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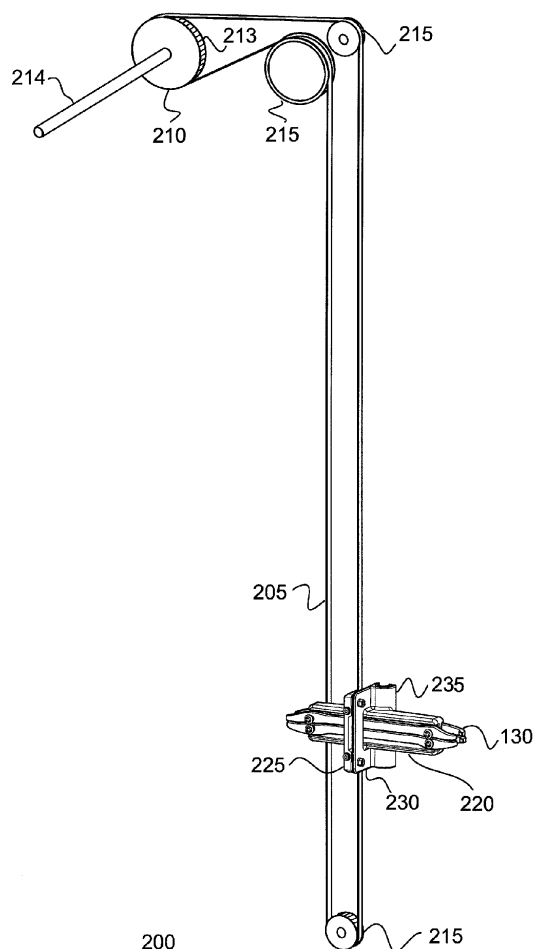
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(54) **Tap changer**

(57) A tap changer is disclosed which comprises a set of fixed contacts, each fixed contact arranged to be connected to a tap of the regulating winding; at least one current collector located at a distance from the set of fixed contacts so that a contact gap space is formed therebetween; and at least one contact carrier including at least one moveable contact arranged to electrically bridge a contact gap between a current collector and a fixed contact. The tap changer further comprises a drive system for moving the contact carrier from one fixed contact position to another. The drive system includes at least one electrically insulating, mechanically flexible positioning loop provided with a plurality of evenly distributed positioning items. The positioning loop is attached to the contact carrier in order to allow for transmission of a driving force thereto.

**Fig. 2a**



## Description

### Technical field

**[0001]** The present invention relates the field of power transmission, and in particular to tap changers for controlling the output voltage of a transformer.

### Background

**[0002]** Tap changers are used for controlling the output voltage of a transformer by providing the possibility of switching in, or switching out, additional turns in a transformer winding. A tap changer comprises a set of fixed contacts, each of which is connectable to a different tap of a regulating winding of a transformer, where the taps are located at different positions in the regulating winding. A tap changer further comprises a moveable contact which is connected to a current collector at one end, and connectable to one of the fixed contacts at the other end. By switching in or out the different taps, the effective number of turns of the transformer can be increased or decreased, thus regulating the output voltage of the transformer. A tap changer thus includes various parts at different electrical potentials. In order to satisfy insulation requirements, the distance between such two such parts should exceed a distance over which the insulation medium, in which the tap changer is immersed, can withstand the maximum expected potential difference between the two parts. The higher the voltage rating of the tap changer, the larger will the insulation distances be for the same insulation medium. Furthermore, the insulation distances vary between different insulation media. In dry tap changers, which are insulated by means of air, the insulation distances are approximately one order of magnitude larger than in conventional oil insulated tap changers. Thus, air insulated tap changers for use in high voltage applications tend to be very large, and therefore space-consuming and unwieldy to handle.

### Summary

**[0003]** A problem to which the present invention relates is how to obtain a compact design of a tap changer.

**[0004]** One embodiment provides a tap changer for connection to a regulating winding of a transformer. The tap changer comprises a tap selector including: a set of fixed contacts comprising at least two fixed contacts, each arranged to be connected to a tap of the regulating winding; at least one current collector located at a distance from the set of fixed contacts so that a contact gap space is formed therebetween; and at least one contact carrier including at least one moveable contact arranged to electrically bridge a contact gap between a current collector and a fixed contact. The tap changer further comprises a drive system for moving the at least one contact carrier from one fixed contact position to another, where the drive system comprising at least one electri-

cally insulating, mechanically flexible positioning loop provided with a plurality of evenly distributed positioning items. The positioning loop is attached to the contact carrier in order to allow for transmission of a driving force thereto.

**[0005]** By use of an electrically insulating and mechanically flexible positioning loop, a compact design of the tap changer can be achieved. Such positioning loop allows for a design where the contact gap is determined by the insulation distance required between the fixed contacts and the current collector, thus allowing for a compact design in the contact gap direction. Furthermore, a compact design in the extension direction is also facilitated, since the drive system is confined to the same space regardless of at which fixed contact position the moveable contact is currently located.

**[0006]** The positioning loop can advantageously be at least partly located in the contact gap space. A mechanically advantageous design of the drive mechanism can hereby be achieved, and since the positioning loop is electrically insulating, the minimum requirements on the contact gap will not be effected. In one embodiment, a point of mechanical connection of the positioning loop to the contact carrier is located within a distance of  $[0.2d_{\text{gap}}; 0.8d_{\text{gap}}]$  from the current collector in the contact gap direction. Hereby is achieved that the influence on forces acting on the moveable contact will be small. In one implementation, the point of mechanical connection is located within a distance of  $[0.45d_{\text{gap}}; 0.55d_{\text{gap}}]$ , in order to improve the mechanical advantage in relation to forces acting on the ends of the moveable contact.

**[0007]** The positioning loop could be implemented as a timing belt, having evenly distributed positioning items formed as integral teeth, holes or protrusions. The positioning loop could alternatively be implemented as a chain.

**[0008]** The drive system advantageously further comprises at least one drive wheel the periphery of which is provided with evenly distributed positioning items arranged to interact with the positioning items of the positioning loop, so that upon rotation of the drive wheel, the contact carrier will perform a linear movement.

**[0009]** In order to obtain a time-independent relation between the rotation of a drive wheel and the linear movement of the moveable contact, the positioning loop can advantageously be formed from an electrically insulating material which is expected to experience, during its lifetime, a mechanical crimpage/elongation in the range of  $\pm 1\%$  due to temperature changes, moisture changes and mechanical creep. The electrically insulating material could for example be a polymer-composite comprising a liquid crystal polymer or a para-aramid synthetic material.

**[0010]** In order to ensure a pre-defined relation between the rotation of a drive wheel and the linear movement of the moveable contact, the positioning loop can pre-stressed so that the initial pre-stressed elongation of the positioning loop is larger than the largest expected

sum of the mechanical creep elongation, the change in the length of the positioning loop due to thermal expansion and the change in the positioning loop due to moisture elongation, in order to ensure a tension in the positioning loop throughout its lifetime.

**[0011]** In one embodiment, the drive system comprises a wheel the centre of which may be adjusted in order to adjust the length of the positioning loop. Hereby is achieved that a suitable pre-stress can be applied to the positioning loop, ensuring that there will be a tension in the positioning loop throughout its lifetime, allowing for example for flow of time, for temperature changes, and for changes in moisture content.

**[0012]** In order to facilitate for the application of a pre-stress to a positioning loop made from an elastic material, the spacing of the positioning items of driving wheel exceeds the spacing of the corresponding positioning items of the positioning loop. In one implementation, the ratio of the spacing of the positioning items of the driving wheel to those of the positioning loop falls within the range of [1.0005; 1.006].

**[0013]** The drive system can further comprise an electrically insulating linear guide located in the contact gap space for mechanically guiding the movement of the contact carrier. The contact carrier could for example have a guiding part arranged to follow the linear guide.

**[0014]** The tap changer could comprise a clamp for mechanically connecting the positioning loop to the contact carrier, wherein the clamp and/or the contact carrier is provided with at least one positioning item to mesh with at least one corresponding positioning item of the positioning loop.

**[0015]** Further aspects of the invention are set out in the following detailed description and in the accompanying claims.

### **Brief description of the drawings**

#### **[0016]**

- Fig. 1a is a schematic illustration of a tap changer.
- Fig. 1b is a sectional view of a contact gap space of a tap selector as seen from along the extension direction of the tap changer.
- Fig. 1c is a sectional view of a compact contact gap space of a tap selector as seen from along the extension direction of the tap changer.
- Fig. 2a is an illustration of an example of a drive system for providing movement to a moveable contact, where the drive system comprises a mechanically flexible positioning loop.

- Figs. 2b-d schematically illustrate different drive system configurations, each providing an alternative path for the positioning loop.
- 5 Figs. 3a-3d illustrate different embodiments of a positioning loop.
- Fig. 4a shows attachment means for connecting a positioning loop to a moveable contact.
- 10 Fig. 4b shows an example of a clamp for attaching a positioning loop to a contact carrier.
- Fig. 4c shows another example of a clamp for attaching a positioning loop to a contact carrier.
- 15 Fig. 5a shows circular length adjustment mechanism for adjusting the length of the positioning loop.
- 20 Fig. 5b shows linear length adjustment mechanism for adjusting the length of the positioning loop.
- 25 Fig. 6 shows the molecule structure of Vectran®, a material which could be used for cords in a polymer-cord composite from which a positioning loop may be formed.
- 30 Fig. 7 shows an example of a tap selector wherein the drive system for moving the moveable contact comprises an insulating positioning loop.
- 35

### **Detailed description**

**[0017]** Fig. 1a schematically illustrates a tap changer 100 which is connected to a regulating winding 105 having a set of different taps 110. The tap changer of Fig. 1a is of diverter switch type, and comprises a diverter switch 115 and a tap selector 120. The tap selector 120 of Fig. 1a comprises two current collectors 125, two moveable contacts 130 and a set of fixed contacts 135, where each fixed contact 135 is arranged to be connected to one of the taps 110 of the regulating winding. A moveable contact 130 is arranged to electrically bridge a contact gap between a current collector 125 and a fixed contact 135. The tap changer 100 of Fig. 1a is mechanically linear in the sense that the current collectors 125 are implemented as linear rods, and the fixed contacts 135 are arranged in a linear fashion. In the following, the term linear tap changer should be construed as a mechanically linear tap changer, unless stated otherwise. The two current collectors 125 together form a current collector part. In a tap changer 100 having a single current collector 125, the current collector part is formed by the single current collector 125, etc. The following description will,

for illustrative purposes only, be made in terms of a tap changer having two current collectors 125 and two moveable contacts 130. The invention is however equally applicable to a tap changer having a different number of current collectors 125 and/or moveable contacts 130, such as a single current collector 125, three current collectors 125, etc.

**[0018]** The diverter switch 115 of Fig. 1a comprises two series connections of a main contact 140 and a transition contact 145, with a transition resistor 150 connected in parallel with the transition contact 145. Each of the series connections are, at one end, connected to a respective one of the two current collectors 125, and, at the other end, connected to an external contact 155 of the tap changer 100.

**[0019]** The two moveable contacts 130 are, at one end, in electrical contact with a respective one of the current collectors 125. A moveable contact 130 can move along the current collector 125 to which it is connected, in order to reach different positions at which the other end of the moveable contact 130 is in electrical contact with one of the fixed contacts 135. The moveable contacts 130 could for example be sliding contacts arranged to slide along the current collectors 125, to allow for electrical connection between the current collectors 125 and the different fixed contacts 135. The driving of the moveable contacts 130 of Fig. 1a is arranged so that if one of the moveable contacts 130 is in contact with a fixed contact 135, connected to a first tap, the other moveable contact 130 is in contact with a second fixed contact 135, adjacent to the first tap and connected to a second tap 110.

**[0020]** By switching of the main contacts 140 and transition contacts 145 in a conventional manner, one or the other of the moveable contacts 130 will be in electrical contact with the external contact 155, and thus provide an electrical path through the tap changer 100. Hence, the two current collectors 125 will take turns at being part of the electrical path through the tap changer 100. The electrical path through the tap changer 100 ends at the external contact 155 at one end, and at the other end at the fixed contact 135 which is currently connected to the regulating winding 105. At the other end of the regulating winding 105 is provided a further contact 175, so that a path is provided through the tap changer 100 and the regulating winding 105 between contacts 155 and 175. An example of a diverter switch 115 is described in EP0116748. The diverter switch 115 of Fig. 1a is an example only, and any suitable type of diverter switch 115 can be used.

**[0021]** When the tap changer 100 is in use, the different fixed contacts 135 will be at different potential levels, corresponding to the different potential levels of the different taps 110 of the regulating winding 105. Thus, the potential difference between the current collectors 125 will correspond to the potential difference between two adjacent taps 110,  $U_{adj}$ .  $U_{adj}$  is typically constant throughout the regulating winding 105. Only one fixed contact 135 at a time will be connected, via the moveable contact 130, to

the current collector 125 which is currently connected to the external connection 155 of the tap changer, this fixed contact 135 being referred to as the connected fixed contact 135.

**[0022]** The potential difference between a current collector 125 and a particular fixed contact 135 varies depending on at which position the moveable contact 130 is connected, and could be considerably larger than the potential difference between two adjacent fixed contacts 135. In a linear tap changer 100, the maximum potential difference between a current collector 125 and a fixed contact 135 occurs when one of the end fixed contacts 135, denoted 135e in Fig. 1a, are connected and forms part of the current path through the tap changer 100. In this case, the potential difference between the current collector 125 that is connected, and the end fixed contact 135e which is not connected, corresponds to the entire voltage across the regulating winding 100,  $U_{reg}$ .  $U_{reg}$ , also referred to as the regulation voltage, is illustrated in Fig. 1a by arrow 170.

**[0023]** In order to prevent flashover within the tap changer 100 when in use, the distances between two parts at different potential should reach or exceed the minimum distance over which the medium, in which the tap changer 100 is immersed, can withstand the voltage obtained between the two parts. Such insulation distances depend on the medium surrounding the tap selector 120, and increase with increasing rated regulation voltage (which typically depends on the rated voltage of the transformer as well as on the desired number of taps 110). The particular regulation voltage used for defining the insulation distances is often a test voltage and are one of the parameters for which the tap changer 100 is rated.

**[0024]** Two insulation distances which are often of particular interest are the required insulation distance between adjacent fixed contacts 135, this distance referred

to as the adjacent contact insulation distance,  $d_{adj}^{insul}$ , as well as the distance between a current collector 125 and the fixed contacts 135, this distance referred to as the

contact gap insulation distance,  $d_{gap}^{insul}$ . The contact gap

insulation distance  $d_{gap}^{insul}$  typically varies along the

length of the tap changer 100, so that  $d_{gap}^{insul} = d_{gap}^{insul}(y)$ ,

where  $y$  denotes a position along the length of the tap changer, since the largest possible potential difference between the current collectors 125 and the fixed contacts 135 can occur at the end fixed contacts 135e - the nearer the centre of the arrangement of fixed contact(s) 135, the smaller the maximum potential difference between the current collector 125 and the fixed contacts 135. The direction  $y$  as indicated by the coordinate system in Fig. 1a, in which direction the current collectors 125 extend,

will in the following be referred to as the extension direction of the linear tap changer 100.

**[0025]** The actual distance between two adjacent fixed contacts 135 will hereinafter be referred to as the adjacent contact distance,  $d_{adj}$ , while the actual distance between a current collector 125 and the fixed contacts 135 will be referred to as the contact gap,  $d_{gap}$ . In order to prevent flashover in the tap changer,  $d_{adj}$  should reach

or exceed  $d_{adj}^{insul}$ , while  $d_{gap}$  should reach or exceed

$d_{gap}^{insul}$ . If any further electrically conducting parts are present in the space formed between the current collector 125 and the arrangement of fixed contacts 135, the contact gap  $d_{gap}$  will often have to be increased. This is for example the case when the moveable contact 130 is connected to a metallic drive mechanism for providing a force required to move the moveable contact 130 between different fixed contact positions. In this case, the distance between the fixed contacts 135 and such drive mechanism, as well as the distance between the current collector(s) and such drive mechanism, should both reach or

exceed  $d_{gap}^{insul}$ .

**[0026]** The actual distances  $d_{adj}$  and  $d_{gap}$  of the tap changer of Fig. 1a have been indicated in the drawing. The contact gap  $d_{gap}$  in Fig. 1a is shown to be independent on position  $y$  along the extension direction. The contact gap  $d_{gap}$  should, when  $d_{gap}$  is independent on position, reach or exceed the maximum required insulation distance i.e. the insulation distance at the end fixed contacts 135e. In the following, the term insulation distance

$d_{gap}^{insul}$  will be used to refer to the maximum required insulation distance.

**[0027]** A space referred to as the contact gap space is defined by the current collectors 125 and the set of fixed contacts 135, in which space the electric field is to a large extent determined by the potential difference between the current collectors 125 and the fixed contacts 135. The contact gap space 165 is here defined as the space confined by i) an (imaginary) plane through the centers of the current collectors 125, if more than one; ii) an (imaginary) plane through the rows of fixed contacts 135, if more than one row; iii) a set of (imaginary) semi-cylinders parallel to the extension direction, each semi-circle having a radius corresponding to the contact gap space, where the center of a corresponding (full) cylinder coincides with the location of row of fixed contacts 135 or a current collector 125; iv) the "top" and "bottom" (imaginary) spherical surfaces having their centers at the end of the current collectors 125 and adjacent end fixed contacts 135e. A sectional view of the contact gap space 165 as seen from along the extension direction of the tap changer 100 is shown in Fig. 1b. A more compact version

of the contact gap space, referred to as the compact contact gap space 175, is shown in Fig. 1c. The compact contact gap space 175 is a sub-space of the contact gap space 165. The compact contact gap space 175 is defined for a tap changer 100 having two current collectors 125 or less as the space confined by the surfaces as defined in i), ii) and iv) above, as well as by v) (imaginary) semi-cylinders having a diameter corresponding to the contact gap, and the centers of which are located at the centre of the line interconnecting a current collector 125 with the corresponding fixed contact 135.

**[0028]** When only one current collector 125 is provided, the contact gap space 165 (and the compact contact gap space 175) will be smaller than if two or more current collectors 125 are provided. Unless the contact gap space 165 is shielded from external electric fields, the potential difference between the current collectors 125 and the fixed contacts 135 will typically further be influenced by the surrounding electrical fields, thus requiring a larger contact gap  $d_{gap}$ , and thereby a larger contact gap space, than if no external fields were present in the contact gap space 165.

**[0029]** In a tap changer 100 which is air insulated, the insulation distances need to be considerably larger than in an oil insulated tap changer 100. For example, in an air insulated tap changer 100 wherein an insulation distance is 30 cm, the corresponding insulation distance could typically be around 3 cm in an oil insulated tap changer. Thus, an air insulated tap changer 100 typically needs to be physically larger than if the tap changer 100 were insulated by means of oil. However, in many applications, air insulation is preferred over oil insulation, such as inside buildings, where the risk of fire should be minimized (e.g. in a skyscraper); or in environmentally sensitive areas, where the risk of contamination should be minimized. The term air insulated tap changer 100 should here be construed to include tap changers 100 which are insulated by air, or by air-like gases in a controlled space, such as tap changers 100 insulated by nitrogen gas ( $N_2$ ), tap changers 100 insulated by air at a controlled pressure, etc.

**[0030]** As mentioned above, the insulation distances of a tap changer depend on the voltage rating of the tap changer and the insulation medium. For higher voltage ratings, and in particular in high voltage dry tap changers being insulated by means of a gas, a conventional design of the tap changer may be impractical due to the size required in order to fulfill the insulation requirements. Hence, a more compact design of a tap changer is desired.

**[0031]** According to the invention, a tap changer is provided having a drive system for moving the moveable contact(s) from one fixed contact position to another, where the drive system comprises an electrically insulating, mechanically flexible, positioning loop. The positioning loop is mechanically connected to the moveable contact for transmission of a driving force thereto.

**[0032]** By providing a drive system which comprises

an electrically insulating and mechanically flexible positioning loop, a compact design of the tap changer 100 is achieved.

**[0033]** Alternative designs of a drive system for providing the force for moving a moveable contact 130 include a metallic ball screw as described in CN2879373 or a Geneva rod as described in US4,562,316. Compared to a metallic ball screw which, if located in the contact gap space would drastically increase the required contact gap, the inventive drive system facilitates for a considerably more compact design in the direction of the contact gap, since no flashover will occur to the insulating positioning loop. Thus, by use of an electrically insulating and mechanically flexible positioning loop, the contact gap can be set at approximately the contact gap insula-

tion distance  $d_{\text{gap}}^{\text{insul}}$ , even if the positioning loop is located in the contact gap space 165 (it may still be desir-

able to use a contact gap which exceeds  $d_{\text{gap}}^{\text{insul}}$ , for example in order to ensure adequate insulation even when the electric field within the contact gap space 165 is influenced by external electric fields). Furthermore, compared to a Geneva rod, the inventive drive mechanism facilitates for a considerably more compact design in the extension direction of the tap selector 120 since the positioning loop, as opposed to the Geneva rod, will be confined to the same space, regardless of at which fixed contact position the moveable contact 130 is currently located.

**[0034]** An example of a drive system 200 comprising an electrically insulating and mechanically flexible positioning loop 205 is shown in **Fig. 2a**. The drive system 200 of **Fig. 2a** further comprises a driving wheel 210 arranged to mesh with the positioning loop 205 for driving thereof. The driving wheel 210 thus includes, on its periphery, a set of evenly distributed positioning items 213, to engage with corresponding positioning items 300 of the positioning loop (cf. **Figs. 3a-3d**). The driving wheel 210 is arranged to be driven by a shaft 214 which is connected to an electric motor via a gear box (not shown). The drive system 200 of **Fig. 2a** further comprises three pulleys 215. The pulleys 215, together with the driving wheel 210, define a path for the positioning loop 205.

**[0035]** The positioning loop 205 of **Fig. 2a** is mechanically connected to a contact carrier 220 via a clamp 225 for clamping the positioning loop 205 to the contact carrier 220. The contact carrier 220 of **Fig. 2a** is arranged to carry the moveable contact 130 and includes a flange 230 providing a counterpart to the clamp 225, facilitating for the clamping of the positioning loop 205 to the contact carrier 220. The positioning loop 205 of **Fig. 2a**, when brought to move by the driving wheel 210, thus transfers a force to the contact carrier 220 along the extension direction of the tap selector 120.

**[0036]** The contact carrier 220 of **Fig. 2a** further includes a guiding part 235 in the form of a circular tube

which is open along its axial direction, the guiding part 235 being arranged to run along a guiding rod of the tap changer 100 for appropriate guiding of the contact carrier 220 in the extension direction of the tap changer 100. A guiding part 235 of a contact carrier 220 could alternatively be of another shape, such as a closed tube, a hollow parallelepiped, etc. A guiding rod (not shown) of the tap changer 100 could advantageously be of a cross section which corresponds to the cross section of the guiding part 235. The design illustrated in **Fig. 2a** where the guiding part 235 and the flange 230 are integral parts of the contact carrier 220 is an example only, and alternative designs may be contemplated. For example, a separate guide 235 and/or a separate flange 230 attached to the contact carrier 220 could be provided; the flange 230 could be replaced by different means of attaching the positioning loop 205; etc. The positioning loop 205 could, in a simple embodiment, be directly attached to the moveable contact. In its simplest implementation, the contact carrier 220 could simply consist of one or more moveable contacts 130. However, for tap changers 100 having a larger number of fixed contact positions and larger isolation distances, a guide 235 would generally be advantageous.

**[0037]** The four wheels/pulleys of **Fig. 2a**, jointly referred to as wheels 210/215, together define a path for the positioning loop such that the path can provide a linear motion of the moveable contact 130 in the extension direction of the tap changer 100 in the region between the current collectors 125 and the set of fixed contacts 135. Such a path can be defined in many different ways by use of a different number of wheels 210/215, or by simply arranging the wheels 210/215 in a different manner. A suitable wheel configuration should comprise at least one driving wheel 210 and at least one pulley 215, where the distance between at least two of the wheels 210/215 define at least one linear path part of along the extension direction of the tap changer 100. Further examples of drive systems 200 of alternative wheel configurations defining a path having such linear part are schematically shown in **Figs. 2b-2d**. The drive system 200 of **Fig. 2b** comprises one driving wheel 210 and one pulley 215; the drive system 200 of **Fig. 2c** comprises one driving wheel 210 and two pulleys 215; while the drive system 200 of **Fig. 2d** comprises one driving wheel 210 and four pulleys 215. Depending on the design of the tap changer 100, a different wheel configuration may be advantageous. For example, in a design wherein the diverter switch 115 is located behind the current collectors 125 as seen from the fixed contacts 135, the configuration shown in **Fig. 2a** would be beneficial. In this configuration, the driving wheel 210 will not be part of forming the linear path part in the extension direction of the tap changer, but will be located in line with the diverter switch 115 in the y-direction. Thus, the same driving shaft 214 could be used for controlling the movement of the moveable contact 130 and for controlling the diverter switch 115, while the point of attachment between the positioning

loop 205 and the contact carrier 220 can be provided in the contact gap space 165. Furthermore, in many tap changer designs, a wheel configuration wherein a return path of the positioning loop 205 runs parallel to the part of the path which provides a linear movement of the moveable contact 130 is beneficial in order to save space (cf. Figs. 2a, 2b, 2d).

**[0038]** Which wheel 210/215 is the driving wheel 210 could e.g. be selected in accordance with the most favourable location of the driving shaft 214. The configurations shown in Figs. 2a-2d include a single driving wheel 210. In an alternative implementation, two or more driving wheels 210 could be employed.

**[0039]** In Figs. 3a-3d, different embodiments of a positioning loop 205 are shown (only part of a positioning loop 205 has been shown for illustration purposes). Each embodiment of the positioning loop 205 is provided with a plurality of evenly distributed positioning items 300, which positioning items are designed to mesh with corresponding positioning items 213 of a driving wheel 210 of the drive mechanism (cf. Fig. 2a) and thereby mechanically convey rotary movement of the wheel into linear movement of the moveable contact 130. The positioning loop 205 of **Fig. 3a** is a timing belt provided with evenly distributed integral teeth on the inside of the timing belt, so that the positioning loop can run along the circumference of a positioning wheel. These integral teeth are designed to mesh with a driving wheel 210 in the form of a sprocket having a corresponding toothing. The positioning loop 205 of **Fig. 3b** is also a timing belt which is provided with evenly distributed positioning items 300 in the form of integral teeth, designed to mesh with a sprocket, where the teeth are provided at the inside, as well as outside, of the timing belt. The positioning loop 205 of **Fig. 3c** is a timing belt which is provided with evenly distributed positioning items 300 in the form of circular holes, which are designed to mesh with a driving wheel 210 having evenly distributed cylindrical or part-spherical protrusions along its circumference. If desired, the holes could be of a different shape, such as elliptic, rectangular or triangular, designed to mesh with wheel protrusions of a corresponding shape. The positioning loop 205 of **Fig. 3d** is a string provided with evenly distributed positioning items 300 in the form of spherical beads, where a bead is designed to mesh with a corresponding positioning item in the form of a recess in the circumference of a driving wheel 210. Further embodiment of the positioning loop 205 may be contemplated. For example, the positioning loop 205 could be implemented as an insulating chain - for instance in the shape of a bicycle chain or similar, manufactured from an insulating material.

**[0040]** The circumference of a driving wheel 210 comprises a plurality of evenly distributed positioning items 213 for engaging with corresponding positioning items 300 of the positioning loop 205, such positioning items for example being teeth (the driving wheel 210 thus being a sprocket), protrusions or recesses. The circumference of the pulleys 215 could be smooth, or, if desired, the

circumference of one or more of the pulleys 215 could comprise a plurality of evenly distributed positioning items 213.

**[0041]** An example of an embodiment a contact carrier 220 and a clamp 225 for attaching the positioning loop 205 to the moveable contact 130 is schematically shown in **Fig. 4a**, where the contact carrier 220 includes a guiding part 235 for interacting with a guiding rod, as well as a flange 230 for interacting with the clamp 225. Either the clamp 225 and/or the flange 230 could furthermore advantageously be provided with positioning items 213 arranged to engage with the positioning items 300 of the positioning loop 205. Either the clamp 225 and/or the flange 230 could moreover be provided with a track 410 for receiving the positioning loop 205, in order to mechanically stabilize the positioning loop 205 in the direction perpendicular to the linear movement of the moveable contact 130 (i.e. perpendicular to the extension direction). The clamp 225 could for example be attached to the flange 230 by means knurling and a suitable screw arrangement. In order to facilitate for achieving an adjustment possibility of the location of the moveable contact 130 in relation to the fixed contact 135, the holes, through which the attachment screws 415 are to be inserted, may be of an elongated shape in one of the contact carrier 220 and the clamp 225, while the corresponding holes in the other of the contact carrier 220 and the clamp 405 are circular. The elongated shape could advantageously provide a play of half the distance between the positioning items 213 of the driving wheel 210, or more.

**[0042]** In **Fig. 4b**, an example of a clamp 225 is shown, where the clamp 225 is provided with positioning items 213 as well as a track 410 for receiving the positioning loop 205, the positioning items 213 being located in the track 410. In order to improve the attachment between the clamp 225 and the contact carrier 220, all or part of the surfaces 420, and/or all or part of the corresponding surfaces of the contact carrier 220 (flange 230), could be knurled. An alternative implementation of a clamp 225 is shown in **Fig. 4c**, where the clamp 225 comprises a surface provided with positioning items 213, which surface is provided with holes for receiving attachment screws 215. Thus, by this design, which is simpler than the design of the clamp 225 of Fig. 4c, holes will be required in the positioning loop 205 for the attachment screws. Typically, the clamp design shown in Fig. 4b is desirable, since holes through the positioning loop 205 may reduce the mechanical strength of the material.

**[0043]** In yet another implementation of the attachment of the positioning loop 205 to the contact carrier 220, no clamp is provided, but the positioning loop 205 is screwed directly onto the contact carrier 220.

**[0044]** The positioning loop 205 could be a closed loop which is attached to the contact carrier 220, or could be an open piece of belt/band/string/etc., which is formed into a loop and attached to the contact carrier 220.

**[0045]** By use of the positioning loop, the correspond-

ence between the rotation of the driving wheel 210 and the transportation of the moveable contact 130 along the extension direction of the tap changer will be well defined. By rotating the driving wheel 210 through a certain angle, determined by the relationship between the radius of the driving wheel and the distance between two adjacent fixed contacts 135, the moveable contact 130 will move from one fixed contact position to an adjacent fixed contact position. The use of a positioning loop 205 for the transfer of a force from a rotating shaft 214 to the moveable contact 130 provides a flexible solution as to the angle of rotation required for obtaining a movement of the moveable contact 130 between two adjacent fixed contact positions-the certain angle for obtaining this movement will be determined by the ratio between the radius of the driving wheel 210,  $R$ , and the distance between adjacent fixed contacts 135,  $d_{adj}$ . A certain angle of rotation for obtaining movement between two adjacent fixed contacts 135 can thus be obtained by a design having the required ratio between  $R$  and  $d_{adj}$ .

**[0046]** In addition to participating in the transmission of a movement from the shaft 214 to the positioning loop 205 and thereby to the moveable contact 130, the wheel configuration comprising at least one driving wheel 210 and at least one pulley 215 operates to keep the positioning loop 205 in the desired position. In order to ensure correct operation of the tap changer 100, it is important that the predetermined relationship between rotary movement of the driving wheel and the linear movement of the moveable contact 130 applies at all times. Hence, any slipping between the driving wheel 210 and the positioning loop 205 should be avoided. Such slipping can be avoided by keeping the positioning loop 205 stretched.

**[0047]** The length of the positioning loop 205 will typically depend on time (through mechanical creep), on temperature and on the moisture content of the positioning loop 205. When arranged in the path defined by the wheels 210/215, the length of the positioning loop 205 will typically depend on the temperature expansion of a structure which keeps the wheels 210/215 in position, as well as on the temperature expansion of the positioning loop itself.

**[0048]** In order to be in control of the length of the positioning loop 205, so that the predetermined relationship between rotary movement of the driving wheel and the linear movement of the moveable contact 130 does not vary when the temperature and/or the moisture content changes, the positioning loop 205 could advantageously be pre-stressed before the tap changer 100 is used for the first time. The positioning loop 205 could advantageously be pre-stressed so that the initial pre-stressed elongation of the loop is larger than the largest expected sum of the mechanical creep elongation, the change in the length of the positioning loop due to thermal expansion and the change in the positioning loop due to moisture elongation. In this way, the positioning loop 205 can be expected to stay stretched at all times, thus avoiding a slacking positioning loop 205 (the stress in the loop

may on the other hand vary over time). A well-defined relationship between the angle of rotation of the driving wheel 210 and the obtained movement of the moveable contact 130 can thus be obtained.

**[0049]** In order to achieve such well-defined relationship, the spacing  $d_{300}$  of the positioning items 300 of the positioning loop 205 could advantageously be slightly smaller than the spacing  $d_{213}$  of the corresponding positioning items 213 of the driving wheel 210 and the clamp 225 (and of the pulleys 215, when applicable), so that by initially stretching of the positioning loop 210, the spacing  $d_{300}$  of the position loop positioning items 300 can be made to coincide with the spacing  $d_{213}$  of the corresponding positioning items 213. An optimal ratio of  $d_{213}$  to  $d_{300}$ ,

$d_{213}$

$d_{300}$ , will typically depend on the creep properties of the material from which the positioning loop 205 is formed.

**[0050]** In one embodiment of the wheel configuration, at least one of the wheels 210/215 is arranged so that the position of the centre of the wheel 210/215 can be adjusted, thereby allowing for the adjustment of the length of the positioning loop 205. The position of the centre of the other wheels will typically be fixed. A wheel 210/215, the centre of which can be adjusted, will in the following be referred to as an adjustable wheel. In principle, a length adjustment mechanism could be implemented either at a drive wheel 210 or at a pulley 215, although it is often best implemented in relation to a pulley 215 rather than a driving wheel 210, since the location of the centre of the driving wheel 210 should correspond to the location of the transmission shaft 214.

**[0051]** Adjustability of a wheel 210/215 could be implemented by use of suitable assembly tools upon installation of the tap changer 100, or by means of an integrated length adjustment mechanism, examples of which are shown below in Figs. 5a and 5b. The position of the wheel can thus be adjusted to achieve a desired length of the positioning loop 205. In other words, a length adjustment mechanism operates to obtain a desired elongation rather than a desired force on the positioning loop 205.

**[0052]** The combination of a length adjustment mechanism and a smaller spacing of the positioning items 300 than the spacing of the corresponding positioning items 213 facilitates for simple installation of the drive system 200. Adjustment of the length of the positioning loop 205 can for example be performed in an iterative manner upon installation of the tap changer 100, until a desired spacing of the positioning items 300 of the positioning loop 205 has been obtained. Ideally, a material with a low creep coefficient would be desired, so that the part of the elongation due to creep will occur during installation of the tap changer, rather than when the tap changer 100 is in use. The initial pre-stressed elongation of the positioning loop 205 could for example be in the order of 0.05-0.5 %, although depending on the circumstances, a different elongation may be used.

**[0053]** A length adjustment mechanism could for example operate to provide a circular or a linear displacement of an adjustable wheel. An example of a circular length adjustment mechanism 500 is shown in Fig. 5a, while a linear length adjustment mechanism 500 is shown in Fig. 5b. The circular adjustment mechanism 500 of **Fig. 5a** is an eccentric, which comprises a cylindrical plug 505 having a shaft 510 arranged to accept the wheel 210/215 at a location which is offset from the center of the plug 505, so that by rotating the plug 505, the location of the wheel (and hence the elongation of the positioning loop 215) may be adjusted. The eccentric 500 further includes screws (not shown), by means of which the plug 505 can be fixed in place when the location of the wheel 210/215 has been adjusted. Ball bearings

**[0054]** The linear adjustment mechanism 500 of **Fig. 5b** comprises a shaft 510 arranged to accept the wheel 210/215, where the shaft 510 is arranged on a guide 515 which is linearly movable within a guide holder 520. The linear adjustment mechanism 500 further includes screws (not shown), by means of which the plate 515 can be fixed in place when the location of the wheel has been adjusted.

**[0055]** By use of a driving system 200 which comprises an electrically insulating and mechanically flexible positioning loop 205, part or whole of the positioning loop 205 can be located in the contact gap space 165 as defined in relation to Fig. 1b, without influencing the electric field distribution in the contact gap space 165. For example, a part of the positioning loop path which defines a straight path, for the contact carrier 220 to move along, could be located in the contact gap space 165. Thus, the point of the attachment between the drive system 200 and the contact carrier 220 can be located in the contact gap space 165 without having to extend the contact gap  $d_{\text{gap}}$

beyond the contact gap insulation distance,  $d_{\text{gap}}^{\text{insul}}$ . By placing the point of attachment between the drive system 200 and the contact carrier 220 in the contact gap space 165, a direct transfer of the force from the driving wheel 210 to the contact carrier 220 along the extension direction of the tap changer 100 can be achieved. An example of such a drive system 200 is shown below in Fig. 7. For mechanical purposes, it will often be advantageous to place at least part of the positioning loop 205 in the compact contact space 175 as defined in relation to Fig. 1c.

**[0056]** Placing the point of attachment in the contact gap space 165, and advantageously in the range of  $0.3d_{\text{gap}}$  or less from the centre of the contact gap in the contact gap direction, gives an advantageous mechanical stability to the tap selector 120, by means of which the positioning may be improved. A moveable contact 130 experiences a risk of being exposed to mechanical and electrical forces, e.g. due to friction between the moveable contact 130 and the fixed contacts 135 and/or the current collector 125; or due to electrical short-circuit forces in case of short circuit currents in a nearby con-

ductor, etc. Such undesired forces act to move the moveable contact 130 from its correct position, thus giving rise to a risk for electrical arcing. Such forces will act on the moveable contact 130, and by placing the point of attachment of the moveable contact 130 to the positioning loop 205 in the middle region of the contact gap, the mechanical advantage will typically be optimal. Oftentimes, the optimal location of the point of attachment will be in at the centre of the contact gap, although other considerations may be in favour of an alternative location. Please note that positioning loop 205 need not be directly mechanically connected to the contact carrier 220 but could be mechanically connected to the moveable contact 130 via an intermediary part, such as an electrical insulating or non-insulating part (e.g. a bar).

**[0057]** An electrically insulating positioning loop 205 could advantageously be made from an insulating material which exhibits low mechanical creep, for example a polymer of good creep resistance. Since accurate correspondence between the spacing of the positioning items 300 of the positioning loop 205 and the spacing of the corresponding positioning items 213 of a driving wheel 210 will ensure accurate positioning of the moveable contact 130 at the different fixed contact positions, a material which exhibits very low long term creep would be advantageous. For example, a material having creep properties in the range of 0-0.3 % during lifetime would be suitable. Low moisture absorption is also desirable since moisture can influence the mechanical strength properties, such as elongation and/or strength, as well as the electrical conductivity, of the material.

**[0058]** An example of mechanically flexible and electrically insulating materials which can be designed to have the desired creep properties is polymer-cord composite materials, where a polymer, such as polyurethane, polyester, or rubber, is reinforced with cords of an electrically insulating and mechanically creep resistant material, so that the cords are embedded in a polymer matrix. The cords could for example be made from a liquid crystal polymer, which can for example be melt spun into a high performance material. Vectran® is an example of a liquid crystal polymer. Vectran® is a wholly aromatic polyester made by the acetylation polymerisation of p-hydroxybenzoic acid and 6-hydroxy-2-naphthoic. The molecular structure of Vectran® is shown in **Fig. 6**. Other naphthalene-based thermotropic liquid crystal polymers could also be contemplated. Another example of suitable flexible and insulating materials is the para-aramid synthetic fibres, such as Kevlar or Twaron. Both the liquid crystal polymers and the para-aramid synthetic fibres show a high creep resistance, a low coefficient of thermal expansion and low moisture absorption.

**[0059]** In an embodiment wherein the spacing  $d_{300}$  of the positioning items 300 of the positioning loop 205 is smaller than the spacing  $d_{213}$  of the corresponding positioning items 213 as discussed above, a suitable ratio

$d_{213}$

of  $d_{213}$  to  $d_{300}$ ,  $d_{300}$ , could for example lie within the range of [1.0005; 1.004] when the positioning loop 205 comprises liquid crystal polymers and within the range of [1.0005; 1.006] when the positioning loop 205 comprises para-aramid synthetic materials. Under some circumstances, an even larger value of this ratio may be beneficial, such as e.g. if the expected temperature contraction (negative elongation) of the structure in which the drive system 200 is suspended is large. In many implementations, however, a ratio within the range of [1.001; 1.003] for liquid crystal polymers and within the range of [1.003; 1.004] for para-aramid synthetic materials will be sufficient.

**[0060]** Other materials which could be used for the cord of a polymer-cord composite in a positioning loop 205 include glass fibre. When the positioning loop 205 is implemented in the form of a chain or similar, the material itself does not have to be flexible, since the flexibility is provided in the mechanical design of the loop. Examples of suitable rigid materials which could be used for the positioning loop when implemented as a chain include composites of polyester/glass; epoxy/glass; polyphthalamide/glass.

**[0061]** An example of a tap selector 120 wherein the moveable contact 130 is moved from one fixed contact position to another by means of a driving system 200 having an electrically insulating, mechanically flexible positioning loop 205 is shown in **Fig. 7**. The moveable contact 130, the fixed contacts 135 with cables 160, and the current collector 125 with a cable 700 for connecting to a diverter switch 115 are shown, as is the driving system 200 comprising the positioning loop 205, a drive wheel 210, pulleys 215, and guiding rod 705. The guiding rod 705, as well as the positioning loop 205, is made from an electrically insulating material such as a polymer or a ceramic material. A guiding part 235 of the contact carrier 220 could contain a low friction part or coating, made of a suitable low friction material (e.g. polytetrafluoreten (PTFE)). Low friction between the guiding part 235 and the contact carrier 220 could alternatively be achieved by providing the guiding rod 705 with a coating of low friction material.

**[0062]** The tap changer 100 of which the tap selector 120 is shown in **Fig. 7** has one moveable contact 130. A tap changer 100 having more than one independently moveable contacts 130 can advantageously be provided with one positioning loop 205 for each independently moveable contact 130. In a tap changer 100 having two or more moveable contacts 130, which can only be moved in a joint movement, a single positioning loop 205 would be sufficient for the jointly moveable contacts 130.

**[0063]** The invention could advantageously be used in an on-load tap changer 100, where the regulation of the transformer output voltage takes place while the transformer is in operation, as well as in a non-excited, off-load tap changer.

**[0064]** Since the insulation distances are so much larger in air than in oil or for example SF<sub>6</sub>, the benefits of a compact design are more pronounced in an air insulated tap changer. However, the invention can advantageously be applied also in oil or SF<sub>6</sub> insulated designs, which can then be very compactly designed.

**[0065]** Although various aspects of the invention are set out in the accompanying independent claims, other aspects of the invention include the combination of any features presented in the above description and/or in the accompanying claims, and not solely the combinations explicitly set out in the accompanying claims.

**[0066]** One skilled in the art will appreciate that the technology presented herein is not limited to the embodiments disclosed in the accompanying drawings and the foregoing detailed description, which are presented for purposes of illustration only, but it can be implemented in a number of different ways, and it is defined by the following claims.

## Claims

1. A tap changer (100) for connection to a regulating winding (105) of a transformer, the tap changer comprising:

a tap selector (120) including:

a set of fixed contacts comprising at least two fixed contacts (135), each arranged to be connected to a tap (110) of the regulating winding;

at least one current collector (125) located at a distance from the set of fixed contacts so that a contact gap space (165) is formed therebetween; and

at least one contact carrier (220) including at least one moveable contact (130) arranged to electrically bridge a contact gap between a current collector and a fixed contact; the tap changer further comprising:

a drive system (200) for moving the at least one contact carrier from one fixed contact position to another, the drive system comprising at least one electrically insulating, mechanically flexible positioning loop (205) provided with a plurality of evenly distributed positioning items (300), the positioning loop being attached to the contact carrier in order to allow for transmission of a driving force thereto.

2. The tap changer of claim 1, wherein the positioning loop is at least partly located in the contact gap space (165).
3. The tap changer of claim 1 or 2, wherein

the positioning loop is a timing belt.

4. The tap changer of claim 3, wherein the positioning items are evenly distributed integral teeth.
5. The tap changer of claim 3, wherein the positioning items are evenly distributed holes.
6. The tap changer of claim 1 or 2, wherein the positioning loop is a chain.
7. The tap changer of any one of the above claims, wherein the positioning loop is formed from an electrically insulating material which is expected to experience, during its lifetime, a mechanical crimpage/elongation in the range of  $\pm 1\%$  due to temperature changes, moisture changes and mechanical creep.
8. The tap changer of any one of the above claims, wherein the electrically insulating material is a polymer-composite comprising a liquid crystal polymer or a para-aramid synthetic material.
9. The tap changer of any one of the above claims, wherein wherein the drive system comprises a wheel (210; 215) the centre of which may be adjusted in order to adjust the length of the positioning loop.
10. The tap changer of any one of the above claims, wherein the drive system further comprises at least one drive wheel (210) the periphery of which is provided with evenly distributed positioning items (213) arranged to interact with the positioning items of the positioning loop, so that upon rotation of the drive wheel, the contact carrier will perform a linear movement.
11. The tap changer of claim 10, wherein the spacing of the positioning items (213) of driving wheel exceeds the spacing of the corresponding positioning items (300) of the positioning loop.
12. The tap changer of any one of the above claims, further comprising a clamp (225) for mechanically connecting the positioning loop to the contact carrier, wherein the clamp and/or the contact carrier is provided with at least one positioning item (213) to mesh with at least one corresponding positioning item of the positioning loop.
13. The tap changer of any one of the above claims, wherein the drive system further comprises an electrically in-

ulating linear guide (705) located in the contact gap space for mechanically guiding the movement of the contact carrier.

- 5 14. The tap changer of any one of the above claims, wherein a point of mechanical connection of the positioning loop to the contact carrier is located within a distance of  $[0.2d_{\text{gap}}; 0.8d_{\text{gap}}]$  from the current collector in the contact gap direction.
- 10 15. The tap changer of any one of the above claims, wherein the positioning loop is pre-stressed so that the initial pre-stressed elongation of the positioning loop is larger than the largest expected sum of the mechanical creep elongation, the change in the length of the positioning loop due to thermal expansion and the change in the positioning loop due to moisture elongation, in order to ensure a tension in the positioning loop throughout its lifetime.

Fig. 1a

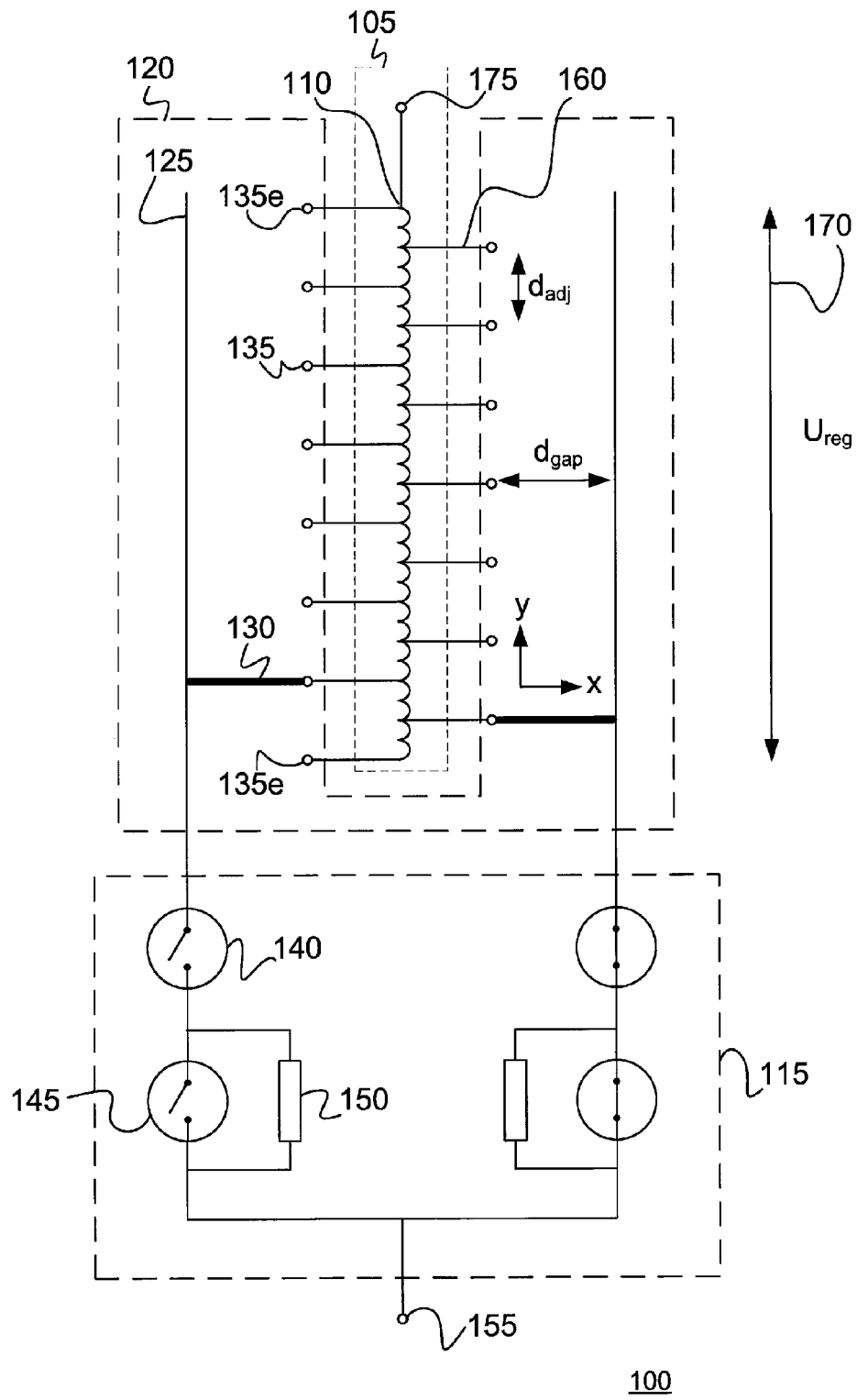


Fig. 1b

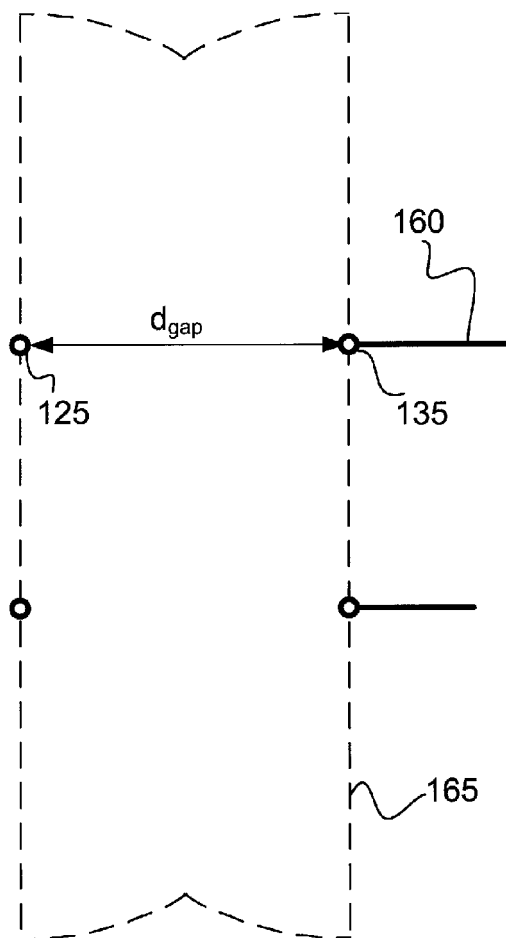


Fig. 1c

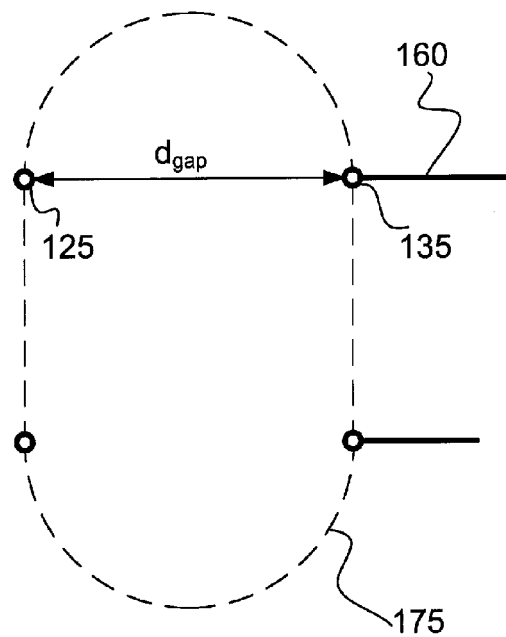


Fig. 6

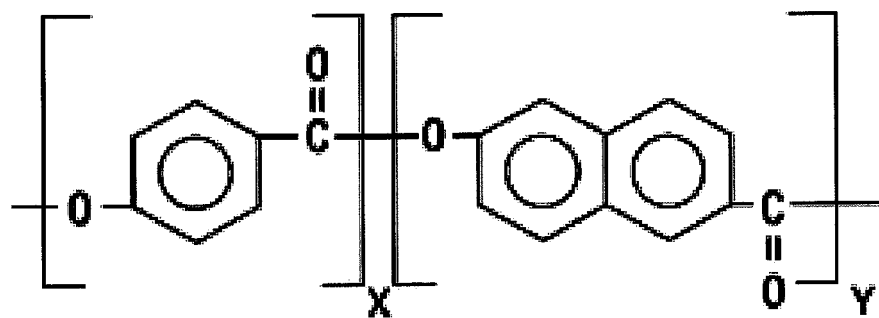


Fig. 2a

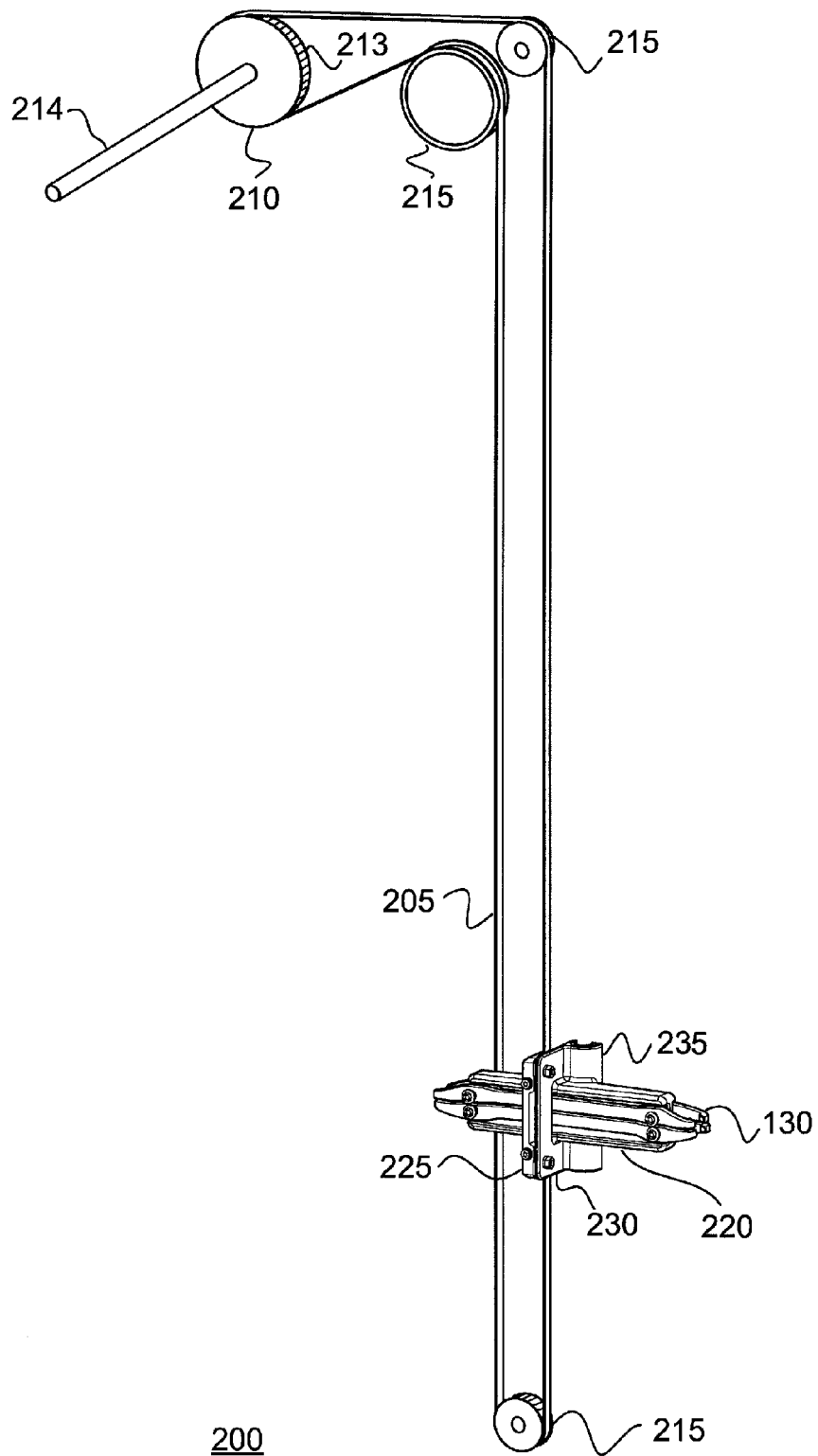
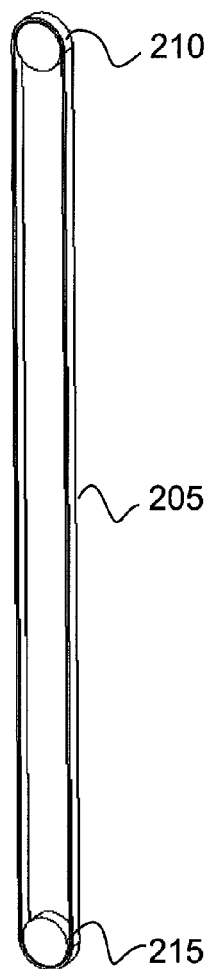
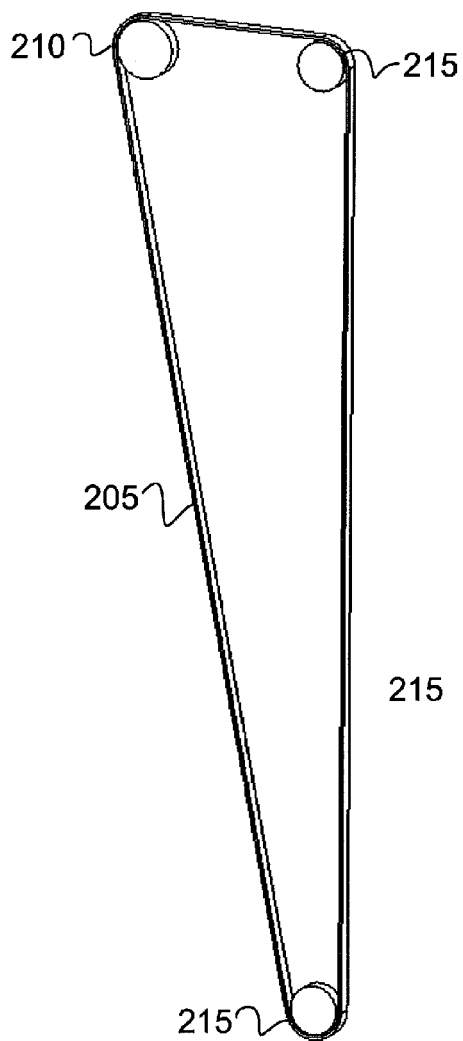


Fig. 2b



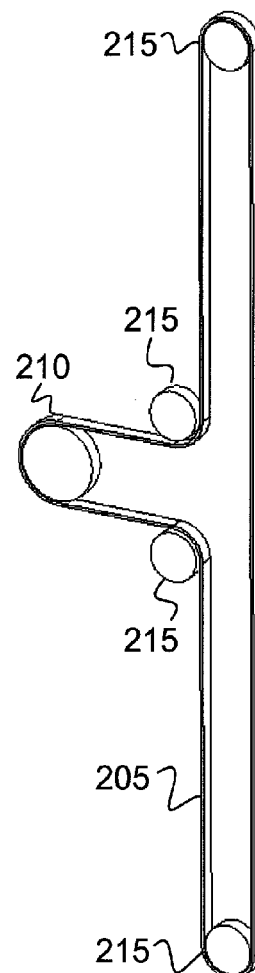
200

Fig. 2c



200

Fig. 2d



200

Fig. 3a

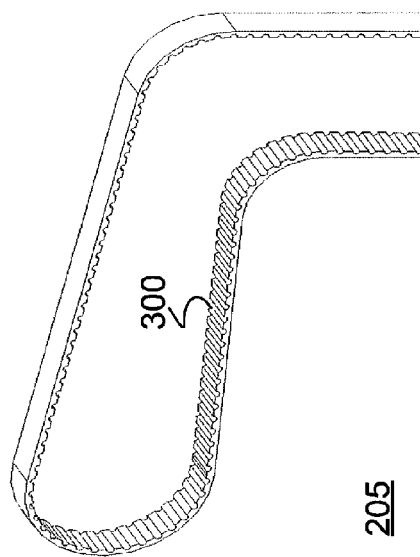


Fig. 3b

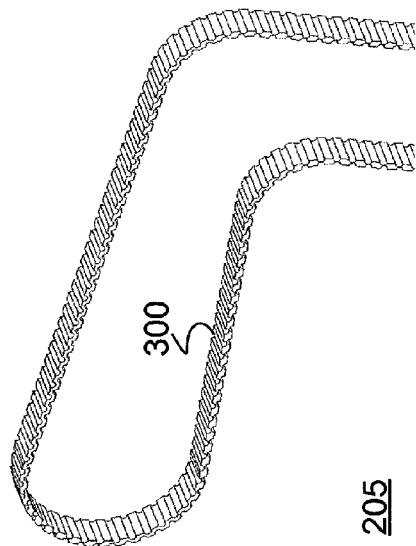


Fig. 3c

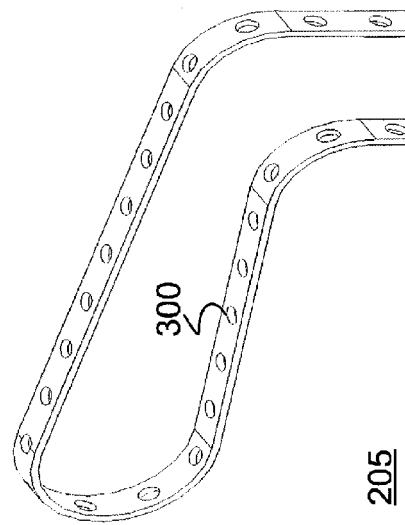


Fig. 3d

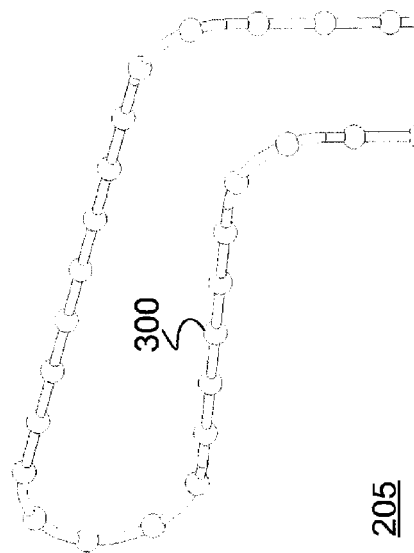


Fig. 4a

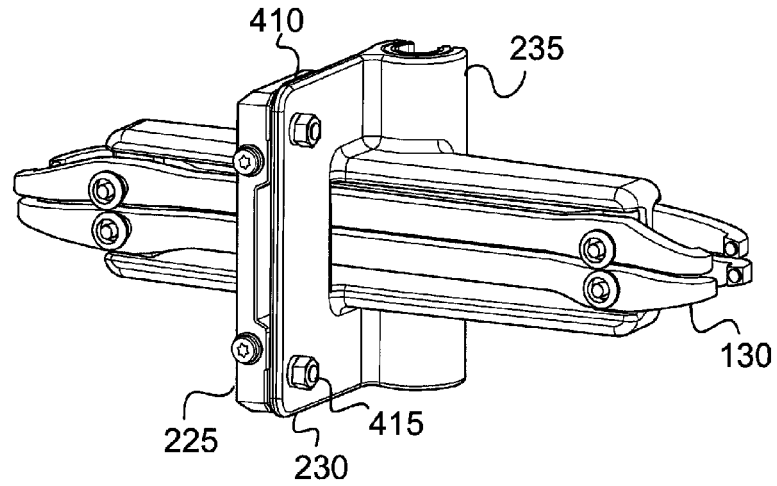


Fig. 4b

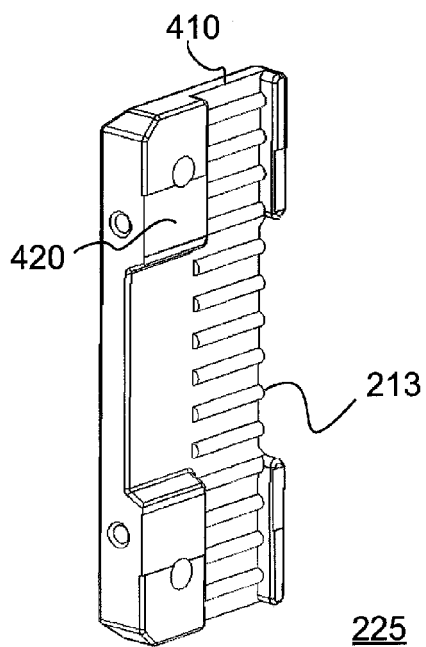


Fig. 4c

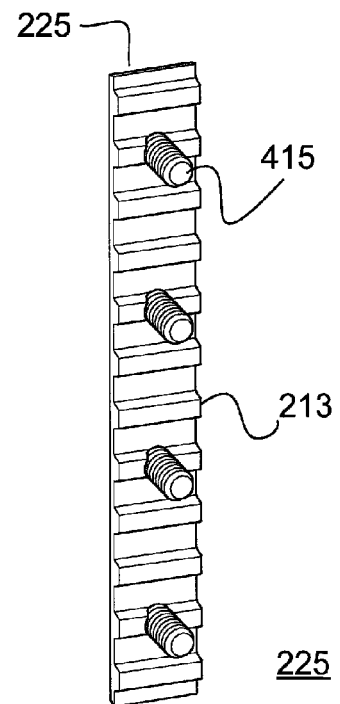


Fig. 5a

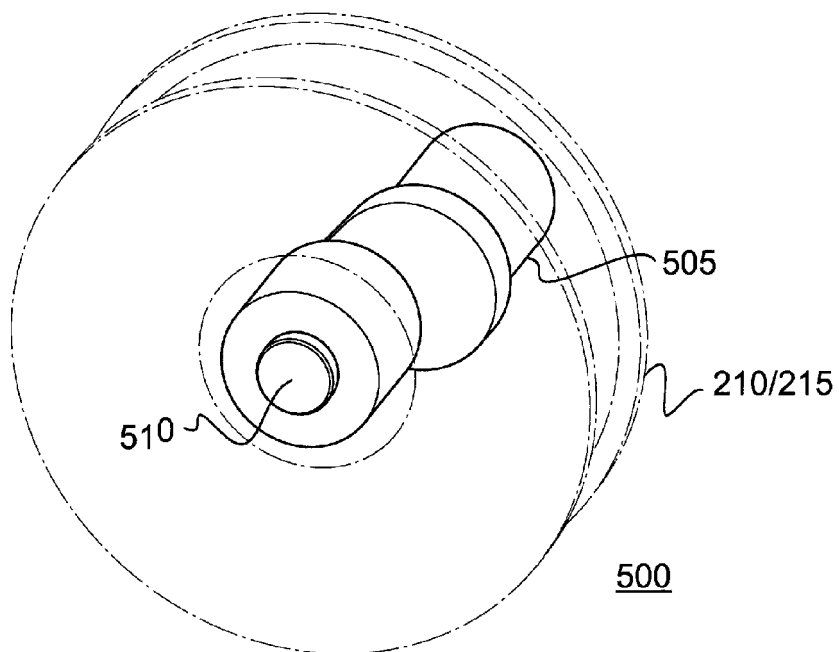


Fig. 5b

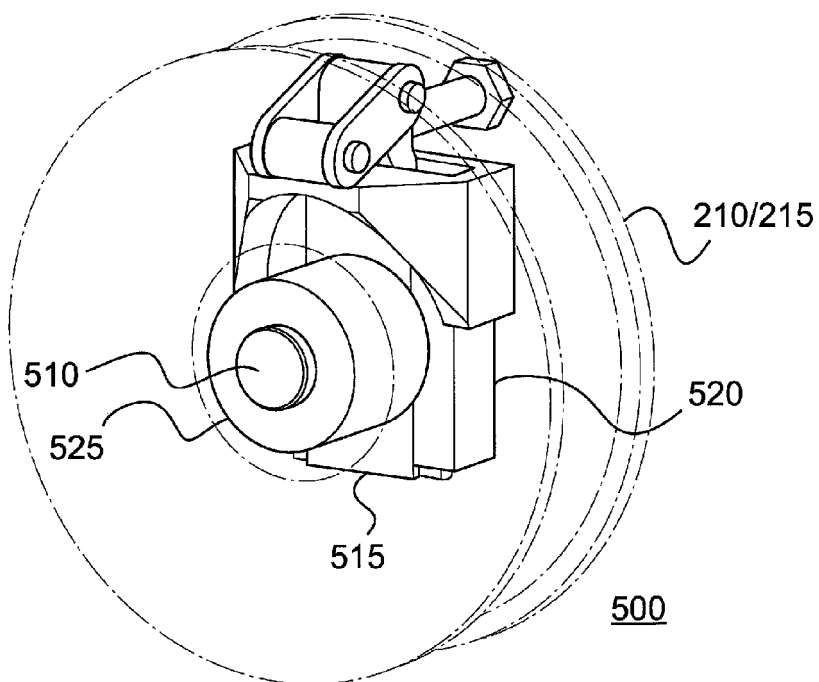
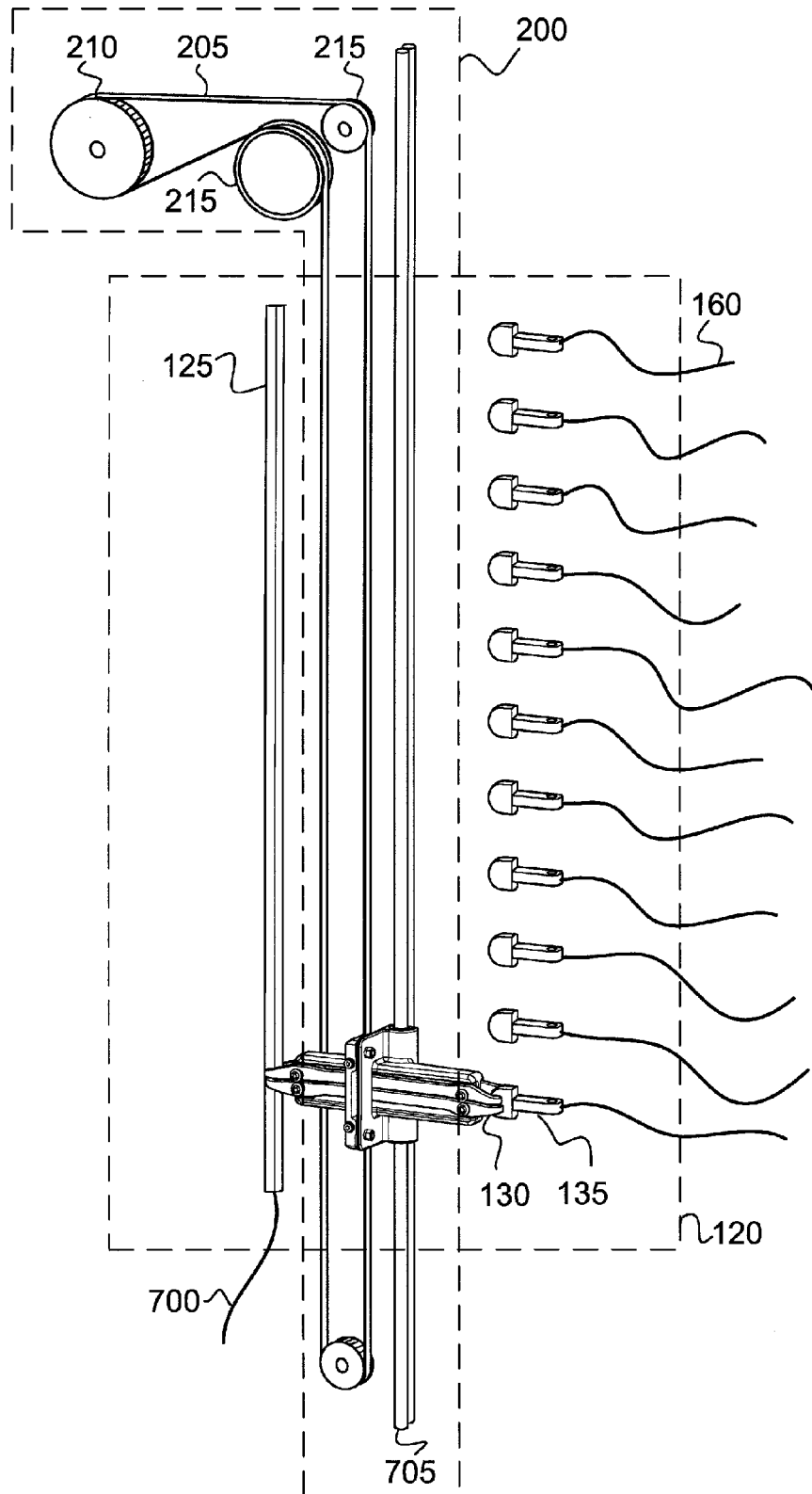


Fig. 7





## EUROPEAN SEARCH REPORT

Application Number  
EP 11 16 8222

| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                    |                                                                                 |                                                                                                                                                                                                                                                                                       |                                             |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|
| Category                                                                                                                                                                                                                                               | Citation of document with indication, where appropriate, of relevant passages   | Relevant to claim                                                                                                                                                                                                                                                                     | CLASSIFICATION OF THE APPLICATION (IPC)     |
| Y                                                                                                                                                                                                                                                      | CH 247 544 A (HERMES PATENTVERWERTUNGS GMBH [DE]) 15 March 1947 (1947-03-15)    | 1,2,6                                                                                                                                                                                                                                                                                 | INV.<br>H01H9/00                            |
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| A                                                                                                                                                                                                                                                      | * figures *                                                                     | 3                                                                                                                                                                                                                                                                                     |                                             |
| The present search report has been drawn up for all claims                                                                                                                                                                                             |                                                                                 |                                                                                                                                                                                                                                                                                       |                                             |
| Place of search<br><b>Munich</b>                                                                                                                                                                                                                       |                                                                                 | Date of completion of the search<br><b>4 November 2011</b>                                                                                                                                                                                                                            | Examiner<br><b>Socher, Günther</b>          |
| CATEGORY OF CITED DOCUMENTS<br>X : particularly relevant if taken alone<br>Y : particularly relevant if combined with another document of the same category<br>A : technological background<br>O : non-written disclosure<br>P : intermediate document |                                                                                 | T : theory or principle underlying the invention<br>E : earlier patent document, but published on, or after the filing date<br>D : document cited in the application<br>L : document cited for other reasons<br>.....<br>& : member of the same patent family, corresponding document |                                             |

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EPO FORM 1503 03/02 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT  
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The members are as contained in the European Patent Office EDP file on  
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