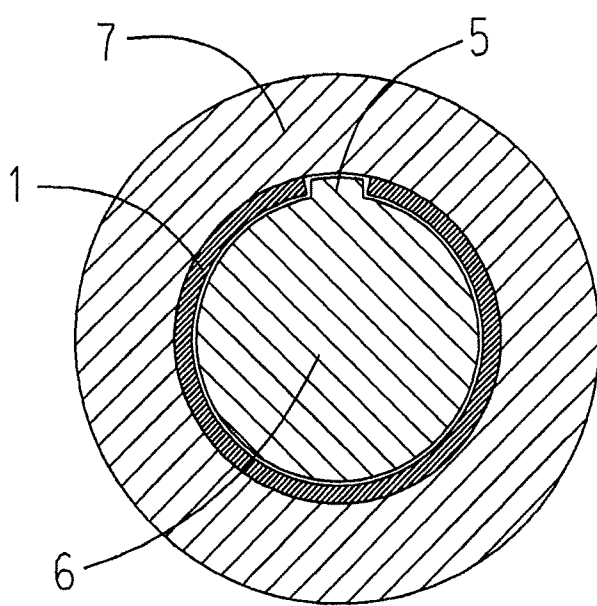


FIG 8A

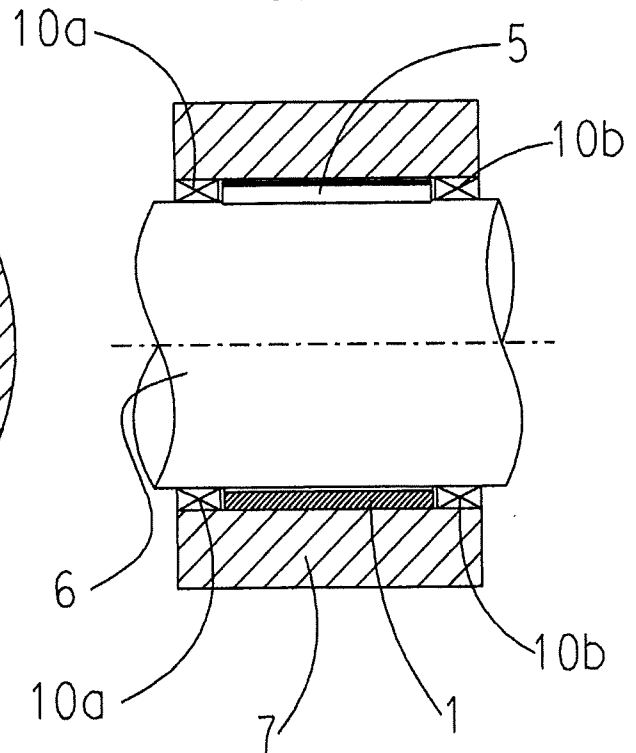


FIG 9A

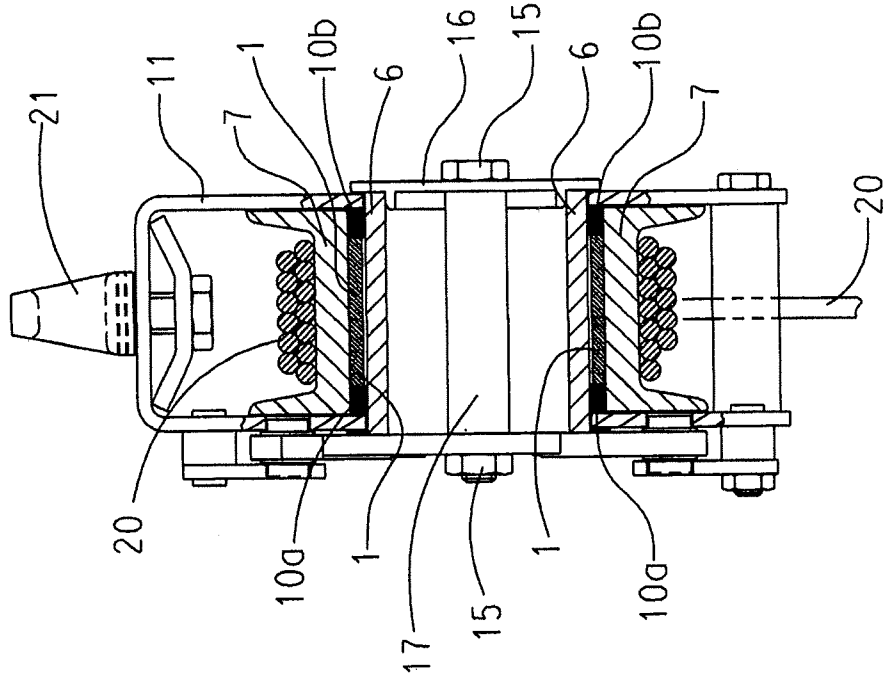


FIG 9

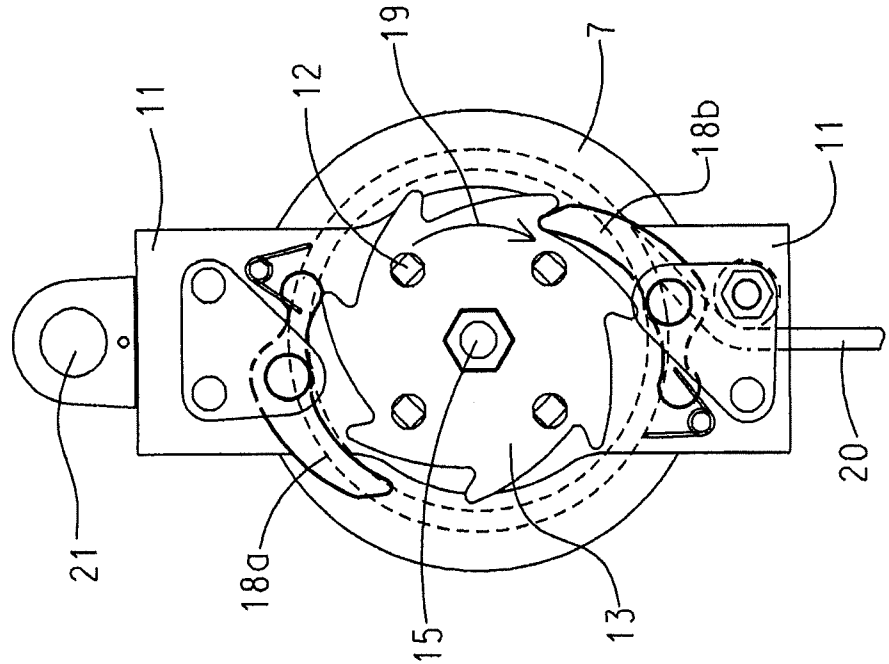


FIG 9B

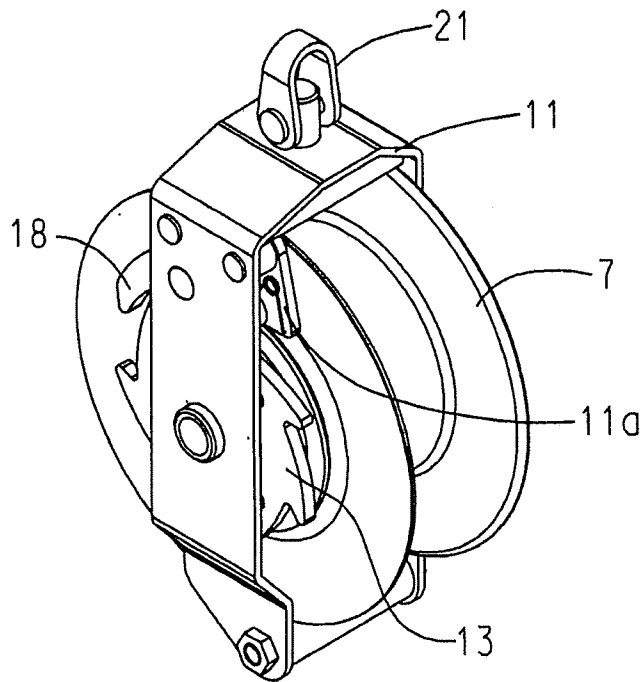


FIG 9C

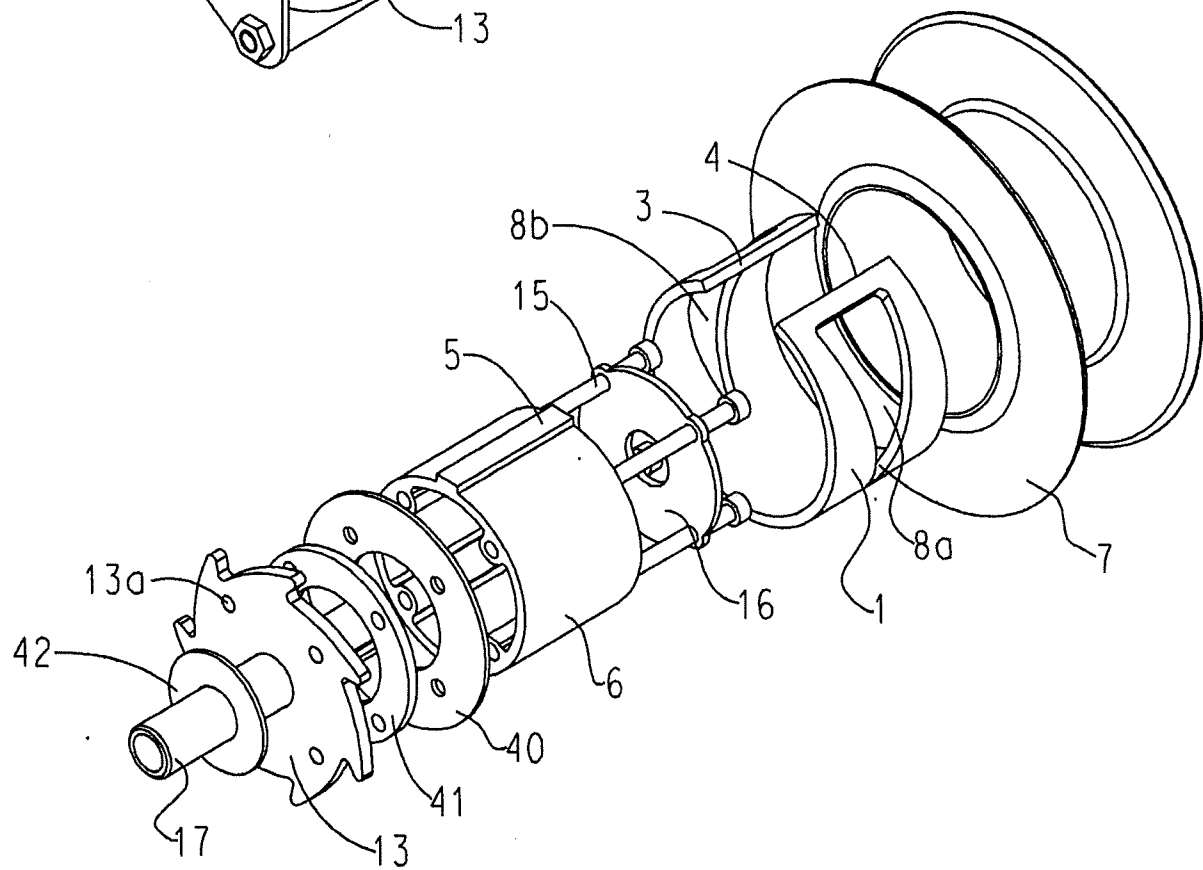


FIG 9D

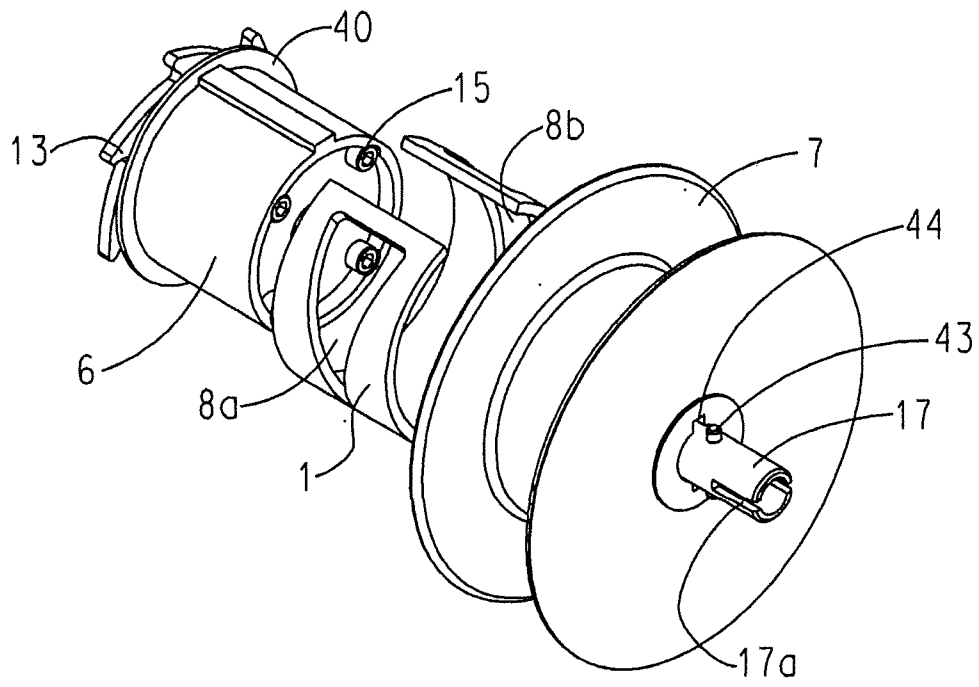


FIG 9E

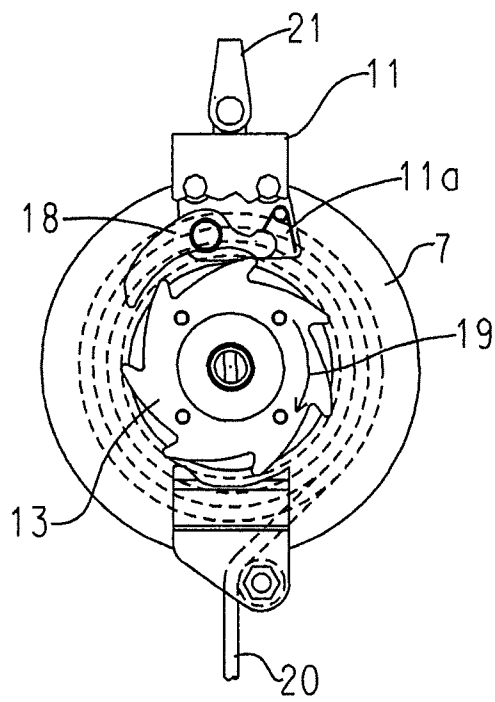


FIG 9F

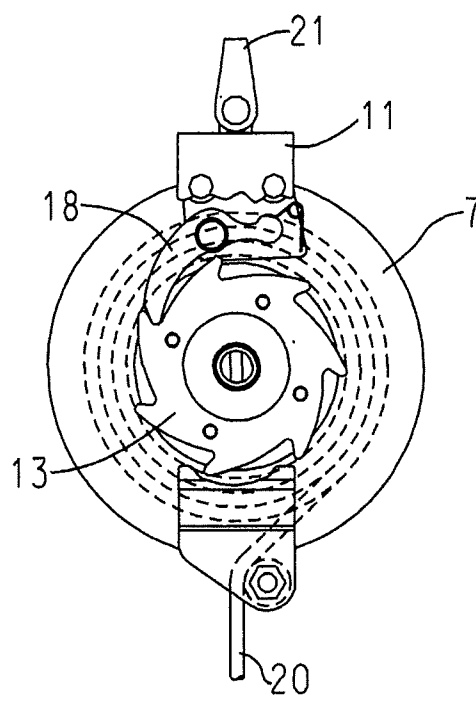


FIG 9G

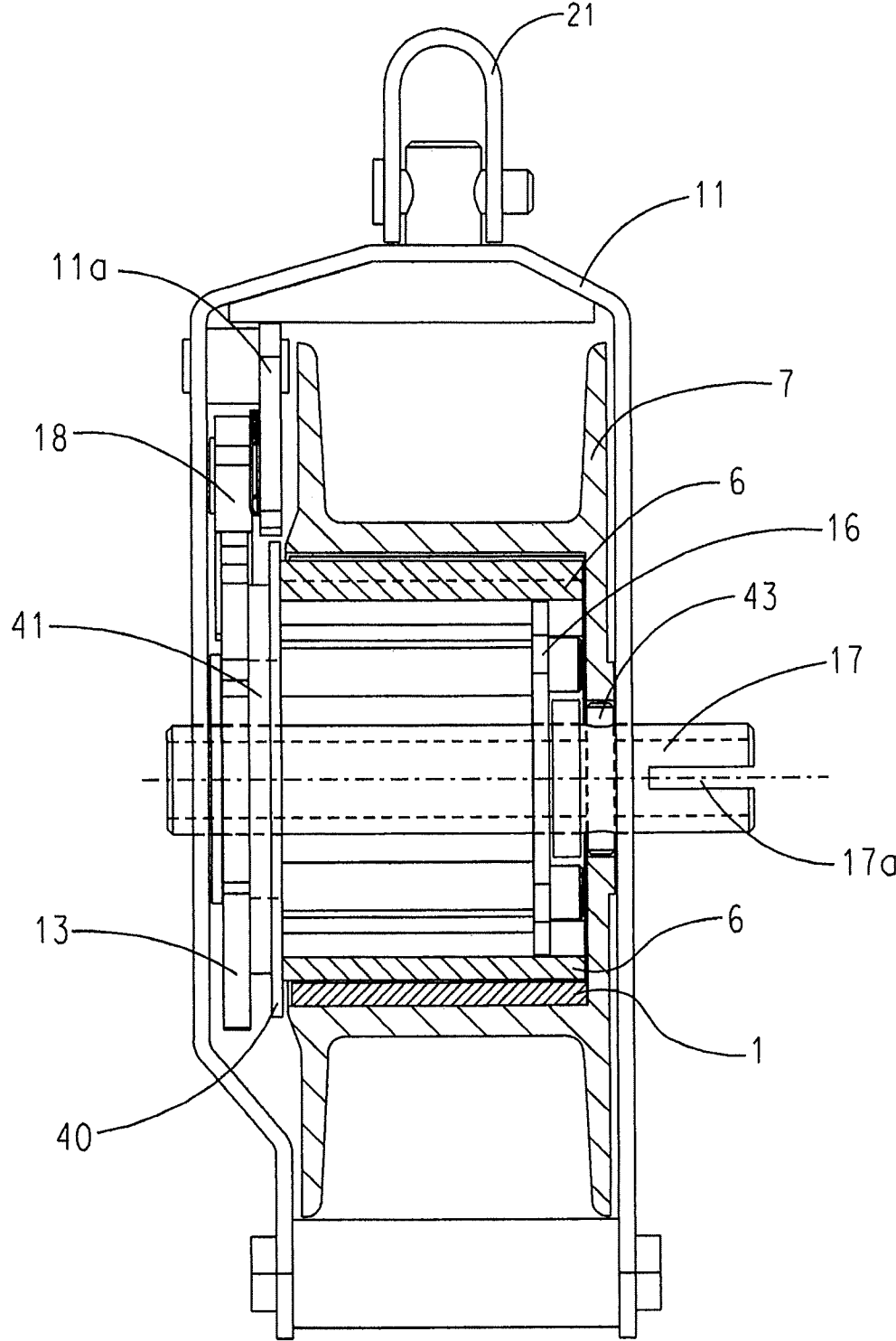


FIG 9H

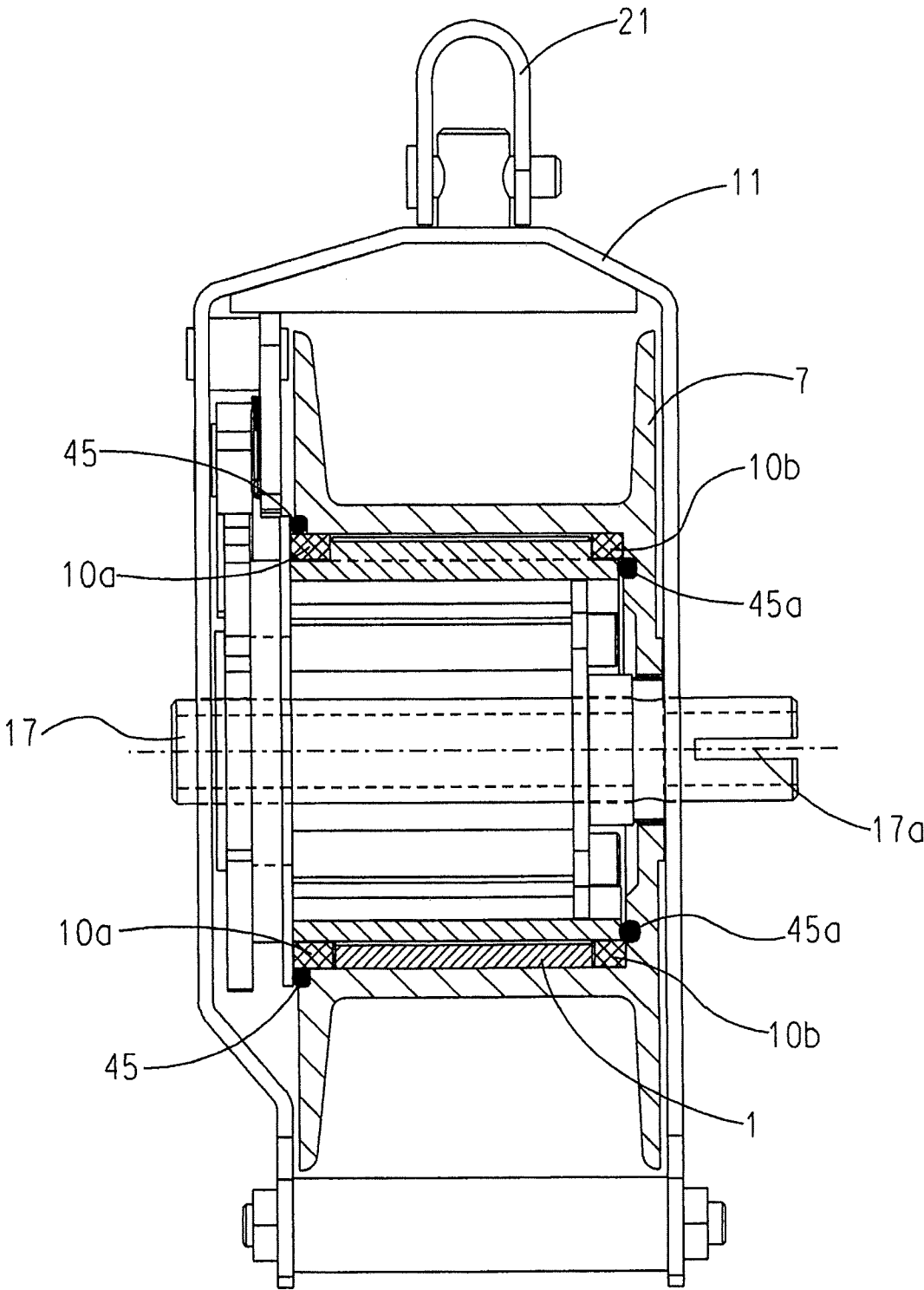


FIG 9J

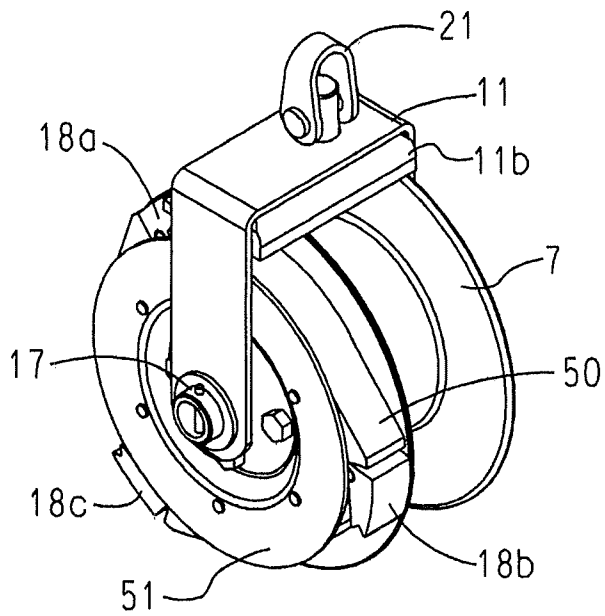


FIG 9K

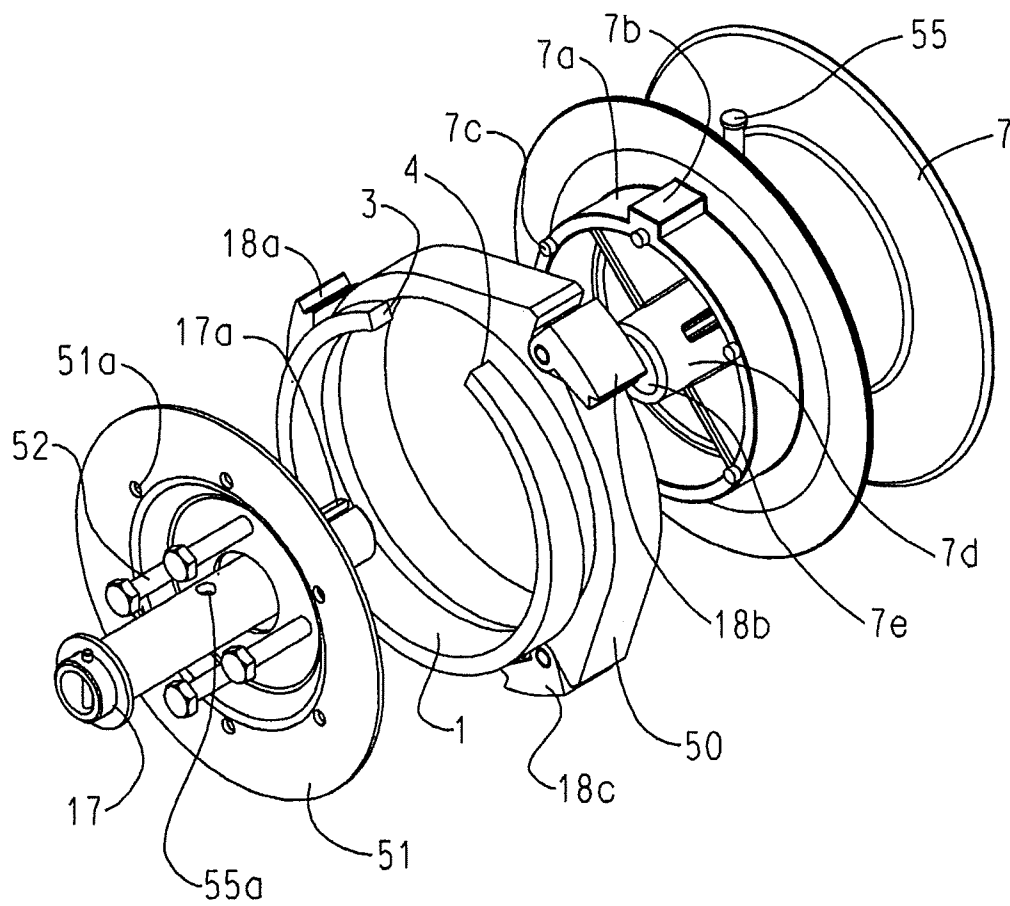


FIG 9L

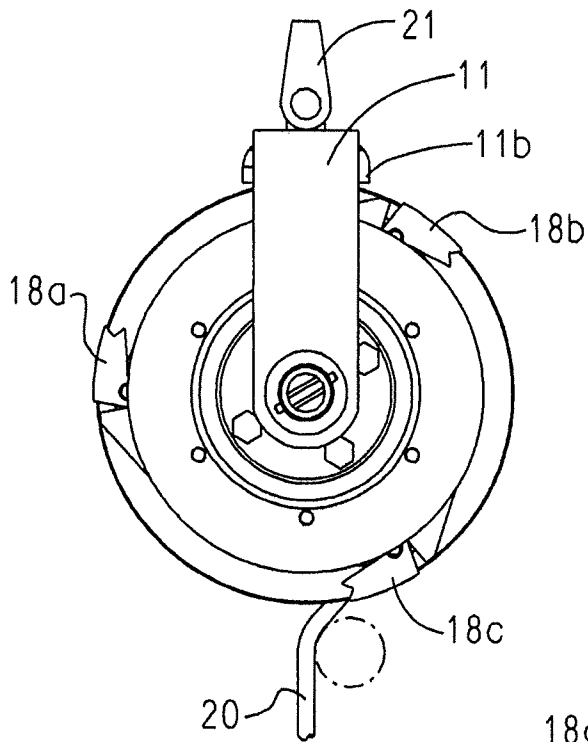


FIG 9M

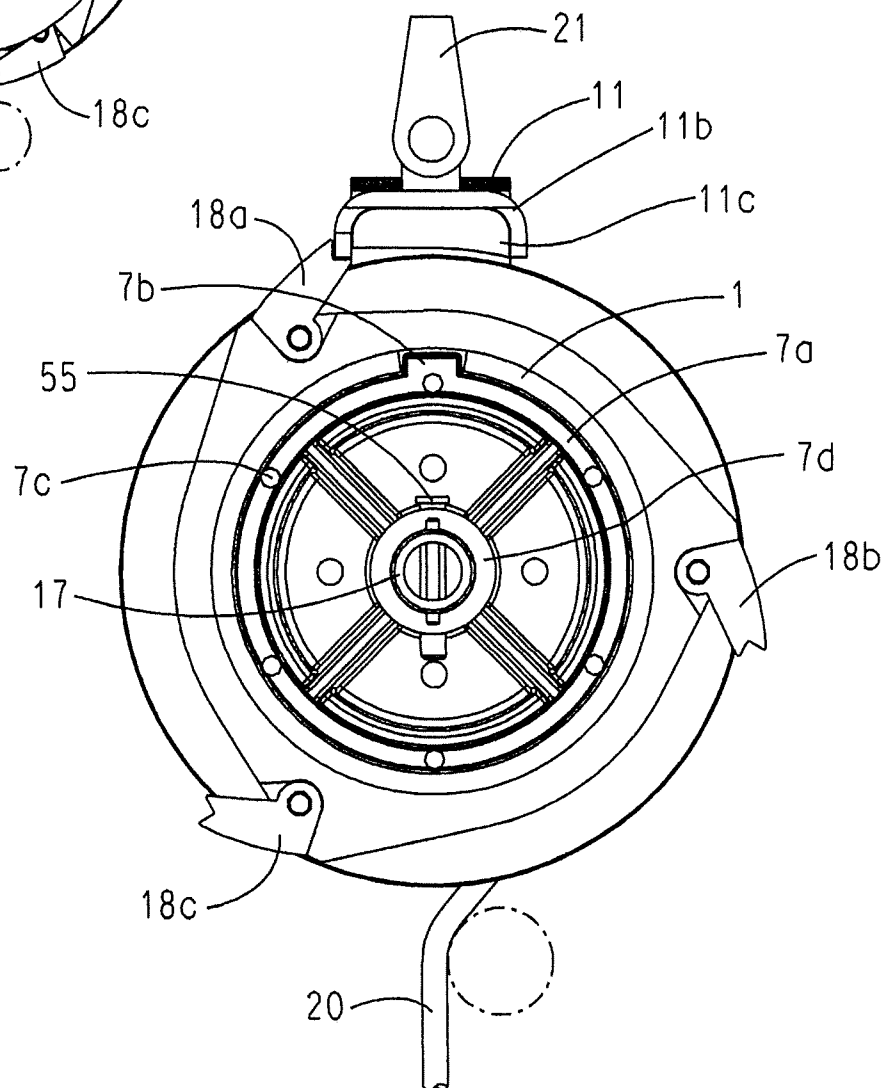
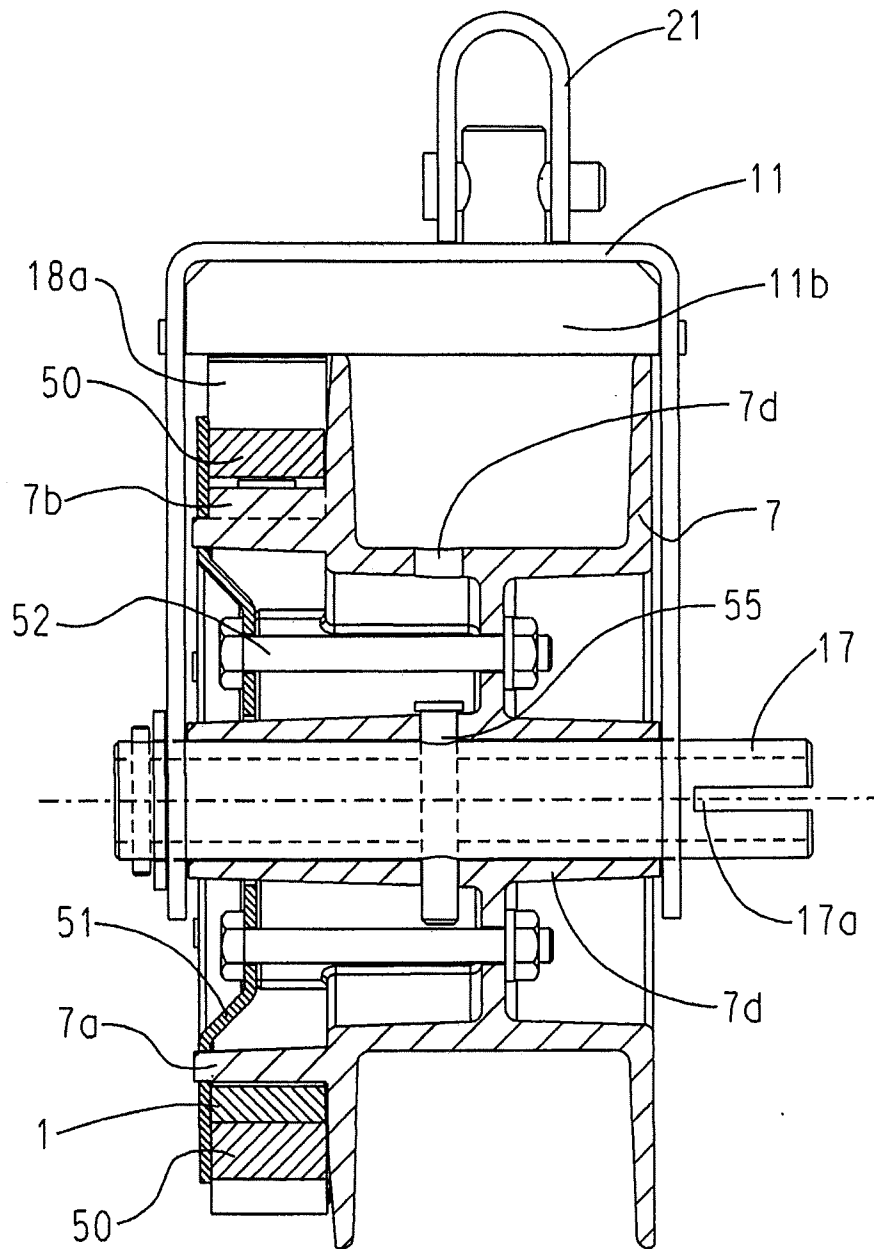
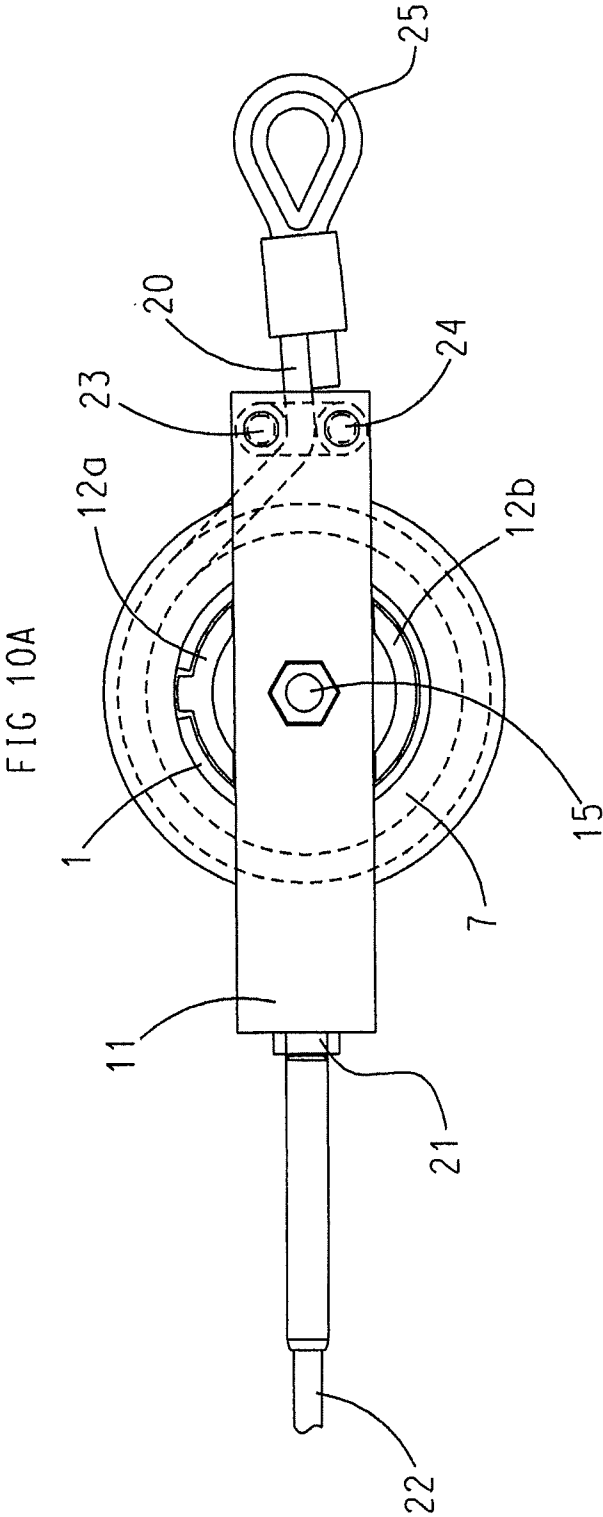
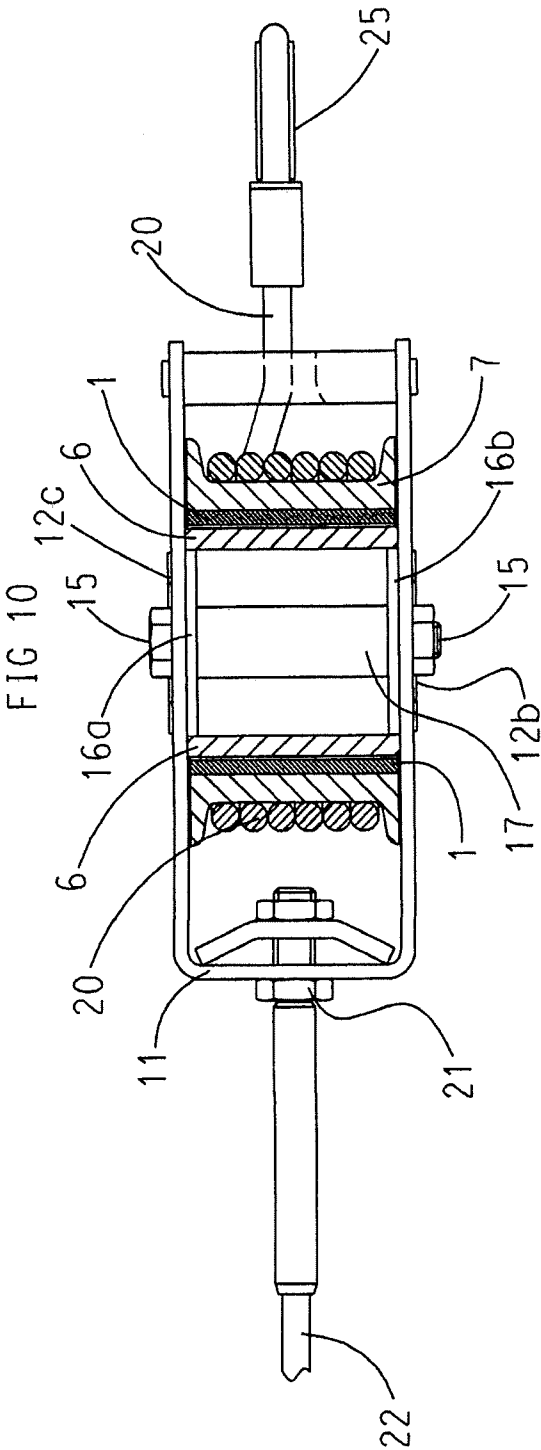
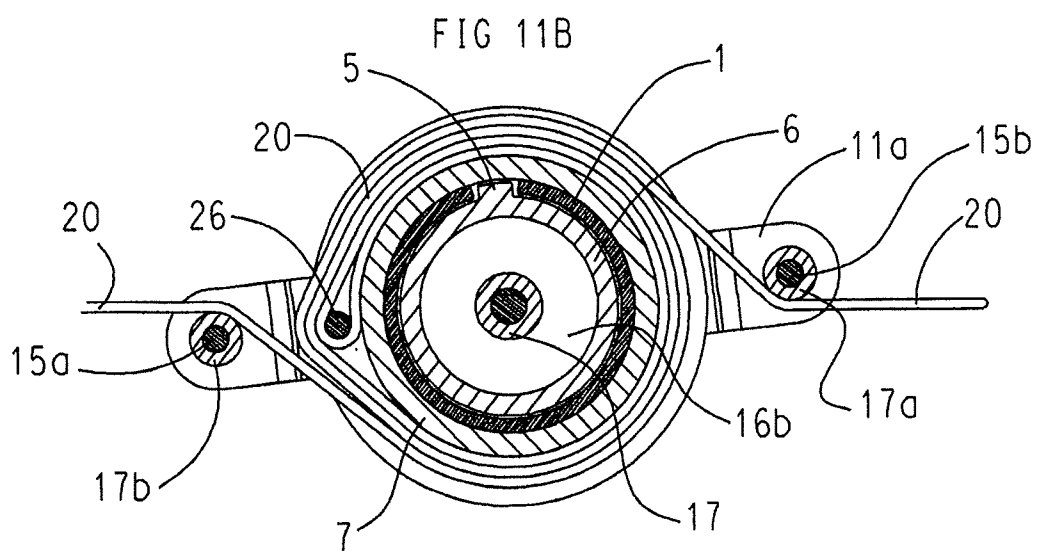
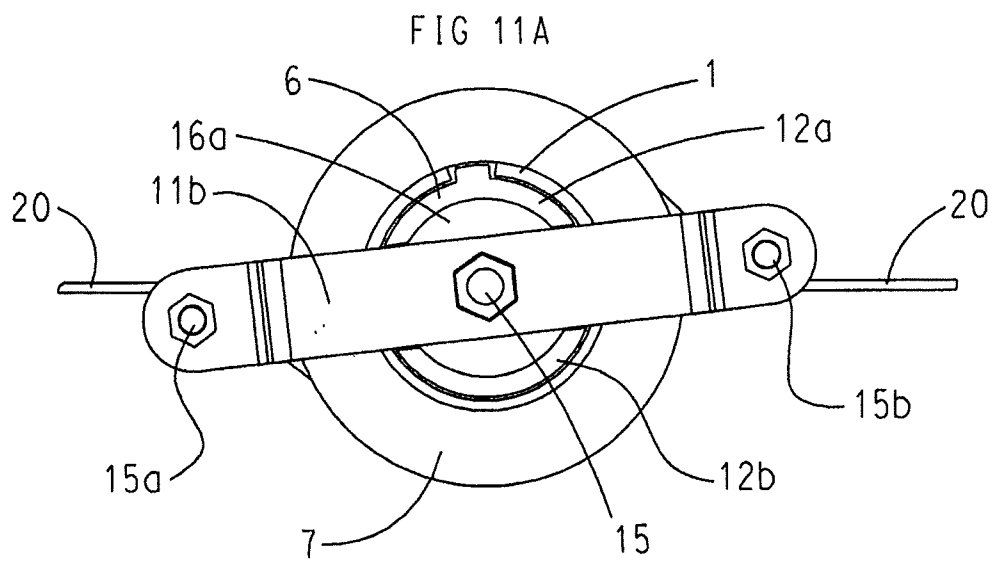
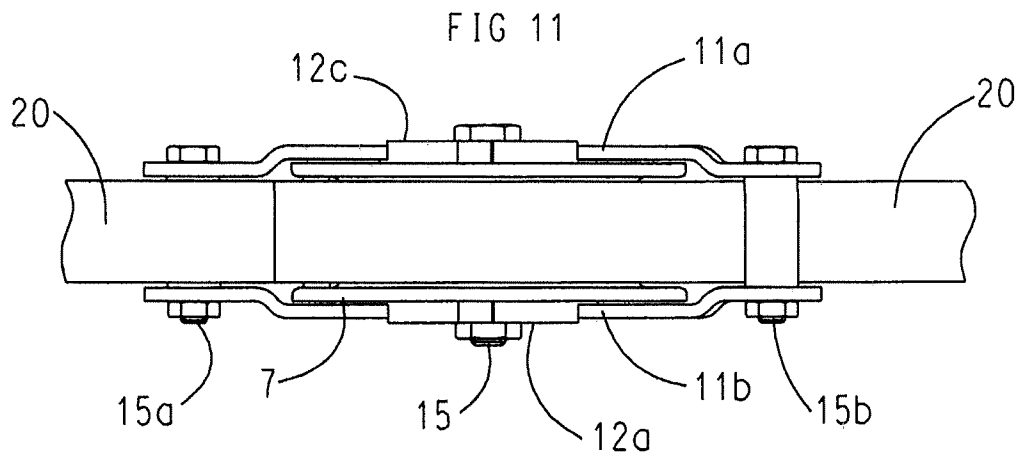


FIG 9N







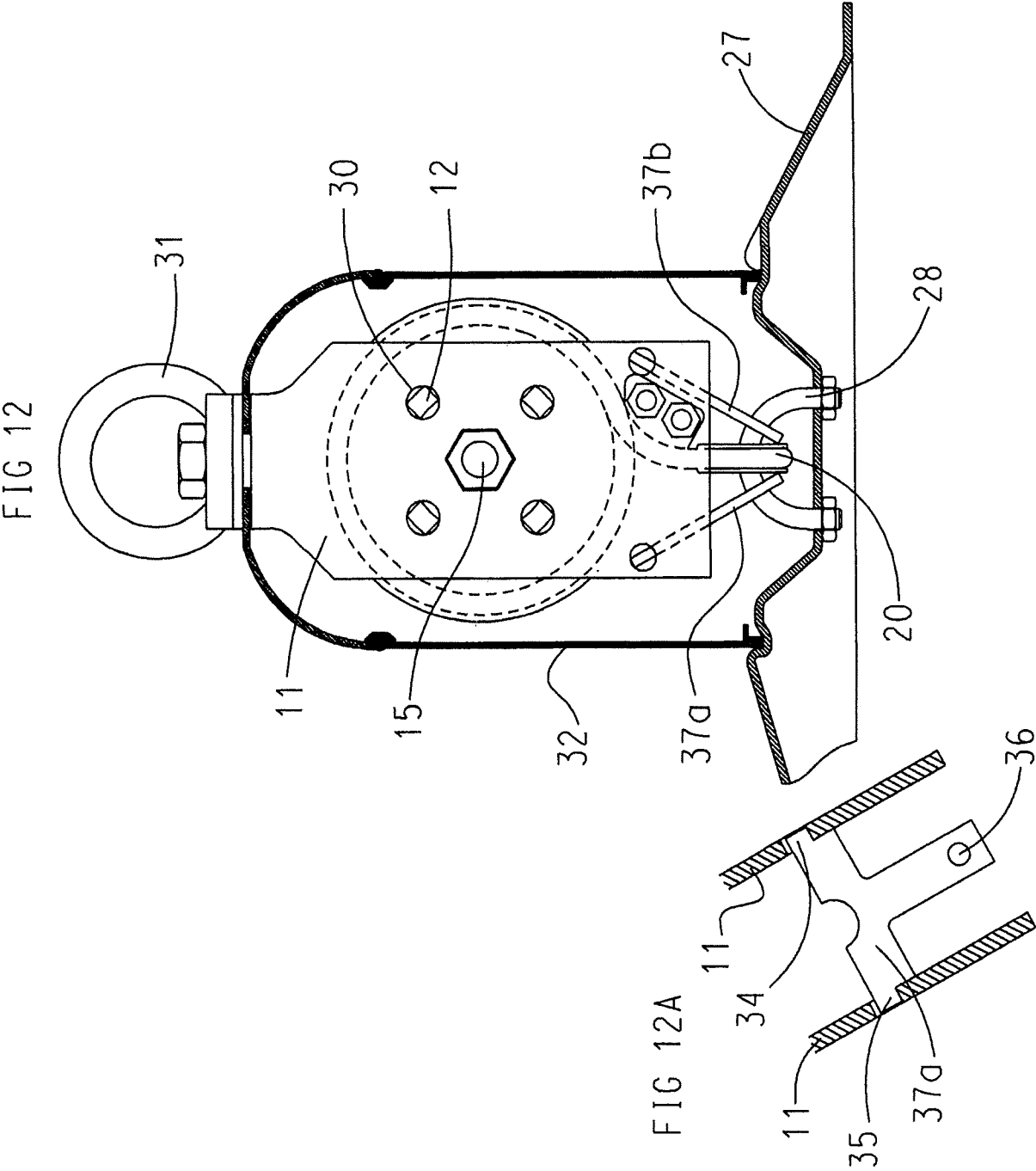
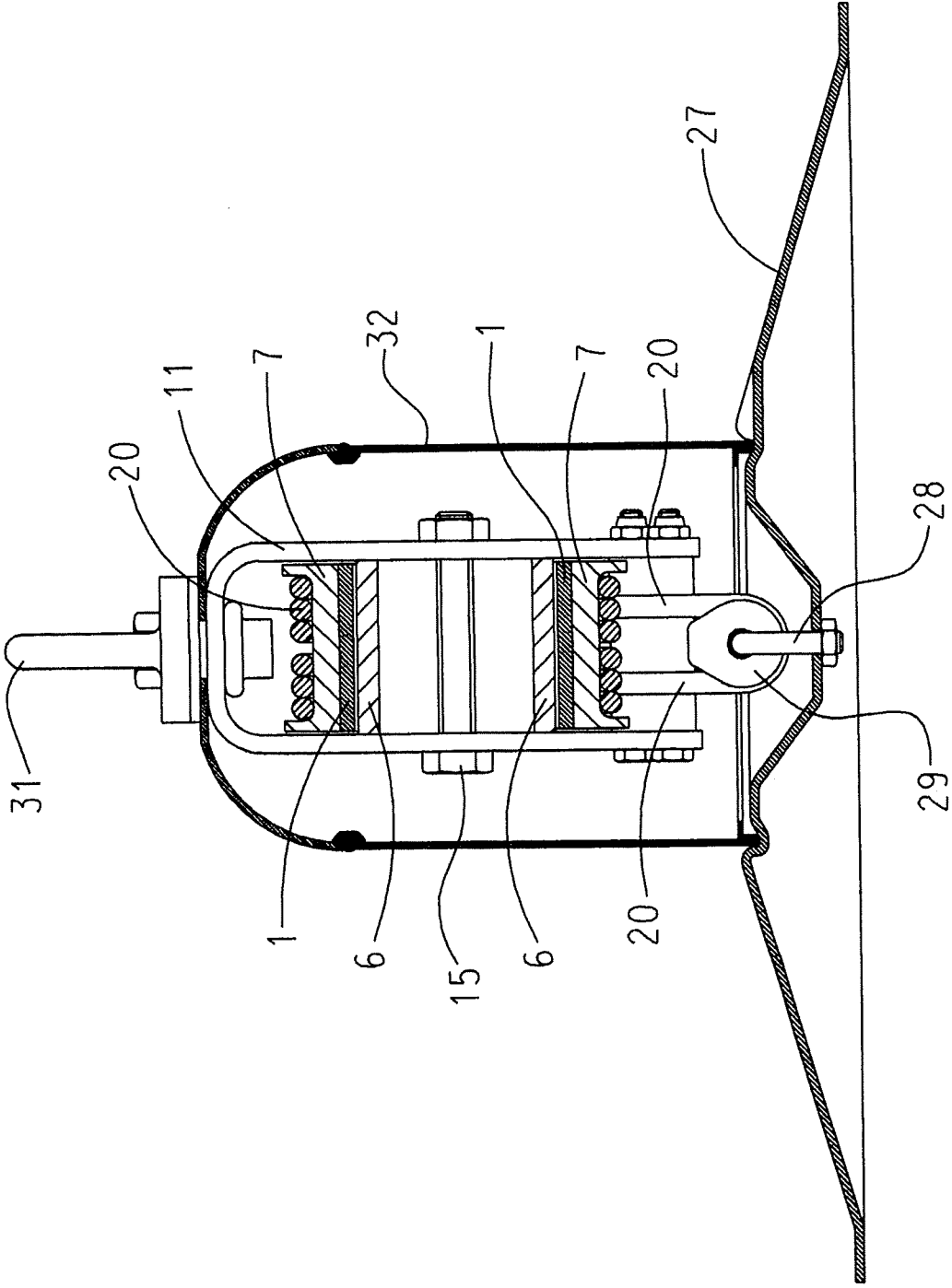


FIG 12B



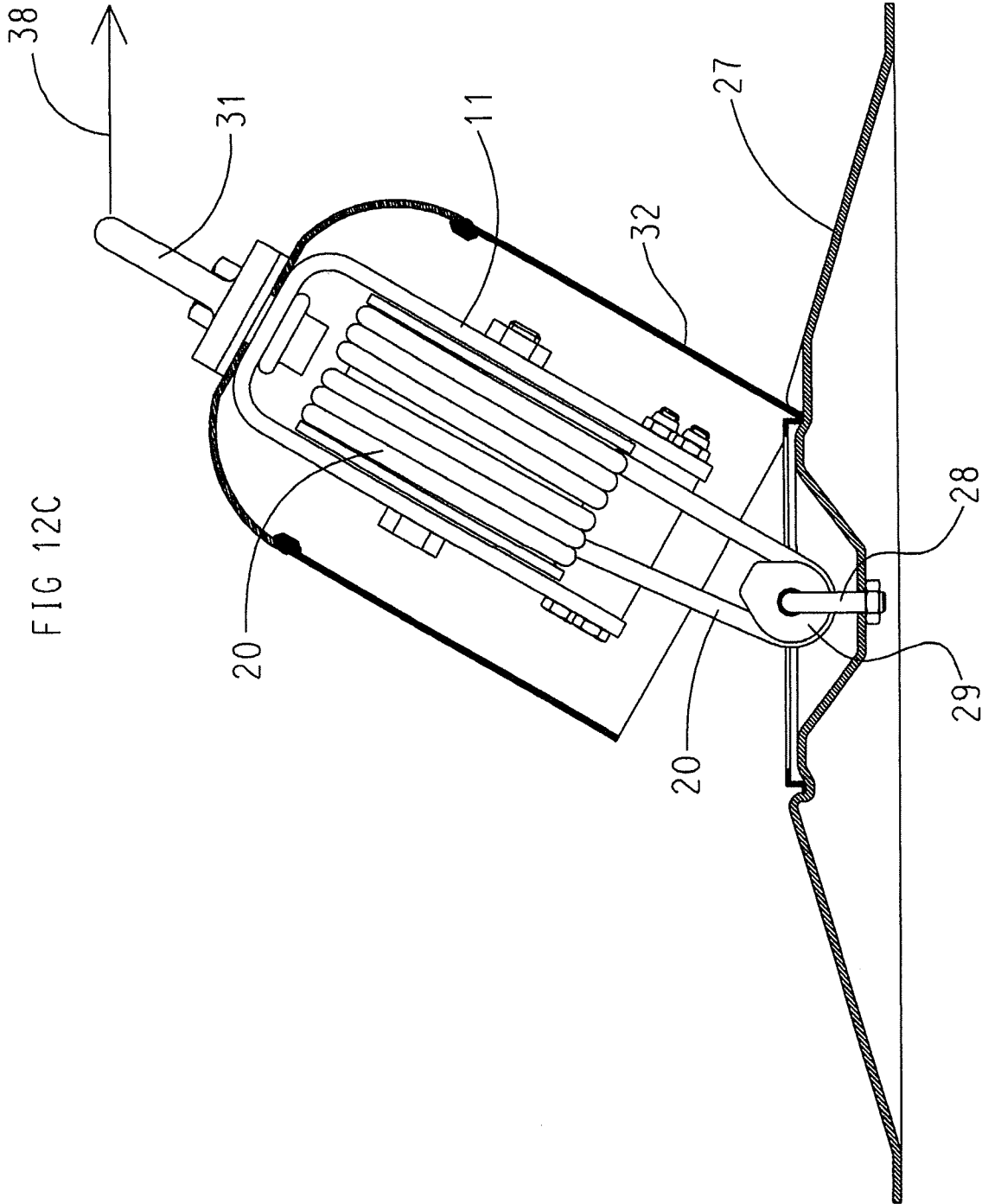
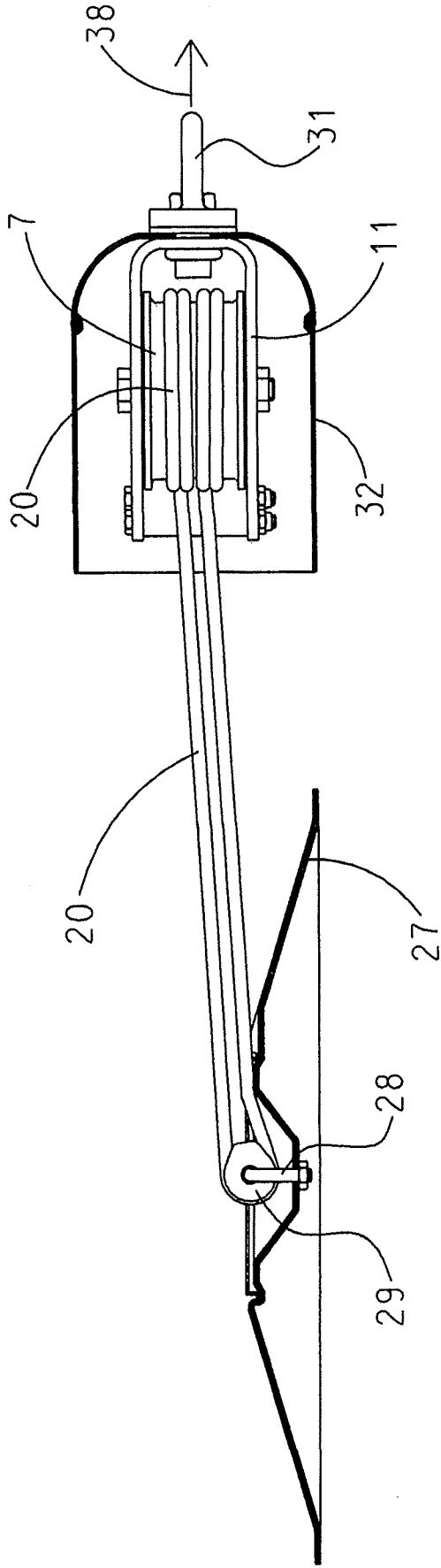


FIG 12D



INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2020/050699

A. CLASSIFICATION OF SUBJECT MATTER

INV. A62B35/00 A62B35/04
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)

A62B

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 771 076 A2 (LATCHWAYS PLC [GB]) 3 September 2014 (2014-09-03) cited in the application paragraph [0040] figures	1,7-12, 15-18
A	----- US 492 180 A (ISAAC H. ATHEY) 21 February 1893 (1893-02-21) figures	2-6,13, 14
A	----- US 3 042 339 A (GSCHWIND ROBERT C) 3 July 1962 (1962-07-03) figures	1
A	----- US 3 042 339 A (GSCHWIND ROBERT C) 3 July 1962 (1962-07-03) figures	1



Further documents are listed in the continuation of Box C.



See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

15 May 2020

Date of mailing of the international search report

27/05/2020

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
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Fax: (+31-70) 340-3016

Authorized officer

Andlauer, Dominique

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2020/050699

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