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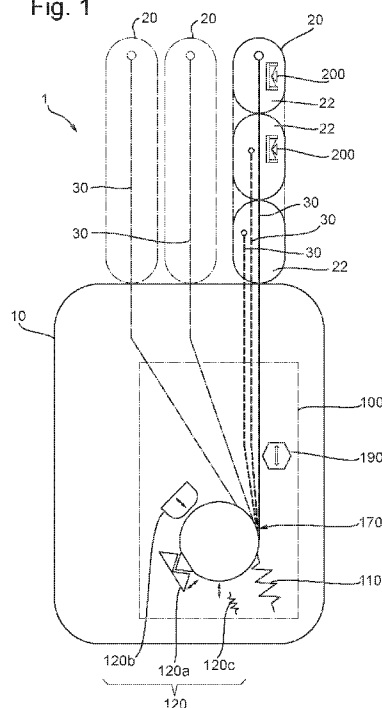
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Fig. 1



(57) Abstract: A haptic glove for providing haptic feedback to a user's hand, the haptic glove comprising: a base portion and one or more finger portions extending from the base portion, wherein each finger portion is pivotally movable relative to the base portion, and one or more cables, each comprising a distal end connected to a respective finger portion and a proximal end extending towards the base portion; and one or more cable control assemblies for constraining movement of the proximal portion of a respective cable with respect to the base portion, thereby constraining movement of a respective finger portion relative to the base portion, wherein each of the one or more cable control assemblies comprises a brake mechanism arranged to apply a frictional force that resists movement of the respective cable, the brake mechanism comprising at least one SMA wire for adjusting the frictional force.

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HAPTIC GLOVE

Field

The present invention relates to a wearable article that provides haptic feedback to a user, in particular to a haptic glove. The present invention in particular relates to such haptic gloves using shape memory alloy (SMA) wires for providing haptic feedback.

Background

Haptic gloves may be used to provide haptic or tactile feedback to a user's hand, for example when used in combination with virtual reality (VR) or augmented reality (AR) technology. Haptic gloves may provide a variety of sensations to a user's hand, ranging from giving the impression of gripping a virtual object (e.g. in a video game) to imitating texture and other surface structure on such a virtual object. Existing haptic gloves, however, are still limited in their capability of providing accurate haptic feedback and tracking a user's hand movement. Additionally, the mechanisms driving existing haptic gloves are large and heavy, limiting the adoption of haptic gloves in VR applications.

Summary

The present invention relates to a haptic glove for providing haptic feedback to a user's hand. The haptic glove comprises a base portion and one or more finger portions extending from the base portion, wherein each finger portion is pivotally movable relative to the base portion, and one or more cables, each comprising a distal end connected to a respective finger portion and a proximal end extending towards the base portion; and one or more cable control assemblies for constraining movement of the proximal portion of a respective cable with respect to the base portion, thereby constraining movement of a respective finger portion relative to the base portion, wherein each of the one or more cable control assemblies comprises a brake mechanism arranged to apply a frictional force that resists movement of the respective cable, the brake mechanism comprising at least one SMA wire arranged, on contraction, to adjust the frictional force.

Due to its high energy density, SMA wire may be used as an actuator in particularly compact applications, reducing the size of the cable control assembly. The SMA wire adjusts the frictional force, for example within a continuous range or between multiple discrete values. The SMA wire

may, on contraction, reduce the frictional force, for example from a maximum value to a minimum value or to zero. Alternatively, the SMA wire may, on contraction, increase the frictional force, for example from a minimum value or zero to a maximum value.

In some embodiments, the brake mechanism comprises a movable part coupled to the proximal portion of the cable and a brake part arranged to frictionally engage the movable part, wherein the at least one SMA wire is arranged to adjust the normal force between the brake part and the movable part so as to adjust the frictional force.

In some embodiments, the movable part is a reel and the cable is wound on the reel. A reel provides a space efficient means for allowing movement of the cable, thus enabling a more compact cable control assembly. The reel may be a multi-diameter reel comprising portions with different diameters, and different cables may be wound on portions of the reel with different diameters. This may be particularly beneficial in situations in which a finger portion comprises a plurality of finger segments and the different cables are connected at their distal ends to different finger segments of a respective finger portion. The cables connected to the finger segments may thus be moved proportionally.

In some embodiments, the brake part comprises a brake band wound at least partly around the reel. Alternatively, the brake part may comprise a brake pad or any other part capable of applying the frictional force. The brake part may comprise a friction surface for engaging a corresponding friction surface of the movable part.

In some embodiments, a contact angle defining the region of contact between the brake band and the reel is greater than 90 degrees and/or less than 360 degrees.

In some embodiments, the brake mechanism comprises a resilient element coupling the at least one SMA wire to the brake part, wherein the at least one SMA wire is arranged to deform the resilient element, thereby adjusting the normal force between the brake part and the movable part. The resilient element ensures that large forces acting on the movable part, e.g. via the cable, are absorbed and do not act directly on the SMA wire. Damage to the SMA wire may thus be reduced. The resilient element may be a compression or tension spring or a flexure.

In some embodiments, the brake mechanism comprises a force amplification mechanism for amplifying variations in tension in the SMA wire to a greater variation in force applied to the brake part. The force amplification mechanism may be a lever arm. Amplifying the force of the SMA wire allows larger frictional forces to be achieved compared to situations in which no amplification is provided.

In some embodiments, the at least one SMA wire is arranged, on contraction, to vary the frictional force within a continuous range. This allows more targeted haptic feedback to be provided. Alternatively, the at least one SMA wire is arranged, on contraction, to vary the frictional force between a plurality of discrete levels. This may reduce the complexity of control of the brake mechanism, and may provide more immediate and tangible haptic feedback.

In some embodiments, the brake mechanism comprises a multi-stage latch. The multi-stage latch may comprise a latch part, and the SMA wire is arranged to move the latch part from an unlatched position to a selected one of multiple discrete positions so as to apply a selected one of multiple discrete levels of frictional force to the cable. The latch part may comprise a release SMA wire arranged, on contraction, to release the latch part from the multiple discrete positions into an unlatched position.

In some embodiments, the brake mechanism is arranged to maintain a constant frictional force upon ceasing energization of the at least one SMA wire. This reduces the energy consumption of the brake mechanism. The constant frictional force may be maintained using the latch. Alternatively, in some embodiments, the brake mechanism comprises a holding mechanism for keeping the end of the SMA wire acting on the brake part in place, upon ceasing energization of the at least one SMA wire. The holding mechanism may comprise a resilient holding element arranged to bias the holding mechanism so as to resist movement of the brake part. The holding mechanism may comprise a holding SMA wire arranged, on contraction, to release the holding mechanism so as to allow movement of the brake part.

Brief description of the drawings

Certain embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 is a schematic overview of a haptic glove;

Figs. 2A and 2B are schematic views of examples of the structure of the haptic glove;

Figs. 3A and 3B show a multi-diameter reel implementing multi-cable control in the haptic glove;

Fig. 4 is a schematic view of a brake mechanism in accordance with embodiments of the present invention;

Figs. 5A and 5B are schematic views of another brake mechanism in accordance with embodiments of the present invention;

Fig. 6 is a schematic view of a latch in accordance with embodiments of the present invention;

Fig. 7 is a schematic view of a brake mechanism in accordance with embodiments of the present invention;

Figs. 8A-C are schematic views of another brake mechanism in accordance with embodiments of the present invention; and

Figs. 9A and 9B are schematic views of another brake mechanism in accordance with embodiments of the present invention; and

Detailed description

Overview of the haptic glove

Fig. 1 schematically depicts a haptic glove 1 in accordance with the present invention. The haptic glove 1 is configured to be worn on a user's hand. The haptic glove 1 comprises a base portion 10 and one or more finger portions 20. The finger portions 20 are pivotally movable relative to the base portion 10. Each finger portion 20 may comprise a plurality of finger segments 22 that are pivotally movable relative to each other and relative to the base portion 10. The base portion 10 and the one or more finger portions 20 make up the structure or exoskeleton of the haptic glove 1. The base portion 10 is herein used as a reference frame relative to which movement of other

components of the haptic glove 1 is described (unless otherwise indicated), but it will be appreciated that the base portion 10 in general may be movable itself and may comprise or be made up of parts that are movable relative to each other. Details and embodiments of the base portion 10 and the one or more finger portions 20 are described below.

The haptic glove 1 further comprises one or more cables 30 that is or are coupled at one end (herein referred to as the “distal end”) to a respective finger portion 20. Multiple cables 30 may be provided per finger portion 20, as described in more detail below. The cable 30 may be any elongate element capable of carrying a tensile force. The cable 30 may be deformed by forces acting laterally to the tensile force carried by the cable 30.

The cable 30, in particular movement of the cable 30, is controlled by a cable control assembly 100. The cable control assembly 100 may control the cable 30 passively, i.e. the cable control assembly 100 may selectively constrain (i.e. resist by a frictional force or bias force, or even prevent) movement of the cable 30. The cable control assembly 100 need not actively move the cable 30. In some embodiments, however, the cable control assembly 100 may actively pull on the cable 30 so as to move the finger portion 20 relative to the base portion 10.

The cable control assembly 100 may be provided on the base portion 10, as schematically shown. However, in general, the cable control assembly 100 may also be provided on the finger portions 20, or distributed between the base portion 10 and the finger portions 20. The end of the cable 30 that is not coupled to the finger portion 20 (herein referred to as the “proximal end” or “proximal portion”) may be coupled to the cable control assembly 100. The cable control assembly 100 may provide haptic feedback to a user by constraining, i.e. resisting or even preventing, movement of the cable 30. Details and embodiments of the cable control assembly 100 are described below.

The cable control assembly 100 may comprise at least one constrain mechanism 120, for example in the form of a locking mechanism 120a, a braking mechanism 120b and/or a spring mechanism 120c. The cable control assembly 100 may selectively engage the constrain mechanism 120. So, the constrain mechanism 120 may selectively constrain movement of the cable 30 relative to the base portion 10. This selectively locks, brakes or otherwise resists (e.g. applies a force that opposes) movement of the finger portion 20 relative to the base portion 10, thereby providing haptic feedback to the user.

Optionally, the cable control assembly 100 comprises at least one retraction mechanism 110. The retraction mechanism 110 may retract the cable 30, for example upon un-bending of the finger portions 20. The retraction mechanism 110 may provide a continuous or permanent biasing force for retracting the cable 30. The retraction mechanism 110 may be embodied by a resilient element, such as a spring (e.g. compression or tension spring, or a torsion spring) that provides the biasing force. In some embodiments, a dedicated retraction mechanism 110 is not provided.

Optionally, the cable control assembly 100 may comprise a multi-cable coupling 170, thereby enabling multi-cable control. So, some provision may be made for the cable control assembly 100 to control multiple cables 30 simultaneously. Each or at least one of the retraction mechanism 110 and/or the constrain mechanism 120 may thus act on multiple cables 30 simultaneously, such that a single retraction mechanism 110 and/or constrain mechanism 120 may act on multiple cables 30. This may make the cable control assembly 100 more compact and simpler. Alternatively, the cable control assembly 100 may control each cable 30 independently. Each retraction mechanism 110 and/or the constrain mechanism 120 may thus act on a single cable 30 only, such that a dedicated retraction mechanism 110 and/or constrain mechanism 120 is provided for each cable 30. This may provide more accurate cable control, and thus improved haptic feedback.

Optionally, the cable control assembly 100 comprises a position sensing arrangement 190. The position sensing arrangement 190 may determine a position of a finger portion 20 relative to the base portion 10. The position sensing arrangement 190 may, for example, determine the position of the cable 30 relative to the base portion 20. A processor (not shown) or other control circuit may receive the position data and make a determination as to whether or not to provide haptic feedback at least in part based on the position data.

Optionally, the haptic glove 1 comprises one or more haptic actuators 200 for providing localized haptic feedback to a user. The one or more haptic actuators 200 may be provided on the finger portion 20 (for example near the fingertip of a user), to selectively provide a localized haptic sensation to a specific portion of the user's hand (for example to the fingertip of the user).

Details of the haptic glove 1 are described below. It will be appreciated that any of the embodiments of the structure of the base portion 10 and/or finger portion 20 may be combined with any of the embodiments of the cable control assembly 100 described below. Furthermore, even though the parts of the cable control assembly 100 are described below in relation to the

haptic glove 1, it will be appreciated that these parts may find application in devices other than the haptic glove and may form embodiments of the present invention in their own right. Specifically, aspects of the constrain mechanism 120, including the locking mechanism 120a, the braking mechanism 120b and the spring mechanism 120c, as well as the latch mechanisms described below, need not be coupled to a cable 30 and/or a haptic glove 1 and may thus form inventions separate from the haptic glove 1 described herein.

Structure of the haptic glove 1

Figures 2A and 2B schematically illustrate examples of the structure of the haptic glove 1, comprising the base portion 10 and a finger portion 20. Only a single finger portion 20 is shown for illustrative simplicity, but it will be appreciated that more than one finger portion 20 (e.g. five finger portions) may be provided. The depicted finger portions 20 comprise multiple finger segments 22, although in general a single finger segment 22 may be provided. Figure 2B also shows the cable control assembly 100 arranged on the base portion 10.

The base portion 10 is arranged, in use, to at least partially be arranged adjacent to a user's hand. Although not shown, the base portion 10 may extend over the wrist of a user's hand, thus providing additional space for other components of the haptic glove 1. In its simplest form, the base portion 10 may comprise a plate provided on the rear of a user's hand. The base portion 10 may be fixed relative to a user's hand, for example using suitable straps. The base portion 10 may also be worn on the user's hand, so as to partially or entirely surround a user's palm.

One or more (e.g. four or five) finger portions 20 may depend from the base portion 10. The finger portion 20 comprises a proximal end arranged next to the base portion 10 and a distal end arranged away from the base portion 10. Each finger portion 20 is to be arranged on or adjacent to a user's finger (where the thumb is considered to be one of the fingers). Each finger portion 20 may be pivotally arranged relative to the base portion 10, i.e. the distal end of each finger portion 20 may pivot relative to the base portion 10. The finger portion 20 may pivot or bend relative to the base portion 10 at least in a direction substantially orthogonal to a user's palm, so as to allow bending of the user's finger. The finger portion 20 may additionally be laterally movable relative to the base portion 10, i.e. in a plane substantially parallel to a user's palm, so as to allow for lateral movement of a user's finger. This avoids constraining natural movement of a user's finger, making the haptic glove 1 more comfortable to wear and providing a more natural feel to a user.

The haptic glove 1 may comprise five finger portions 20, one for each finger of a user's hand. In some embodiments, the haptic glove 1 may comprise fewer than five finger portions 20, for example four finger portions 20 (for surrounding a user's fingers other than the thumb) or fewer finger portions 20. In some embodiments, a finger portion 20 may be provided to be worn on multiple fingers. For example, a single finger portion 20 may be worn on the pinkie finger and ring finger of a user's hand together, such that the pinkie finger and ring finger move together.

In preferred embodiments, each finger portion 20 comprises one or more segments 22, e.g. a plurality of segments 22 mechanically connected in series so as to form a chain of linkages. The segments 22 may be pivotally movable with respect to each other and with respect to the base portion 10, so as to allow bending and/or curling of a user's finger while remaining adjacent to the user's finger. One or more bearings 23 may be provided between adjacent finger segments 22 and between the base portion 10 and the finger portion 20, so as to allow relative movement of the finger segments 22 relative to each other and relative to the base portion 10.

The haptic glove 1 comprises one or more cables 30. The haptic glove 1 may, for example, comprise one cable 30 per finger portion 20. This allows each finger portion 20 to be controlled independently.

In some embodiments, the haptic glove 1 comprises more than one cable 30 per finger portion 20, for example one cable 30 per phalanx of a user's finger. So, the haptic glove 1 may comprise two cables 30 per finger portion 20 corresponding to a thumb of a user, and three cables 30 per finger portion 20 corresponding to another finger of a user. Figure 2B, for example, depicts three cables 30 attached to finger segments 20 corresponding to different phalanxes of a user's hand. This may enable more accurate control of the shape of a user's finger allowed by the haptic glove 1 to provide haptic feedback. The haptic glove 1 may in general comprise any number of cables 30 per finger portion 20.

Figure 2A shows a finger portion 20 with three finger segments 22, one per phalanx of a user's finger. Figure 2B shows an alternative finger portion 20 with additional finger segments 22, allowing the finger portion to conform to different finger sizes of a user. In general, any number of finger segments 22 may form part of the finger portion 20. The finger portion 20 may be formed from a plurality (e.g. more than 10) finger segments 22 provided in a backbone-like arrangement, for

example. The finger segments 22 need not all surround a user's finger, but some finger segments 22 may be provided at the back of a user's finger only. The number of cables 30 per finger portion 20 may be three, two or one regardless of the number of finger segments 22.

Cable control assembly 100 for providing haptic feedback

As described above, controlling (in particular constraining) movement of the cable 30 (in particular of the proximal portion of the cable 30) may be used to provide haptic feedback to a user's hand. The figures described below schematically depict various aspects of the cable control assembly 100. The cable control assembly 100 may comprise or embody one or more of a retraction mechanism 110 for retracting the cable 30, a locking mechanism 120a for locking the proximal portion of the cable 30 in place, a brake mechanism 120b for braking movement of the proximal portion of the cable 30a, and a spring mechanism 120c for selectively applying a spring force to the proximal portion of the cable 30. A respective part of the cable control assembly 100 may be provided individually for each cable 30, or multiple cables 30 (e.g. all cables coupled to a finger portion 20) may be controlled by a single part of the cable control assembly 100, for example by coupling multiple cables using the multi-cable coupling 170. Described below are examples of parts of the cable control assembly 100 that achieve one or more of these functions.

According to the present invention, the cable control assembly 100 comprises a constrain mechanism 120 embodied by a brake mechanism 120b. The cable control assembly 100 may optionally comprise other constrain mechanisms 120, for example embodied by a locking mechanism 120a or spring mechanism 120c.

The brake mechanism 120b is arranged to apply a frictional force that resists movement of the cable 30. The brake mechanism 120b comprises at least one SMA wire for adjusting the frictional force.

Multi-cable coupling 170

As explained above, the haptic glove 1 may in some embodiments comprise more than one cable 30 per finger portion 20, for example one cable 30 per phalanx of a user's hand. The shape of the finger portion 20 can thus be more accurately controlled compared to providing a single cable 30 per finger portion 20, enabling improved haptic feedback.

In general, each cable 30 of the multiple cables 30 per finger portion 20 may be controlled independently, either within the same cable control assembly 100 or by different cable control assemblies 100.

The multiple cables 30 coupled to a finger portion 20 may move by proportional amounts. For example, with reference to Figure 2B, a first cable 30 coupled a first finger segment 22 of the finger portion 20 may move by a first amount, and a second cable 30 coupled to a second finger segment 22 of the finger portion 20 may move by a second amount that is proportional to the first amount. When three cables are provided, a third cable 30 coupled to a third finger segment 22 of the finger portion 20 may move by a third amount that is proportional to the first amount. A cable 30 coupled to a relatively distal finger segment 22 may be allowed to move by a larger amount than a cable 30 coupled to a relatively proximal finger segment 22 (relative to the base portion 10). This allows natural curling of a user's finger.

The multiple cables 30 may be coupled to one another to enable such proportional movement. This allows the multiple cables 30 per finger portion 20 to be controlled simultaneously. Control is thus simplified, because a single cable control assembly 100 may be used to control multiple cables 30.

Figures 3A and 3B schematically show a plan view and a side view of one embodiment of a multi-cable coupling 170 for coupling multiple cables 30 together. In Figures 3A and 3B, the multi-cable coupling is in the form of a reel 175, in particular a multi-diameter reel 175. The multi-diameter reel 175 is, e.g., a rotatable drum or cylinder comprising portions 175A-C of multiple diameters. The cables 30 are wound on the reel 175.

The multi-diameter reel 175 comprises portions 175A-C with different diameters. Each portion 175A-C may be a cylinder or be considered a reel by itself. Different cables 30 are wound on portions of the reel with different diameters. The different cables 30 may be cables coupled to different finger segments 22 of the same finger portion 20, and so may be proportionally moved relative to each other. For example, a cable 30 coupled to a relatively distal finger segment 22 of the finger portion 20 (relative to the multi-diameter reel) may be wound on a relatively larger diameter portion 175C of the reel. A cable 30 coupled to a relatively proximal finger segment 22 of the finger portion 20 (relative to the multi-diameter reel) may be wound on a relatively smaller diameter portion 175A of the reel. This allows the cables 30 coupled to different finger segments 22 of the finger portion 20 to move proportionally, enabling the finger portion to allow a natural curling

motion of a user's finger while simplifying control compared to a situation in which each cable 30 is controlled independently.

So, the portions of the reel 175 have different diameters, and allow for different movement of the different cables 30 relative to the base portion 10. Upon bending of a finger portion, for example, the proximal phalanx may bend less than the middle phalanx, which in turn bends less than the distal phalanx. As such, the cable 30 connected to the distal phalanx may move more relative to the base portion 10 than the cable connected to the middle phalanx and the cable connected to the proximal phalanx. The multi-cable coupling may apply gearing to the movement of the cables 30 relative to the base portion 10.

Another advantage of providing a reel on which the cable 30 is wound is that relatively large cable movement is enabled within a relatively compact space. The excess cable length is neatly wound on the reel. In general, a single diameter reel may be provided to achieve these advantages without implementing multi-cable control 170.

Movable part 102

The brake mechanism 120b comprises a movable part 102 that is coupled to the proximal portion of the cable 30. The brake mechanism 120b further comprises a brake part 124 that is arranged to frictionally engage the movable part 102. The at least one SMA wire is arranged to adjust the normal force between the brake part 124 and the movable part 102 so as to adjust the frictional force.

The movable part 102 may be embodied by any part that is permanently coupled to the proximal portion of the cable 30. The movable part 102 may be any part that moves with the cable 30. In some embodiments, the movable part 102 is integrally formed with the cable 30 or is embodied by the proximal portion of the cable 30 itself. As such, the frictional force may act directly on the cable 30.

Figures 3A and 3B show further examples of the movable part 102, or portions of the movable part 102. As shown in Figure 3A, the reel 175 may form the movable part 102. The brake part 124 may thus frictionally engage the reel so as to apply a frictional force that resists movement of the cable 30. Optionally, other parts may be coupled to the reel to form the movable part 102. For example,

a further cable 102' may be coupled to the reel 175, e.g. a further portion of the reel 175 with different diameter. The brake mechanism 120b may apply the frictional force to the further cable 102' or another part coupled to the further cable 102. Alternatively, a rack 102'' may be coupled to the reel 175, for example by engaging teeth of a gear forming part of the reel 175. The brake mechanism 120b may apply the frictional force to rack 102'' or another part coupled to the rack 102''.

In general, the movable part 102 may be any part that is movable with the cable 30. The movable part 102 may be rotationally movable (like the reel 175) or may be translationally movable (like the rack 102''). In general, the reel 175 of Figure 3 need not be provided.

Retraction mechanism 110

The cable control mechanism 100 may comprise a retraction mechanism 110 for retracting the cable upon unbending of the finger portions. The retraction mechanism 110 may be embodied by any resilient element permanently coupled to the movable part 102 and capable of retracting the cable 30. Preferably, the resilient element is capable of retracting the cable 30 over the entire movement range of the cable 30.

The retraction mechanism may be embodied by a torsion spring, for example for applying a torque to the reel 175 for retracting the cable 30. The retraction mechanism may alternatively be embodied by a tension or compression spring, for example coupled to a movable part in the form of a rack 102'' or the coupling cable 102'.

Brake pads

Figure 4 schematically depicts an embodiment of the brake mechanism 120b. The brake mechanism 120b comprises the movable part 102 in the form of the reel 175 depicted in Figure 3. The brake mechanism 120b comprises the brake part 124 in the form of a brake pad. The brake mechanism 130b of Figure 4 further comprises a force amplifying mechanism 140 in the form of a lever arm 140, a resilient element 126 in the form of a spring that couples to the brake part 124, and a holding mechanism 150. A static (non-movable) brake pad 124' is also provided on the side of the reel opposite to the brake pad 124, to balance the overall normal force acting on the reel.

The SMA wire 130 is arranged to adjust the normal force between the brake part 124 and the movable part 120 so as to adjust the frictional force. In particular, in Figure 4, contraction of the SMA wire 130 pivots the lever arm 140 about pivot point 142. As a result, the spring 126 is extended and the normal force between brake part 124 and movable part 102 is reduced. As such, the SMA wire 130 is arranged, on contraction, to reduce the frictional force. Upon ceasing energization of the SMA wire 130, the SMA wire 130 may be extended, for example due to a biasing spring 132 (provided a separate holding mechanism 150 is disengaged, for example). This may increase the frictional force.

The lever arm 140 of Figure 4 is just one example of a force amplifying mechanism 140. The force amplifying mechanism 140 amplifies variation in tension in the SMA wire 130 to a greater variation in force applied to the brake part 124. In some embodiments, the force amplifying mechanism 140 amplifies the tension in the SMA wire 130 to a greater force applied to the brake part 124. With reference to Figure 4, for example, this may allow the SMA wire 130 to act on a stiffer resilient element 140, thus increasing the normal force that can be applied between brake part 124 and movable part 102. The amount of amplification may be varied by appropriately moving the pivot point 142.

The force amplification 140 thus allows a larger frictional force to be provided, which may be particularly desirable to withstand the forces applied to the haptic glove by a user's hand. In general, however, a force amplifying mechanism 140 need not be provided. The tension in the SMA wire 130 may be equal to the normal force between brake part 124 and movable part 102.

The resilient element 126 couples the SMA wire 130 to the brake part 124. The SMA wire 130 is arranged to deform the resilient element, thereby adjusting the normal force between the brake part 124 and the movable part 102. In Figure 4, the resilient element is a compression spring, i.e. a spring that is in operation biased to be in compression. However, in general, the resilient element may be a tension spring (as in Figure 5), a flexure (not shown), or any other resilient element capable of applying a bias force by deformation.

The resilient element 126 may reduce the risk of damage to the SMA wire due to large external loads acting on the moving part 102, e.g. via the cable by the user's hands. The resilience of the resilient element 124 allows such large external forces to be absorbed rather than acting directly on the SMA

wire 130. In general, however, a resilient element 126 need not be provided. The SMA wire 130 may be directly or at least rigidly coupled to the movable part 124, for example.

The brake mechanism 120b of Figure 4 is arranged to maintain a constant frictional force upon ceasing energization of the at least one SMA wire 130. In Figure 4, this is achieved by provision of the holding mechanism 150. The holding mechanism 150 keeps the brake part 124 and/or the end of the SMA wire acting on the brake part 124, and/or both ends of the resilient element 126 in place upon ceasing energization of the SMA wire 130.

In particular, the holding mechanism 150 comprises a resilient holding element 154, here in the form of a compression spring, arranged to bias the holding mechanism 150 so as to resist movement of the brake part 124. The holding mechanism 150 keeps the end of the SMA wire 130 acting on the brake part 130 in place. The holding mechanism 150 further comprises a holding SMA wire 152 arranged, on contraction, to release the holding mechanism 150 so as to allow movement of the brake part 124 or movement of the end of the SMA wire 130 acting on the brake part 130.

Brake band

Figures 5A and 5B show another embodiment of the brake mechanism 120b. The brake mechanism 120b comprises a movable part 102 in the form of the reel 175 described in relation to Figure 3. The brake mechanism 120b of Figure 5A further comprises the resilient element 126, the lever arm 140, and the holding mechanism 150 already described in relation to Figure 4. Purely for reasons of conciseness, only the differences to the embodiment of Figure 4 are described below.

In Figure 5, the brake part 124 is embodied by a brake band instead of a brake pad. The brake band may be an elongate and flat element. The brake band may carry a tensile force along its length and be flexible in directions orthogonal to its length. The brake band is wound at least partly around the movable part 102. The contact area between the brake band 124 and movable part 102 may be larger than that enabled by the brake pad 124 of Figure 4. As such, the embodiment of Figure 5 may withstand larger external forces acting on the movable part 102, for example.

In embodiments, a contact angle α defining the region of contact between the brake band 124 and the movable part 102 (in the form of reel 175) is greater than 90 degrees and/or less than 360 degrees. Winding the brake band 124 around the reel for less than a full rotation reduces the

height of the brake mechanism. Preferably, the contact angle α is greater than 180 degrees, optionally greater than 210 degrees. This reduces the overall force acting on the movable part 102, because the force of opposing portions of the brake band on the movable part 102 may cancel out.

In Figure 5, the resilient element 126 is a tension spring (as opposed to a compression spring). Contraction of the SMA wire 130 increases the tension in the tension spring, thereby increasing the frictional force.

Latch

In the above-described embodiments, the SMA wire 130 directly acts to vary the frictional force. Any change in tension in the SMA wire 130 leads to a change in frictional force. A dedicated holding mechanism 150 may optionally be provided to maintain the frictional force without continuously powering the SMA wire 130. The SMA wire 130 varies the frictional force within a continuous range.

As an alternative, a latch 200 may be used to vary the frictional force. The latch 200 may require powering only during adjusting of the frictional force. The latch may not require power for maintaining the frictional force. A separate holding mechanism 150 may not be required.

Figure 6 schematically depicts a latch 200, in particular a multi-stage latch 200. The multi-stage latch may be comprised by the brake mechanism 120b.

The latch 200 may, for example, replace the SMA wire 130 in Figures 4 and 5. The latch may be selectively engageable by an SMA wire 228a. So, the SMA wire 228a may be arranged, on contraction, to engage the latch 200 so as to vary the frictional force from a first value to a second value. A release SMA wire 228b may be arranged, on contraction, to disengage the latch 200 so as to return the frictional force from the second value to the first value. The SMA wires 228a,b are thus arranged, on contraction, to vary the frictional force between a plurality of discrete levels. The latch is configured to remain engaged or disengaged when the SMA wires 228a, b cease to be energized, thus maintaining a constant frictional force even when the SMA wires 228a, b are not energized.

The latch 200 depicted in Figure 6 is a multi-stage latch. So, the SMA wire 228a is arranged to move the latch part 220 from an unlatched position to a selected one of multiple discrete positions so as to apply a selected one of multiple discrete levels of frictional force. The release SMA wire 228b

may be arranged, on contraction, to release the latch part 220 from the multiple discrete positions into an unlatched position.

In particular, the latch 200 comprises a support structure 230. The support structure 230 may be fixed relative to the base portion 10, for example. The support structure 230 comprises first and a second surface separated by a first step 211 and a third surface separated from the second surface by a second step 211'.

The latching part 220 is slidably arranged along the first, second and/or third surfaces between an unlatched position engaging the first surface, a first latched position engaging the step 211 and second surface, and a second latched position engaging the second step 211' and the third surface. The SMA wire 228a is arranged, on initial contraction, to move the latching part 220 along the first surface into the first latched position under bias of the resilient element 223. The SMA wire 228a is arranged, on further contraction, to move the latching part 220 along the second surface into the second latched position under bias of the resilient element 223.

The release SMA wire 228b is arranged, on initial contraction, to move the latching part 220 from the second latched position over the second step 211' into the first latched position under bias of the resilient element 223, and, on further contraction, to move the latching part 220 from the first latched position over the first step 211 into the unlatched position under bias of the resilient element 223.

Although a multi-stage latch has been described, in general, the latch may be a bi-stable latch in which the latching part is movable between a latched position and one unlatched position only. Alternatively, more than two steps may be provided to allow further discrete levels of frictional force to be applied.

Furthermore, although a release SMA wire 228b is provided in the latch of Figure 6, in general any other release mechanisms may be implemented. For example, a single SMA wire 228a may be used to both engage and disengage the latch using a retractable mechanism such as that found in a retractable pen, for example.

Figure 7 schematically depicts a further embodiment of the brake mechanism 120b. The frictional force may be variable using the latch mechanism 200 described above, for example.

Figure 7 shows the latch part 220 that may be movable between one or more latched positions and an unlatched position. The latch part 220 is coupled to the brake part 124 via a resilient element 126, such as a spring. Presence of the resilient element 126 allows for some resilience so as to prevent damaging the SMA wire 130 and latch 200 due to larger external forces acting on the movable part 102 via cable 30. When the latch part 220 is in the latched position (not shown), the frictional force between movable part 102 and brake part may be increased or decreased compared to a situation in which the latch part 220 is in the unlatched position.

Drum brake

Figures 8A-C schematically depict further embodiments of the cable control assembly 100. The cable control assembly 100 comprises a constrain mechanism 120 (in the form of a brake mechanism 120b) connected mechanically in series with a retraction mechanism. In Figures 8A and 8B, the retraction mechanism is embodied by a simple spring that provides a biasing force for retracting the cable 30.

In Figure 8A, a fixed part 310 is provided around which the cable 30 is wound. The fixed part 310 is in the form of a fixed drum. When the SMA wire 130 is energized, the cable 30 is allowed to slide over the fixed part 310, thereby allowing the cable 30 to move. When the SMA wire 130 is not energized, the cable 30 is constrained from sliding over the fixed part 310. An advantage of the mechanism of Figure 8A is that a relatively large tensile force in the cable 30 can be held by the friction between cable 30 and fixed drum, even when a relatively low force acts on the SMA wire 130.

In Figure 8B, the drum 310 around which the cable 30 is wound is not fixed, but rotatably mounted. The drum 310 may thus also be considered a movable part 102 to which the cable 30 is coupled, in that constraining movement of the drum 310 may constrain movement of the cable 30. The cable 30 may not slide across the movable part 102, but instead be effectively fixed relative to the movable part 102. A brake mechanism 120b may brake rotation of the movable part 102, thereby constraining movement of the cable 30. In particular, the brake mechanism 120b comprises a brake part 124 in the form of a brake cable or brake band wound around the movable part 102, connected in mechanical series with at least one SMA wire 130. Contraction of the SMA wire 130 increases the

tension in the brake cable 124, such that the brake cable 124 engages (relatively tightly) with the movable part 102 to thereby stop rotation thereof.

Figure 8C depicts a further development of the embodiment in Figure 8B, in particular of the brake mechanism 120b thereof. In Figure 8C, the brake cable is not directly connected in mechanical series with the SMA wire 130, but instead a resilient element 126 is connected between brake cable 124 and SMA wire. Contracting the SMA wire to the left of Figure 7C increases the biasing force of the resilient element 126, so as to brake rotation of the movable part 102. Contracting the SMA wire 130 to the right of Figure 8C decreases the biasing force of the resilient element 126, so as to release the brake and allow rotation of the movable part 102. Compared to the embodiment of Figure 8B, the SMA wires 130 may be better protected from the tensile force in the cable 30, and so the risk of damage to the SMA wires due to high tensile loads in the cable 30 is reduced.

Cable clamp brake

Figs. 9A and 9B schematically depict an alternative embodiment of a brake mechanism 120b. In the depicted embodiment, the movable part 102 is a portion of the cable 30 and arranged on the proximal end of the cable 30. The SMA wire 130 is connected directly between the brake part 124 and the base portion 10. The brake part 124 is biased into engagement with the movable part 102 (i.e. into engagement with the cable 30) by a biasing element (not shown). Actuation of the SMA wire 130, as shown in Fig. 9A, may bring the brake part 124 out of engagement with the movable part 102 and allow the cable 30 to move freely. Ceasing actuation of SMA wire 130 (i.e. allowing the SMA wire to expand) will bring the brake part 124 into engagement with the movable part 102. The movable part 102 (the cable 30) is clamped between the brake part 124 and the base portion 10, thus constraining or even preventing movement of the cable 30 relative to the base portion.

Closing paragraphs

The term 'shape memory alloy (SMA) wire' may refer to any element comprising SMA. The SMA wire may have any shape that is suitable for the purposes described herein. The SMA wire may be elongate and may have a round cross section or any other shape cross section. The cross section may vary along the length of the SMA wire. It is also possible that the length of the SMA wire (however defined) may be similar to one or more of its other dimensions. The SMA wire may be pliant or, in other words, flexible. In some examples, when connected in a straight line between two

elements, the SMA wire can apply only a tensile force which urges the two elements together. In other examples, the SMA wire may be bent around an element and can apply a force to the element as the SMA wire tends to straighten under tension. The SMA wire may be beam-like or rigid and may be able to apply different (e.g. non-tensile) forces to elements. The SMA wire may or may not include material(s) and/or component(s) that are not SMA. For example, the SMA wire may comprise a core of SMA and a coating of non-SMA material. Unless the context requires otherwise, the term 'SMA wire' may refer to any configuration of SMA wire acting as a single actuating element which, for example, can be individually controlled to produce a force on an element. For example, the SMA wire may comprise two or more portions of SMA wire that are arranged mechanically in parallel and/or in series. In some arrangements, the SMA wire may be part of a larger piece of SMA wire. Such a larger piece of SMA wire might comprise two or more parts that are individually controllable, thereby forming two or more SMA wires.

Whilst the embodiments above have described actuator assemblies which use SMA wires, the skilled person will appreciate that the features of the bearing arrangements and the flexures described can be readily used with other forms of actuator components. For example, each actuator component may be a voice coil motor (VCM) actuator, but other types of actuator are possible, for example a piezoelectric actuator, a radial motor or others.

CLAIMS

1. A haptic glove for providing haptic feedback to a user's hand, the haptic glove comprising:
a base portion and one or more finger portions extending from the base portion, wherein each finger portion is pivotally movable relative to the base portion, and
one or more cables, each comprising a distal end connected to a respective finger portion and a proximal end extending towards the base portion; and
one or more cable control assemblies for constraining movement of the proximal portion of a respective cable with respect to the base portion, thereby constraining movement of a respective finger portion relative to the base portion,
wherein each of the one or more cable control assemblies comprises a brake mechanism arranged to apply a frictional force that resists movement of the respective cable, the brake mechanism comprising at least one SMA wire for adjusting the frictional force.
2. A haptic glove according to claim 1, wherein the brake mechanism comprises a movable part coupled to the proximal portion of the cable and a brake part arranged to frictionally engage the movable part, wherein the at least one SMA wire is arranged to adjust the normal force between the brake part and the movable part so as to adjust the frictional force.
3. A haptic glove according to claim 2, wherein the movable part is a reel and the cable is wound on the reel.
4. A haptic glove according to claim 3, wherein the reel is a multi-diameter reel comprising portions with different diameters, and different cables are wound on portions of the reel with different diameters, optionally wherein each finger portion comprises a plurality of finger segments and the different cables are connected at their distal ends to different finger segments of a respective finger portion.
5. A haptic glove according to claim 3 or 4, wherein the brake part comprises a brake band wound at least partly around the reel.
6. A haptic glove according to claim 5, wherein a contact angle defining the region of contact between the brake band and the reel is greater than 90 degrees and/or less than 360 degrees.

7. A haptic glove according to any one of claims 2 to 6, wherein the brake mechanism comprises a resilient element coupling the at least one SMA wire to the brake part, wherein the at least one SMA wire is arranged to deform the resilient element, thereby adjusting the normal force between the brake part and the movable part.
8. A haptic glove according to claim 7, wherein the resilient element is a compression or tension spring or a flexure.
9. A haptic glove according to any one of claims 2 to 8, wherein the brake mechanism comprises a force amplification mechanism for amplifying variations in tension in the SMA wire to a greater variation in force applied to the brake part.
10. A haptic glove according to claim 9, wherein the force amplification mechanism comprises a lever arm.
11. A haptic glove according to any preceding claim, wherein the at least one SMA wire is arranged, on contraction, to vary the frictional force within a continuous range.
12. A haptic glove according to any one of claims 1 to 10, wherein the at least one SMA wire is arranged, on contraction, to vary the frictional force between a plurality of discrete levels.
13. A haptic glove according to any one of claims 1 to 10 or 12, wherein the brake mechanism comprises a multi-stage latch.
14. A haptic glove according to claim 13, wherein the multi-stage latch comprises a latch part, and the SMA wire is arranged to move the latch part from an unlatched position to a selected one of multiple discrete positions so as to apply a selected one of multiple discrete levels of frictional force to the cable.
15. A haptic glove according to claim 13 or 14, wherein the latch part comprises a release SMA wire arranged, on contraction, to release the latch part from the multiple discrete positions into an unlatched position.

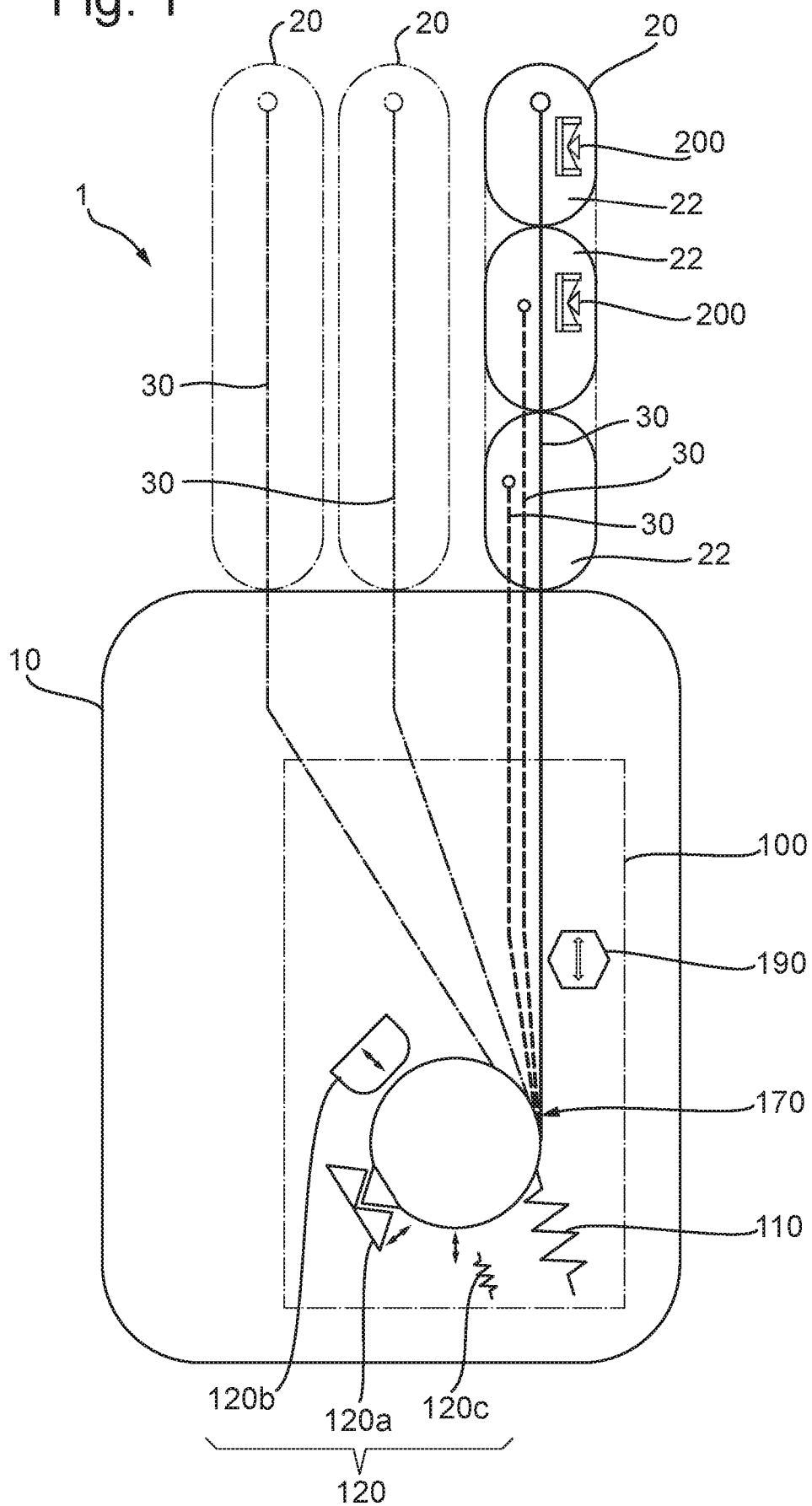
16. A haptic glove according to any one of the preceding claims, wherein the brake mechanism is arranged to maintain a constant frictional force upon ceasing energization of the at least one SMA wire.

17. A haptic glove according to any one of the preceding claims, wherein the brake mechanism comprises a holding mechanism for keeping the end of the SMA wire acting on the brake part in place, upon ceasing energization of the at least one SMA wire.

18. A haptic glove according to claim 17, wherein the holding mechanism comprises a resilient holding element arranged to bias the holding mechanism so as to resist movement of the brake part.

19. A haptic glove according to claim 17 or 18, wherein the holding mechanism comprises a holding SMA wire arranged, on contraction, to release the holding mechanism so as to allow movement of the brake part.

Fig. 1



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Fig. 2A

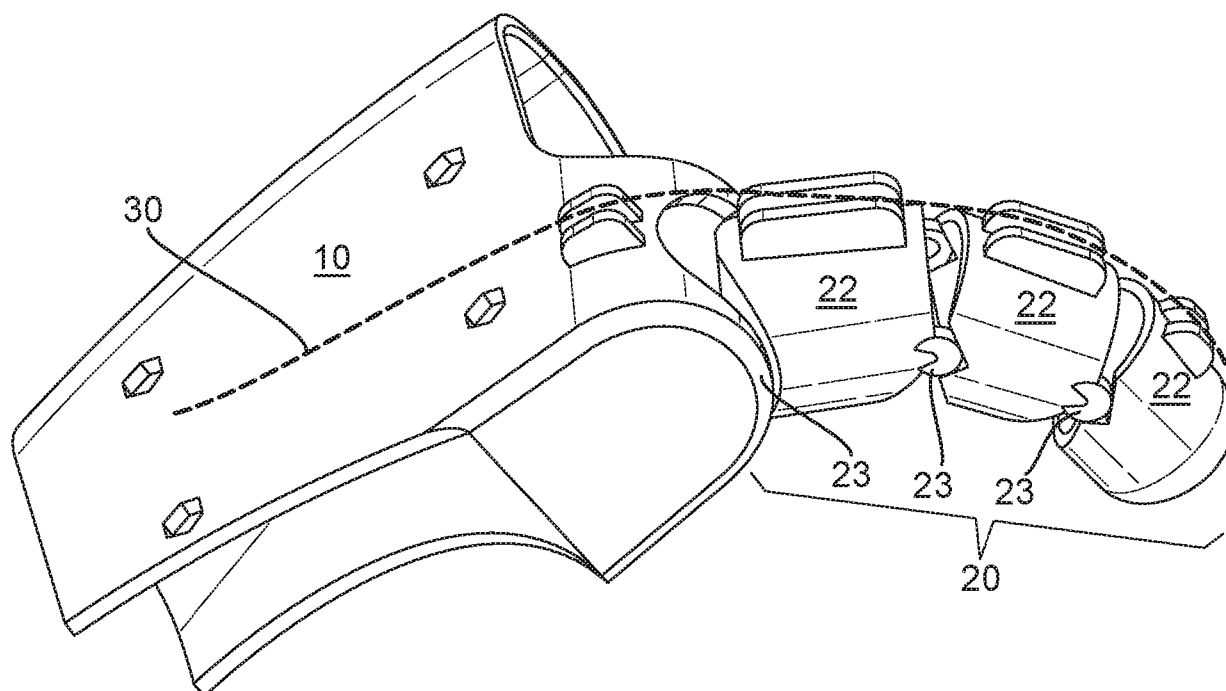
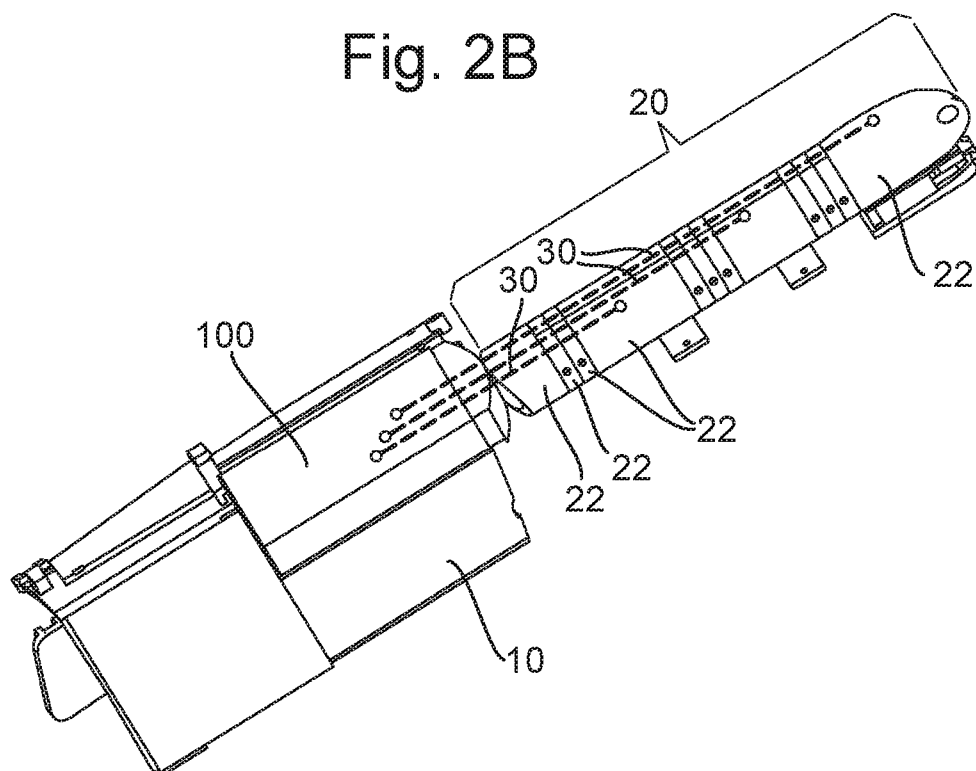


Fig. 2B



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Fig. 3A

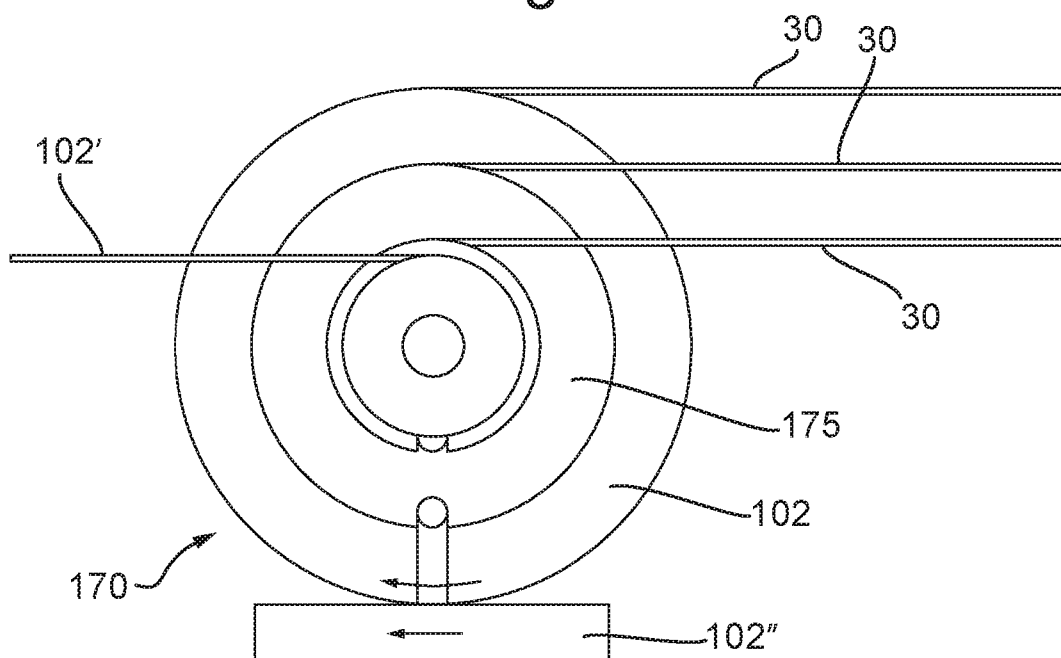


Fig. 3B

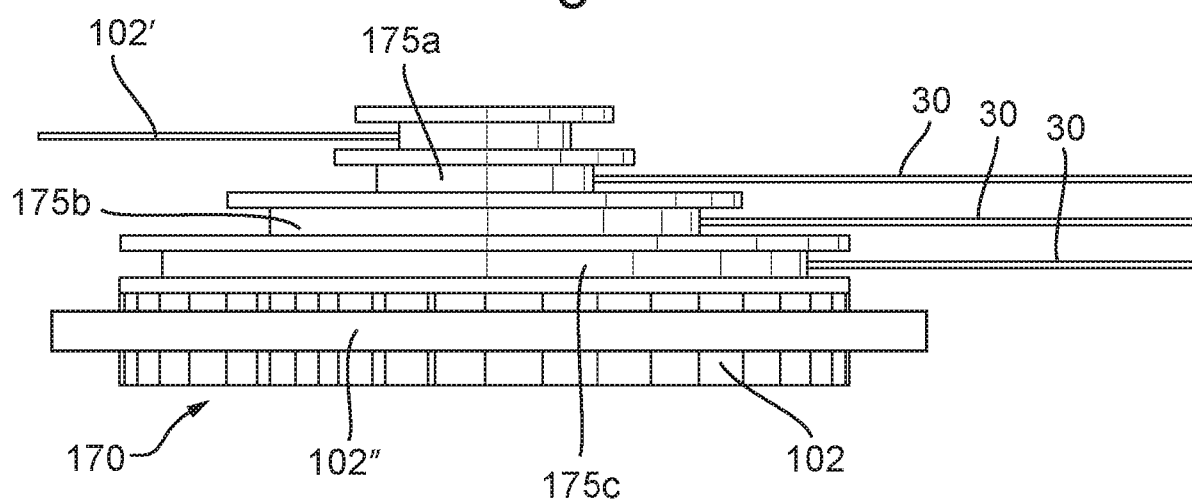
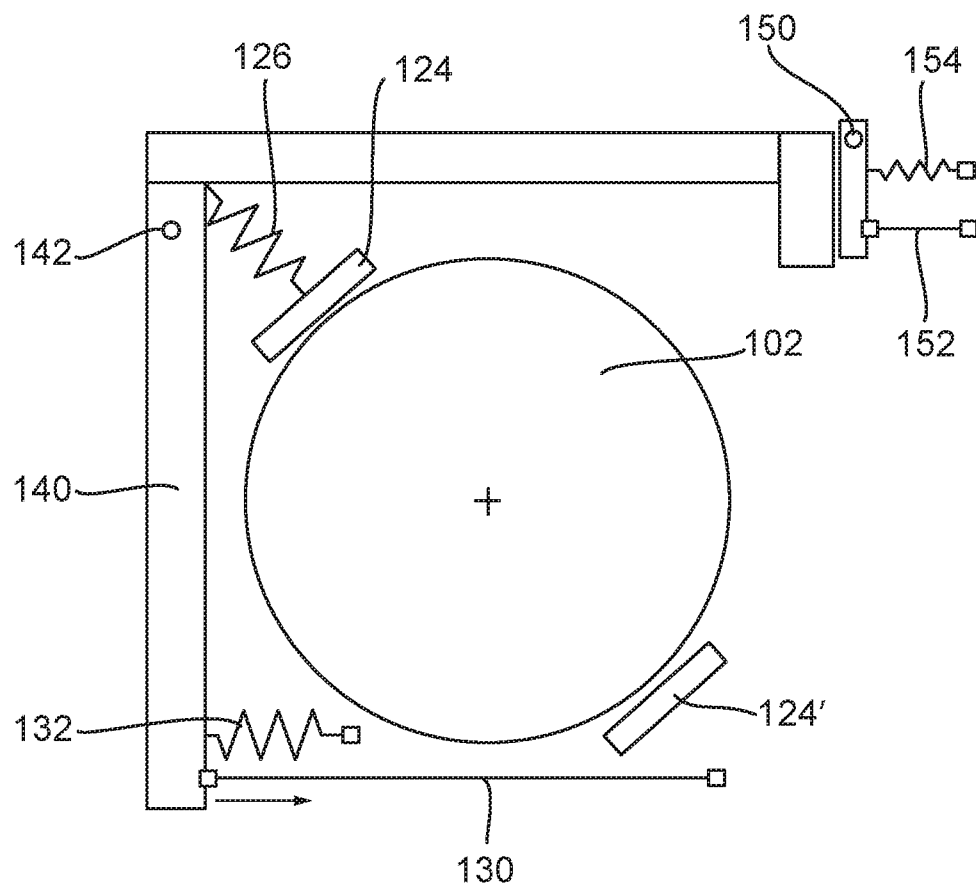


Fig. 4



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Fig. 5A

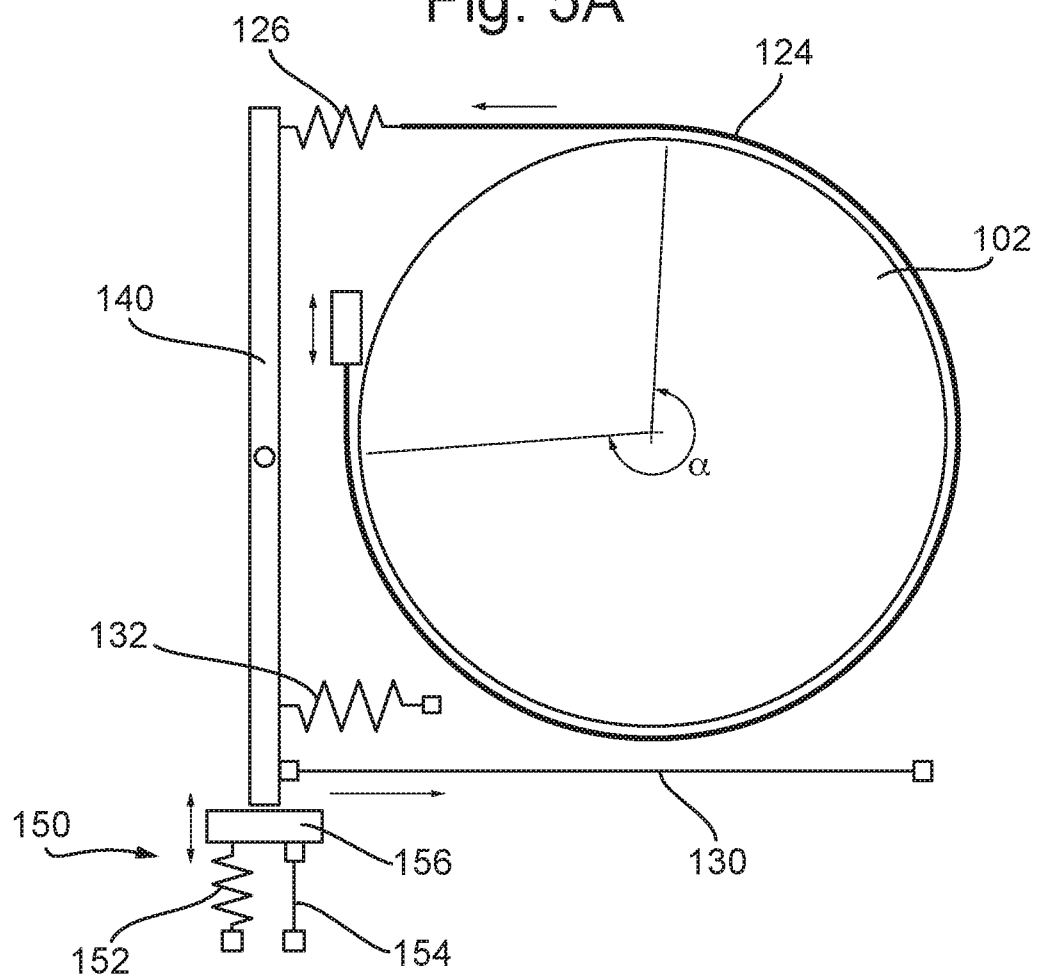
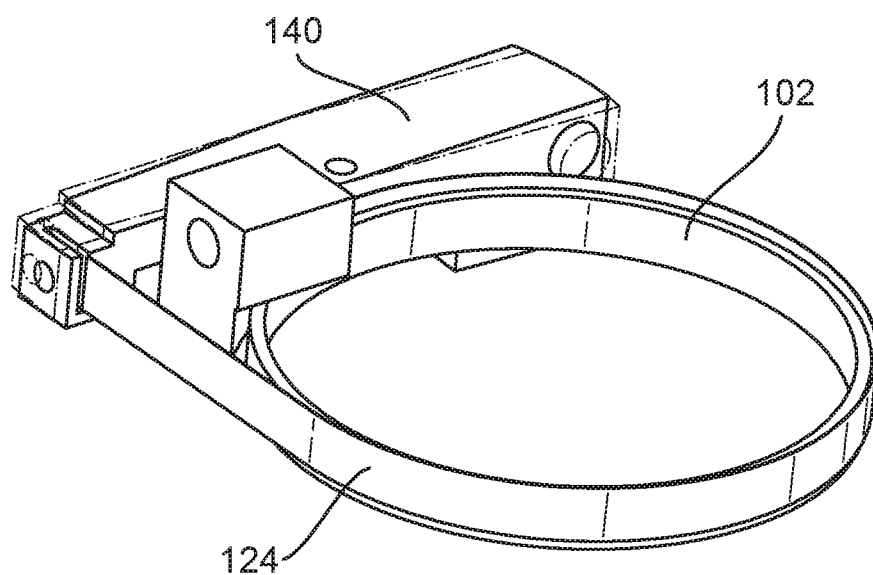


Fig. 5B



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Fig. 6

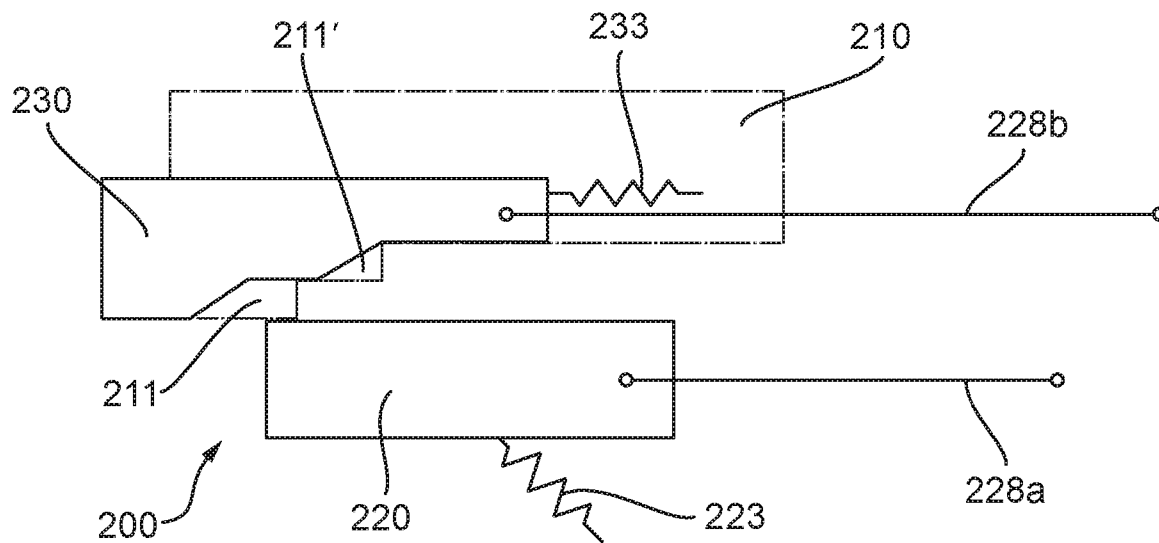
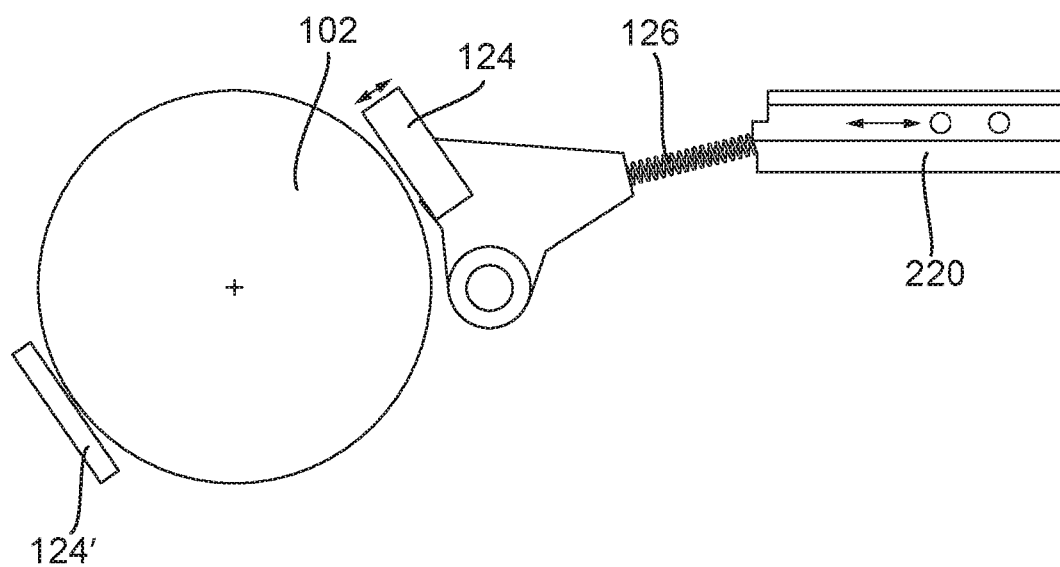


Fig. 7



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Fig. 8A

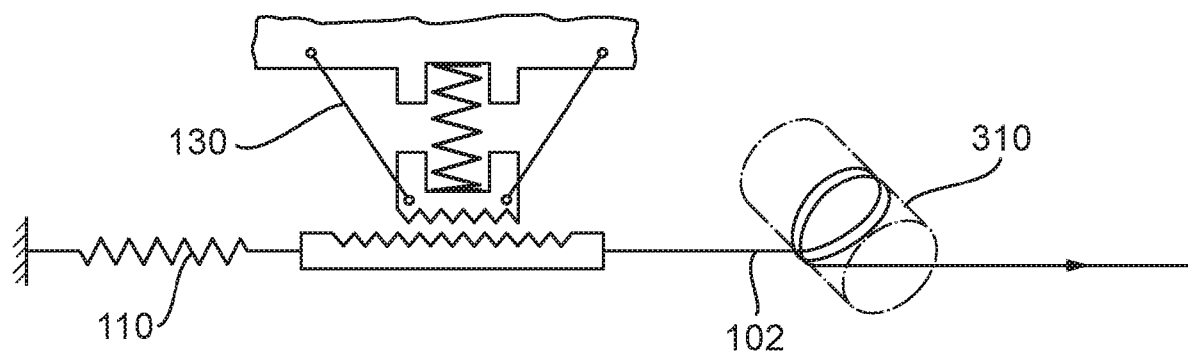


Fig. 8B

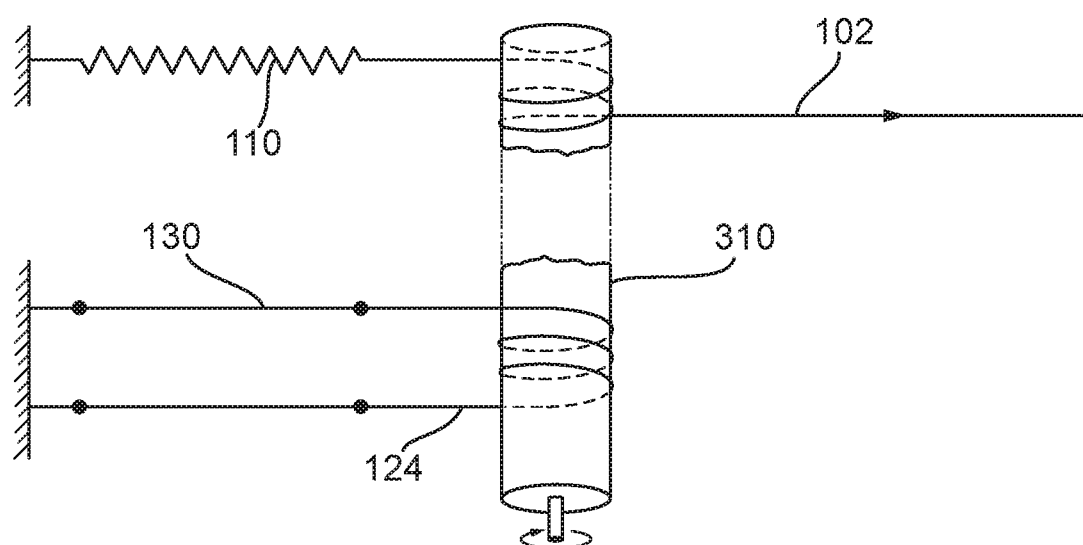


Fig. 8C

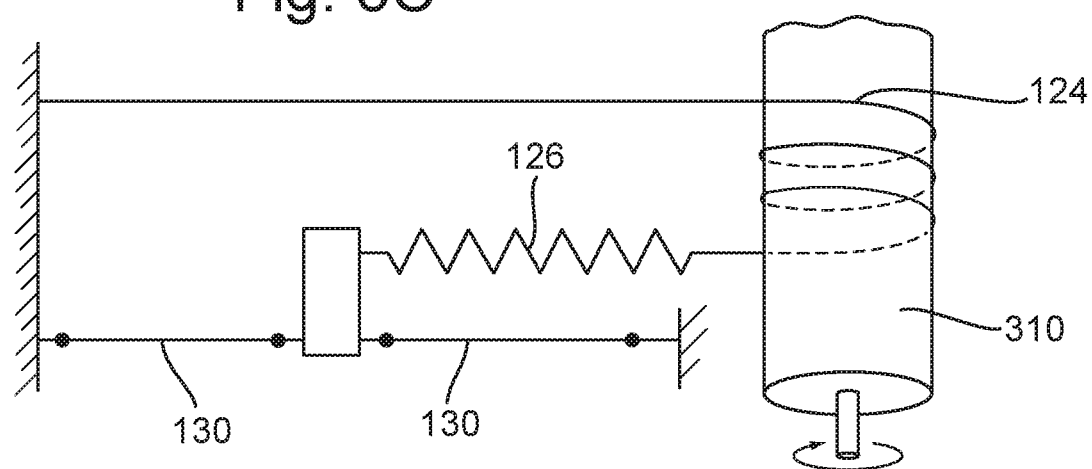


Fig. 9A

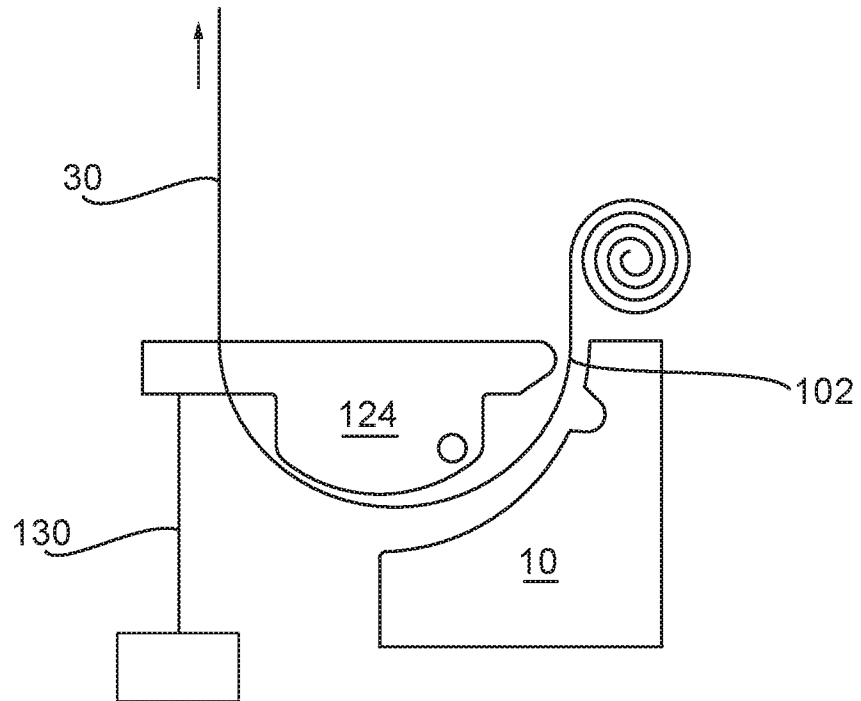
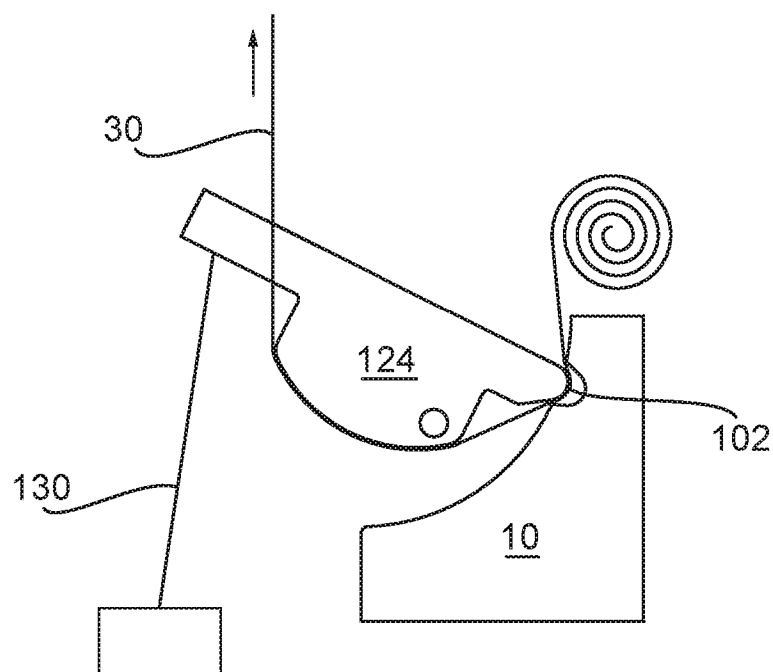


Fig. 9B



INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2022/050934

A. CLASSIFICATION OF SUBJECT MATTER**INV. G06F3/01****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)

G06F

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**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 126 373 A (YEE ALBERT G [US] ET AL) 3 October 2000 (2000-10-03) column 5, line 52 - line 62; figure 1 column 6, line 25 - line 37 column 6, line 47 - line 60; figure 2a column 8, line 41 - line 54 column 13, line 29 - line 54; figure 5c column 4, line 12 - line 23; figures 5a-c -----	1-3,5-19
X	WO 2021/021856 A1 (BRAVE VIRTUAL WORLDS LLC [US]) 4 February 2021 (2021-02-04) paragraph [0069] paragraph [0073] paragraph [0080] ----- -/--	1-3,5-19



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

8 July 2022

Date of mailing of the international search report

12/09/2022

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2

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Authorized officer

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INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2022/050934

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2001/043847 A1 (KRAMER JAMES F [US]) 22 November 2001 (2001-11-22) paragraph [0016] paragraph [0075] - paragraph [0076]; figures 2a,b paragraph [0114] -----	1-3, 5-19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2022/050934

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:
2, 3, 5-19 (completely); 1 (partially)

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 2, 3, 5-19(completely); 1(partially)

How to adjust the frictional force by using the SMA wire to adjust the normal force between a break part and a movable part.

2. claims: 4(completely); 1(partially)

How to move different segments of the same finger proportionally relative to each other (see p. 10-11) by using a multi-diameter reel having wound different cables around reel portions with different diameters.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2022/050934

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 6126373	A	03-10-2000	NONE	
WO 2021021856	A1	04-02-2021	US 2021030613 A1	04-02-2021
			WO 2021021856 A1	04-02-2021
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			US 2001043847 A1	22-11-2001
			US 2006115348 A1	01-06-2006