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(54) Title: DEFORMABLE ACTUATING DEVICE WITH COAXIAL CONFIGURATION

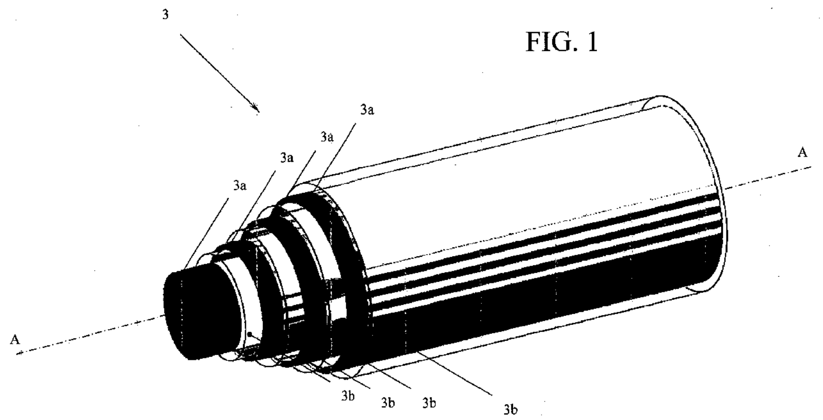

FIG. 1

(57) Abstract: A deformable actuating device (1) with coaxial configuration is described, comprising: at least one structure (3) with concentric layers coaxial with respect to at least one longitudinal axis (A- A) composed of an at least partial alternated overlapping with at least two electro-active concentric layers (3a) coaxial with said longitudinal axis (A-A), and of at least three conductive con - centric layers (3b) coaxial with said longitudinal axis (A-A); at least one controlling and managing system (5) adapted to supply each of such electro-active concentric layers (3a) with at least one different current/voltage value (V_1, V_2, V_3, V_4,..., V_n), said current/voltage values (V_1, V_2, V_3, V_4,..., V_n being mutually independent.

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DEFORMABLE ACTUATING DEVICE WITH COAXIAL CONFIGURATION

The present invention refers to a deformable actuating device, in particular of the type based on electro-active polymers, such as for example dielectric elastomers, with coaxial configuration

From an analysis of multi-criteria selection of the different families of electro-active polymers known in the art, it has been detected that dielectric elastomers are the best trade-off between deformability and maximum stress which they are able to apply. In virtue of their operating principle, these polymeric "smart materials" behave as linear actuators: in response to the application of a voltage, they get deformed, developing a force along a plan, mainly along a direction, if suitably pre-deformed.

In particular, electro-active polymers are currently considered the most suitable materials for making artificial muscles, with applications in the biomedical environment such as active prostheses, rehabilitation supporting systems, for making haptic interfaces, namely interfaces capable of returning a physical feedback to the user, as well as they can find application in audio or optical (autofocus systems) fields, micro-mechanics, screens of flexible solar panels.

Depending on the features of the above materials, the art proposes some solutions of deformable actuators. In particular:

- US20120139393 and EP2323188 disclose a multi-layer device composed of eight conductive concentric layers and eight polymeric layers in which actuation is based on the application of the same potential difference on all layers;
- WO200729275 discloses a multi-layer device obtained by bending a single layer onto itself and in which the applied potential is only one and the same on every bend, obtaining only an actuation resulting in a contraction along the axial direction of the device itself;
- WO2012099854 discloses an actuator which obtains a sliding movement produced by the elongation of the device electrode fastened to a first film of dielectric material with

respect to a second film of dielectric material. To obtain a better elongation or a greater mechanical response, it is necessary to use a high number of such actuators;

- WO2010149385 discloses a multi-layer device obtained by rolling the single layers onto a rigid/semi-rigid (square or rectangular) support. The thereby obtained multi-layers can be connected in series or stacked;
- WO2006121818 discloses various structures, which can be made with electro-active polymers, among which a fiber structure composed of concentric electrodes separated by a dielectric, which however is lacking fiber stimulation selectivity or the variable application of different tensions for every concentric layer.

Devices are also known in the art, which are based on the "unimorph cantilever" operating principle, in which a layer of a dielectric elastomer is coupled with a passive layer, obtained when performing a simple flexure.

Object of the present invention is solving the above prior art problems, by providing a deformable actuating device with coaxial configuration capable of exploiting the operating principle of electro-active polymers, and in particular of dielectric elastomers, to produce a complex deformation.

Another object of the present invention is providing a deformable actuating device with coaxial configuration, which has a structure with concentric layers lacking passive layers.

Moreover, an object of the present invention is providing a deformable actuating device with coaxial configuration, composed of at least one structure with concentric layers, in which every layer is supplied with mutually independent and potentially different voltage/current values, allowing to obtain deformations, both as elongation and as flexure, varying as regards direction and amount, by simply changing such voltage/current values.

Another object of the present invention is providing a deformable actuating device with coaxial configuration capable of performing an accurately controllable actuation according to the needs dictated by the specific application, and in which such actuation can be reversed, namely can be made along two directions, and can be accurately adjusted, providing a high versatility of use for the device itself.

Moreover, an object of the present invention is providing a deformable actuating device with coaxial configuration in which the structure with concentric layers allows reducing the voltages to be applied on the single layers, providing a strong advantage for the safety of the device itself, above all in applications in which there is a direct interaction by the user.

Another object of the present invention is providing a deformable actuating device with coaxial configuration comprising a plurality of such multi-layer structures, each of which being able to be controlled independently from the others, allowing to obtain a selective hierarchical recruiting of such multi-layer structures.

Moreover, an object of the present invention is providing a deformable actuating device with coaxial configuration in which the structure has concentric layers in order to exploit a greater interface surface area between electrode and polymeric dielectric, consequently increasing the functional efficiency of the device itself with respect to prior art multi-layer structures with planar configuration.

Another object of the present invention is providing a deformable actuating device with coaxial configuration in which the structure with concentric layers allows simulating as much as possible the structure and the behavior of natural muscle bundles.

The above and other objects and advantages of the invention, as will appear from the following description, are obtained with a deformable actuating device with coaxial configuration as claimed in claim 1.

Preferred embodiments and non-trivial variations of the present invention are the subject matter of the dependent claims.

It is intended that all enclosed claims are an integral part of the present description.

It will be immediately obvious that numerous variations and modifications (for example related to shape, sizes, arrangements and parts with equivalent functionality) can be made to what is described, without departing from the scope of the invention as appears from the enclosed claims.

The present invention will be better described by some preferred embodiments thereof, provided as a non-limiting example, with reference to the enclosed drawings, in which:

- Figure 1 shows a top perspective view of a preferred embodiment of the structure with concentric layers of the device according to the present invention;

- Figure 2 shows a front sectional view of the structure with concentric layers of Figure 1;

- Figure 3 shows a longitudinally sectioned view of the structure with concentric layers of Figure 1;

- Figure 4 shows a block diagram which schematically shows the device according to the present invention;

- Figures 5a and 5b show side views of the structure with concentric layers of the device according to the present invention in two operating positions thereof;

- Figures 6a and 6b respectively show a functional block diagram and an electric diagram of a preferred embodiment of the controlling and managing system of the device according to the present invention; and

- Figure 7 shows a perspective view of a preferred variation of a component of the device according to the present invention.

With reference to the Figures, it is possible to note that the deformable actuating device 1 with coaxial configuration according to the present invention comprises:

- at least one structure with concentric layers 3 coaxial with respect to at least one longitudinal axis A-A composed of an at least partial alternated overlapping of at least two electro-active concentric layers 3a coaxial with such longitudinal axis A-A, each of which is preferably made of any dielectric material, and of at least three conductive concentric layers 3b coaxial with such longitudinal axis A-A, each of which is preferably made of any conductive material;
- at least one controlling and managing system 5 adapted to supply each of such electro-active concentric layers 3a with a distinct current/voltage value V_1, V_2, V_3, V_4,..., V_n, such current/voltage values V_1, V_2, V_3, V_4,..., V_n being mutually independent, so that every electro-active concentric layer 3a performs a different deformation depending on the related current/voltage value V_1, V_2, V_3, V_4,..., V_n with which such electro-active concentric layer 3a is supplied by such controlling and managing system 5.

As known, muscles are composed of bundles of muscular fibres in turn composed of bundles of myofibrils, each myofibril being characterized by thick filaments of myosin molecules and thin filaments of actin molecules: the mutual interaction between such types of filaments is responsible for the muscle contraction mechanism, namely the mutual sliding of filaments. The stimulus to muscle contraction arrives at the muscle mainly through the axon of a motion, inducing the freeing of the in the excitable membrane of the fibre; the action potential which results therefrom propagates to the whole surface of the membrane and to all its intro-flexures which, as offshoots, reach contractile fibres/fibrils at a depth. The depolarization of the membrane implies the activation of an increase of the permeability to calcium ions contained inside the myofibrils, which, together with the hydrolysis mechanism of the ATP molecule, are mandatory for the contraction phenomenon, favouring the sliding and consequently the contraction of the filaments and of the related innerved muscle.

In order to simulate as much as possible the structure and the behavior of natural muscle bundles, such structure 3 with concentric layers advantageously has a coaxial configuration, such electro-active concentric layers 3a and such conductive concentric layers 3b being adapted to perform an actuation movement related to the longitudinal axis A-A of such structure 3 with concentric layers along both directions, simulating the behavior assumed by filaments during the muscle contraction phenomenon.

Preferably, the dielectric material, of which each of such electro-active concentric layers 3a is made, is at least one electro-active polymer and, still more preferably, at least one dielectric elastomer: according to the operating principle of dielectric elastomers, the coaxial deformation along the axis of such structure 3 with concentric layers increases upon increasing the applied voltage. Advantageously, therefore, by supplying each electro-active concentric layer 3a with a related current/voltage value V_1, V_2, V_3, V_4,…, V_n, such values being regulated by the controlling and managing system 5 in order to be mutually different, every electro-active concentric layer 3a performs a corresponding coaxial elongation, different depending on the current/voltage value

V_1, V_2, V_3, V_4,..., V_n with which it is supplied.

Advantageously, in such structure 3 with concentric layers with coaxial configuration, the surface interface area between electrode and polymeric dielectric is greater with respect to the known planar configuration of a deformable actuating device, inducing an increase of the deformation force exerted by such deformable actuating device 1 with coaxial configuration with a voltage value lower than or at most equal to the one applied to the deformable actuating device with planar configuration.

In particular, such actuating movement along the longitudinal axis A-A of such structure 3 with concentric layers consists in an elongation and/or a shortening of the structure 3 with concentric layers, inducing the mutual sliding of such electro-active concentric layers 3a on such conductive concentric layers 3b.

It is clear that such deformable actuating device 1 with coaxial configuration, applying a deformation force, is adapted to induce an elongation and/or a shortening of such structure 3 with concentric layers depending on a value of applied voltage.

With reference to Figures FIGG. 6a and 6b, it is possible to note a preferred embodiment of the controlling and managing system 5 of the device 1 according to the present invention adapted to supply with voltage such electro-active concentric layers 3a of the structure 3 with concentric layers. In particular, such controlling and managing system 5 comprises:

- electric supply means 7, composed for example of at least one electric battery or of a connection to the electric distribution mains;
- at least one regulating means 9 of the voltage supplied to such electric supply means 7 and cooperating with at least one processing means 11 such as, for example, a microcontroller;
- at least one converter means 13 of DC/DC current adapted to provide the different voltage values V_1, V_2, V_3, V_4,..., V_n to the respective connectors 15 connected to the related electro-active concentric layers 3a of the structure 3 with concentric layers by interposing at least one controlling means of the voltage 17.

Then, with particular reference to Figures 5a and 5b, it is possible to note that, starting from a rest position of the structure 3 with concentric layers (like the one, for example, shown in Figure 5a) and supplying every electro-active concentric layer 3a with a different current/voltage value V_1, V_2, V_3, V_4,…, V_n so that $V_1 > V_2 > V_3 > V_4 > V_n$, a gradient of coaxial deformation is obtained along the structure with concentric layers 3 with a total resulting actuation of the structure 3 with concentric layers, composed of an elongation along such longitudinal axis A-A of such structure 3 with concentric layers, of a shortening along a perpendicular axis to such longitudinal axis A-A of such structure 3 with concentric layers, and of a rotation thereof (as shown in detail in Figure 5b).

Advantageously, therefore, the control of the current/voltage applied on the single electro-active concentric layers 3a allows obtaining an actuation which combines elongation, shortening and flexure. Moreover, the resulting deformation can be modified at will: it is in fact possible to obtain a flexure varying as regards direction and amount, without modifying the structure of the deformable actuating device 1 with coaxial configuration, by simply intervening on the currents/voltages through a selective recruiting, modulating the activation of the single electro-active concentric layers 3a, the number of single activated electro-active concentric layers 3a, and the force intensity of such actuation. This allows having a high versatility in using the device 1 according to the present invention, for example in the textile field (Wearable Technology) by making layers made of electro-active polymers woven inside pieces of clothing, or for example in the biomedical field through the use of such deformable actuating device 1 with coaxial configuration in active prostheses or in rehabilitation supporting systems.

Another advantage is the chance of reducing, in particular, the applied voltages of one order of magnitude (from 3-4 kV to 300-400 V of the prior art device). In spite of the high voltages, the working currents are very small (order of μA) and danger for a man in case of break-down is limited.

As shown in Figure 7, such deformable actuating device 1 with axial configuration has a second preferred embodiment, being equipped with a plurality of structures 3 with concentric layers, controlled ad supplied with current/voltage by such managing and controlling system 5.

Such selective recruiting of the single layers allows, by controlling the values of applied

CLAIMS

1. Deformable actuating device (1) with coaxial configuration comprising:

- at least one structure (3) with concentric layers coaxial with respect to at least one longitudinal axis (A-A) composed of an at least partial alternated overlapping with at least two electro-active concentric layers (3a) coaxial with said longitudinal axis (A-A), and of at least three conductive concentric layers (3b) coaxial with said longitudinal axis (A-A);

- at least one controlling and managing system (5) adapted to supply each of said electro-active concentric layers (3a) with a different current/voltage value (V_1, V_2, V_3, V_4,..., V_n), said current/voltage values (V_1, V_2, V_3, V_4,..., V_n) being mutually independent, each one of said electro-active concentric layers (3a) being adapted to perform at least one different deformation depending on a related current/voltage value (V_1, V_2, V_3, V_4,..., V_n) with which said electro-active concentric layer (3a) is supplied by said controlling and managing system (5);

characterized in that said current/voltage values (V_1, V_2, V_3, V_4,..., V_n) are mutually different, and in that said current/voltage values (V_1, V_2, V_3, V_4,..., V_n) are such that $V_1 > V_2 > V_3 > V_4 > V_n$.

2. Deformable actuating device (1) with coaxial configuration according to the previous claim, characterized in that said deformation induces a mutual sliding of said electro-active concentric layers (3a) on said conductive concentric layers (3b), simulating at least one physiologic phenomenon of muscle contraction.

3. Deformable actuating device (1) with coaxial configuration according to claim 1, characterized in that each of said electro-active concentric layers (3a) is made of a dielectric material.

4. Deformable actuating device (1) with coaxial configuration according to the previous claim, characterized in that said dielectric material is at least one electro-active polymer.

5. Deformable actuating device (1) with coaxial configuration according to the previous claim, characterized in that said electro-active polymer is at least one dielectric elastomer.

6. Deformable actuating device (1) with coaxial configuration according to claim 1, characterized in that said controlling and managing system (5)

comprises:

- electric supply means (7);
- at least one regulating means (9) of a voltage supplied by said electric supply means (7) and cooperating with at least one processing means (11);
- at least one converter means (13) of DC/DC current adapted to supply said different voltage values (V_1, V_2, V_3, V_4,..., V_n) to respective connectors (15) connected to related electro-active concentric layers (3a) by interposing at least one controlling means (17) of the voltage.

7. Deformable actuating device (1) with coaxial configuration according to claim 1, characterized in that said deformation can be modified at will by intervening on said current/voltage value, through at least one selective recruiting of said single electro-active concentric layers (3a).

8. Deformable actuating device (1) with coaxial configuration according to any one of the previous claims, characterized in that it comprises a plurality of said structures (3) with concentric layers.

9. Deformable actuating device (1) with coaxial configuration according to the previous claim,

characterized in that it is adapted to modulate, through at least one selective hierarchical recruiting, at least one deformation of each of said electro-active concentric layers (3a) of each of said structures (3) with concentric layers, and simultaneously at least one deformation of said plurality of said structures (3) with concentric layers.

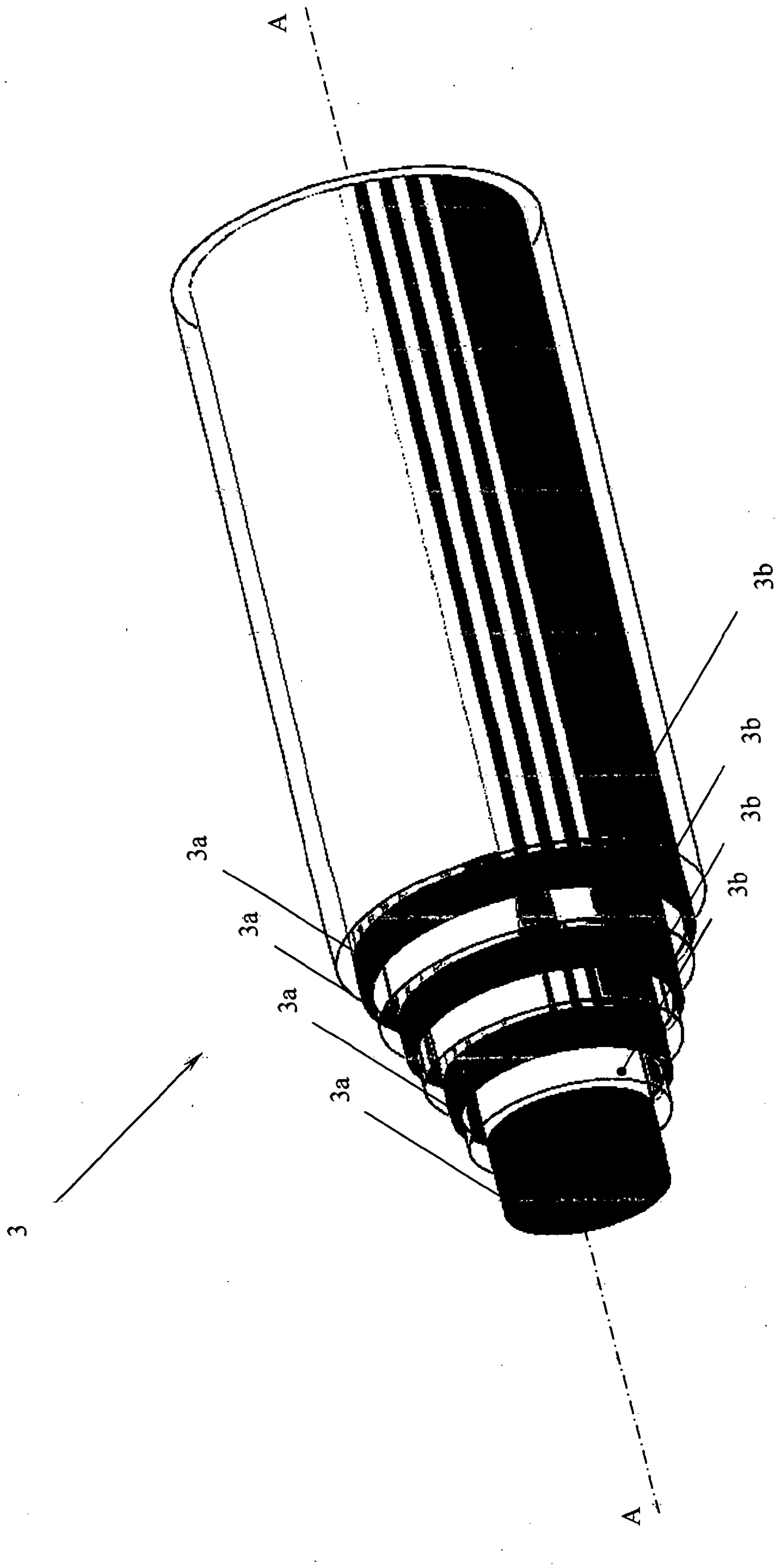


FIG. 1

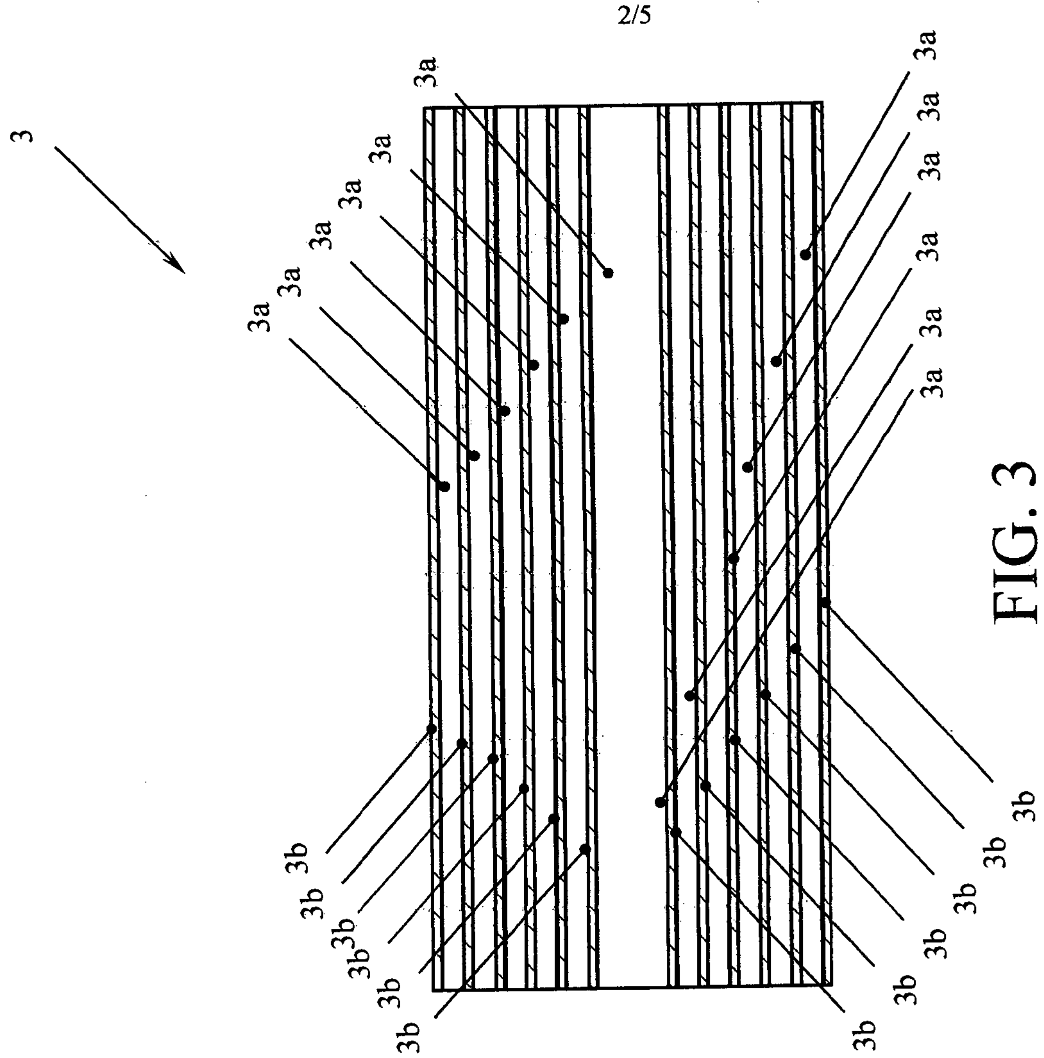


FIG. 3

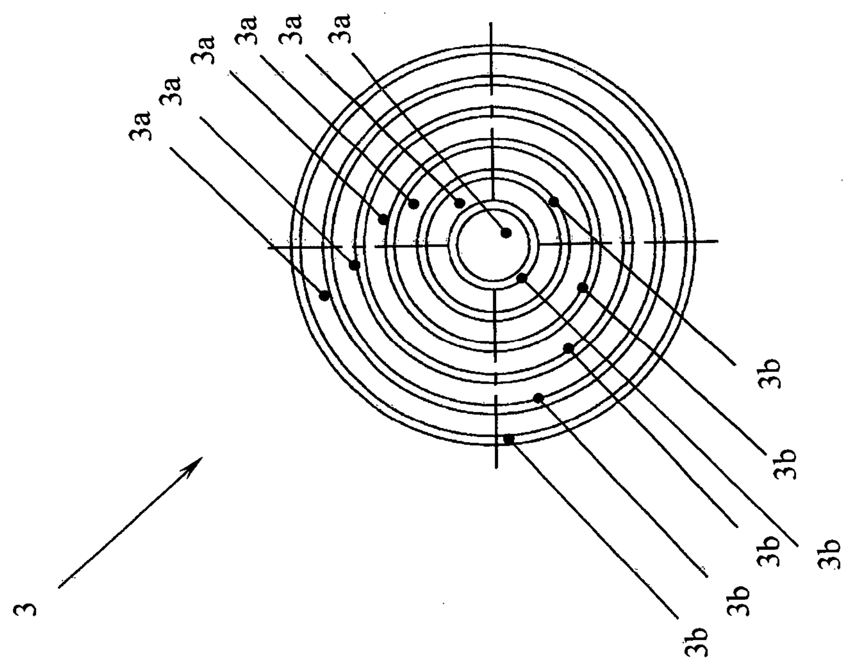


FIG. 2

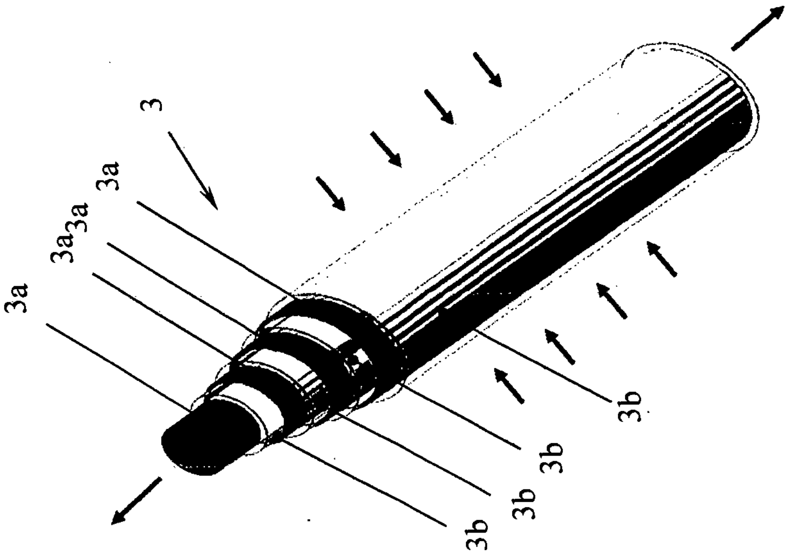


FIG. 5b

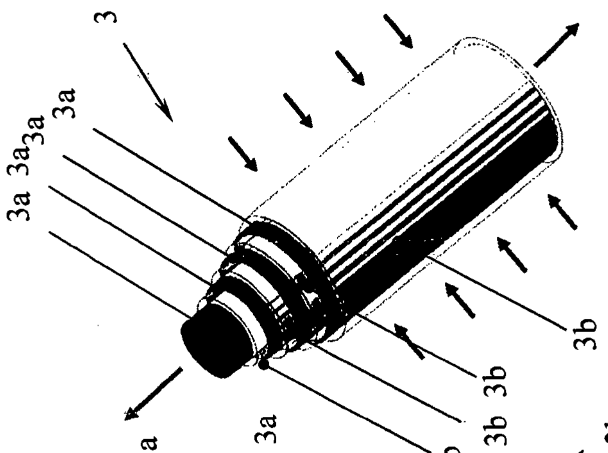


FIG. 5a

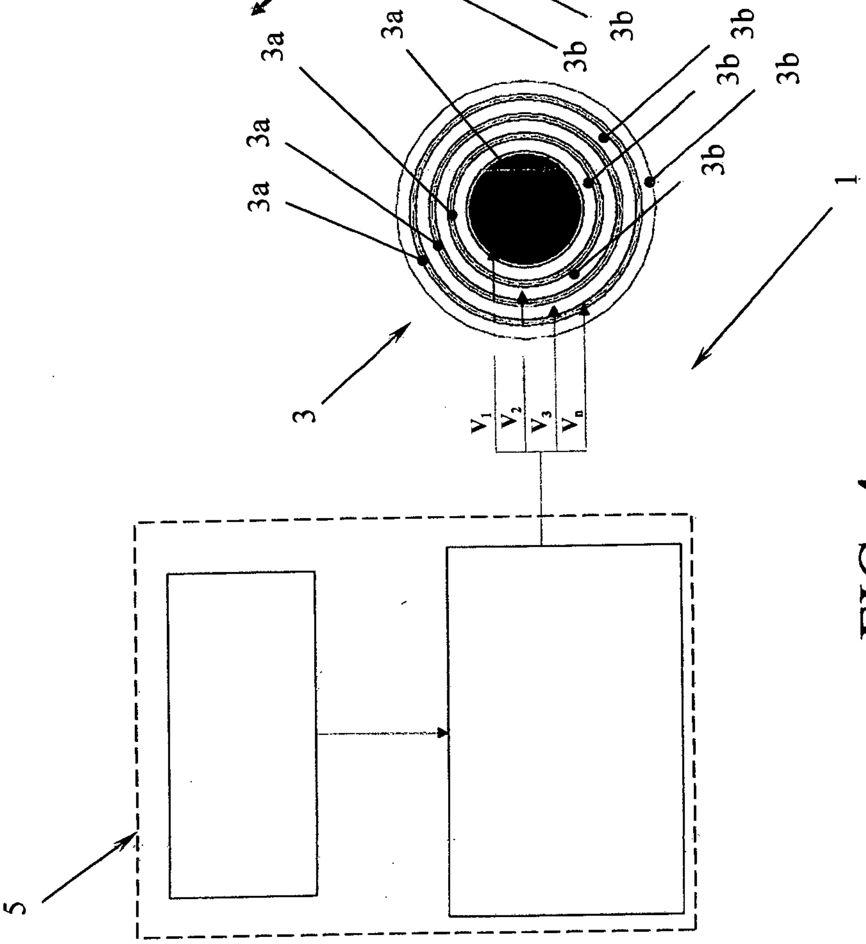
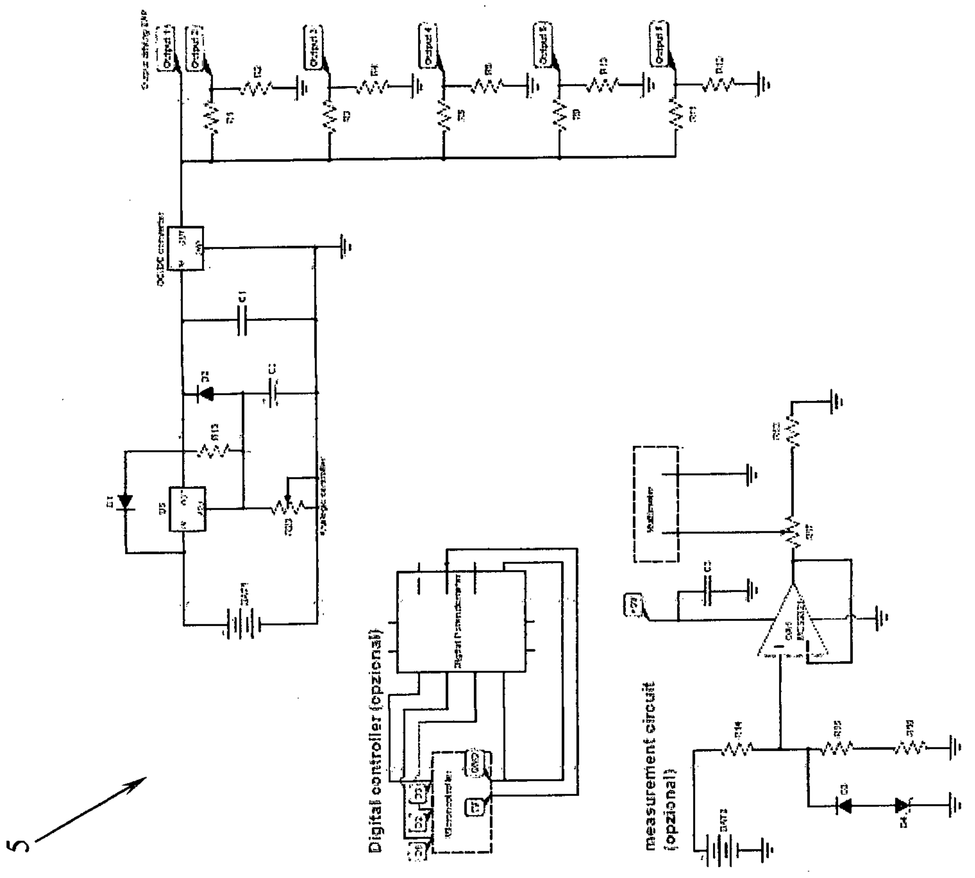


FIG. 4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Digital controller (opzional)
measurement circuit (opzional)

FIG. 6b

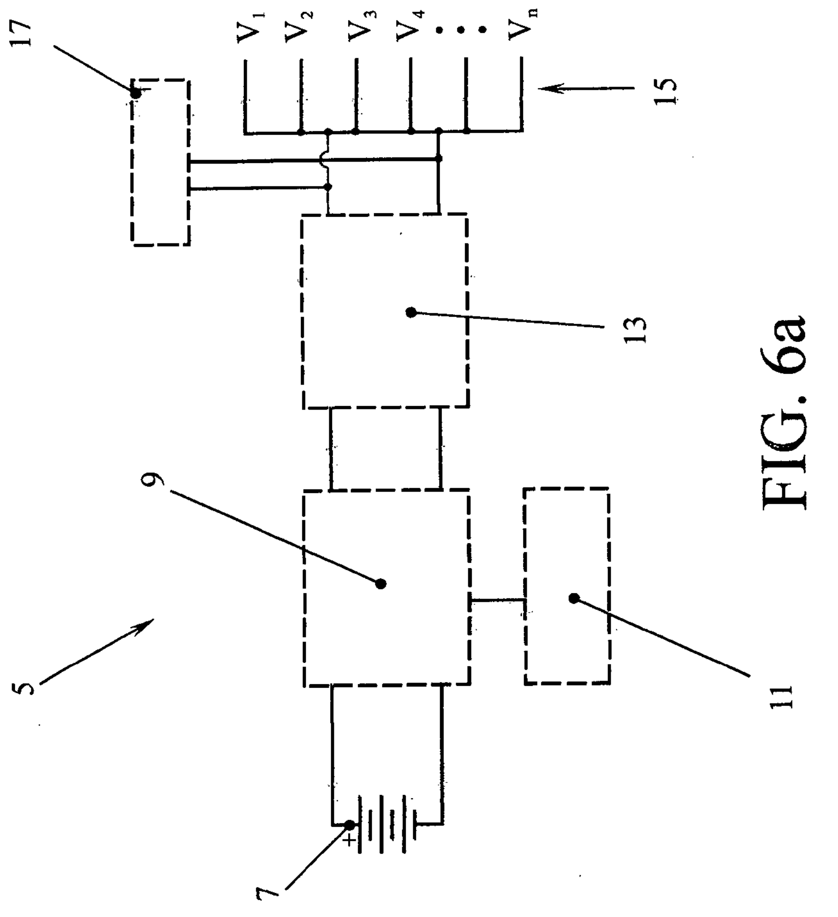
17
V1
V2
V3
V4
Vn
15
13
9
5
11
7

FIG. 6a

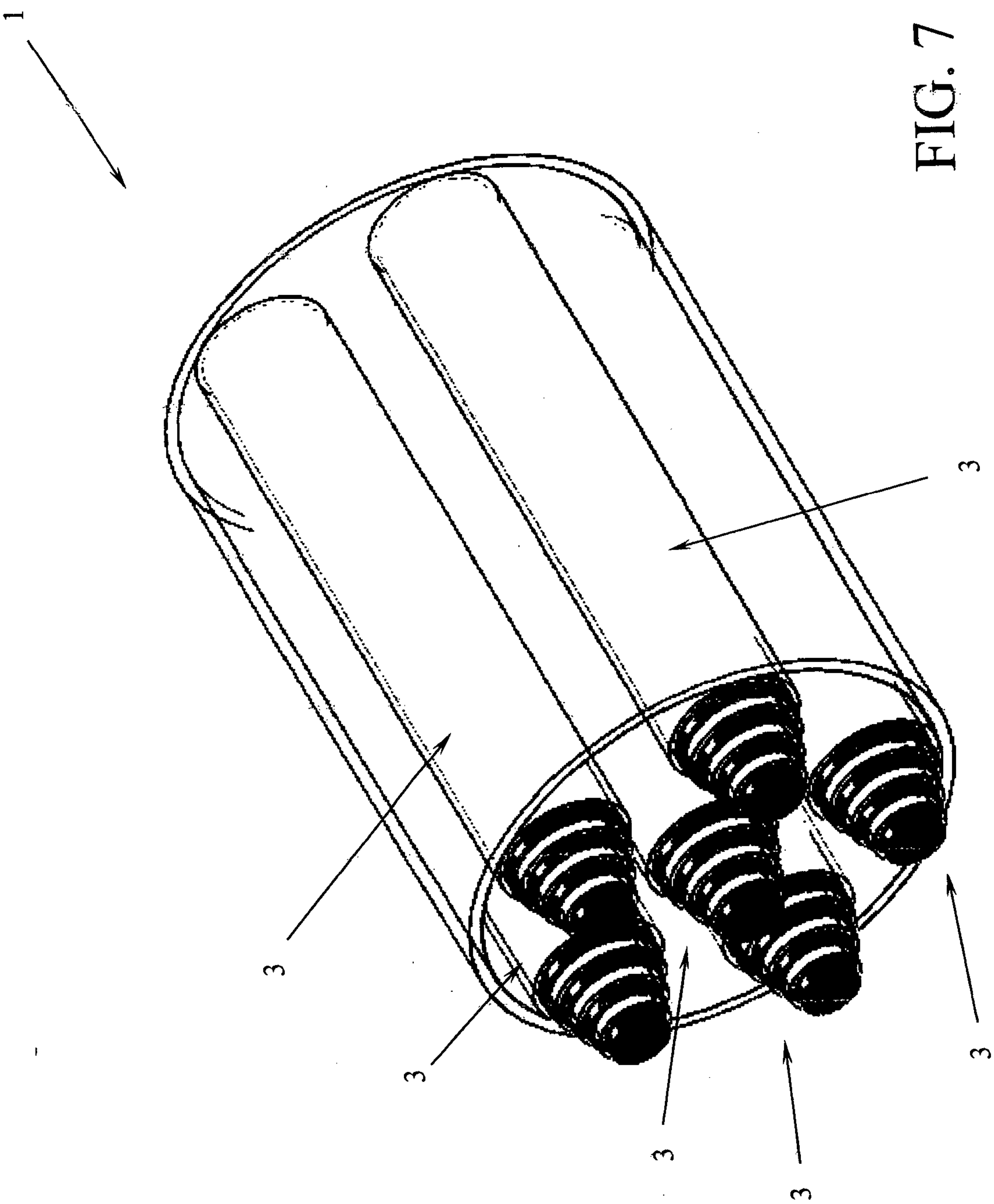

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L41/083 H01L41/087 H01L41/09 H01L41/193 H02N2/02
H02N2/06
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)
H01L H02N

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/217671 A1 (ROSENTHAL ET AL) 4 November 2004 (2004-11-04) paragraphs [0080] - [0107] figures 3b-j	1-9
X	US 2002/130673 A1 (PELRINE ET AL) 19 September 2002 (2002-09-19) paragraph [0156] figure 6e	1-9

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 September 2015	17/09/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Subke, Kai-Olaf

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KOFOD ET AL: "Multilayer coaxial fiber dielectric elastomers for actuation andÂ sensing", APPLIED PHYSICS A, vol. 102, no. 3, 13 October 2010 (2010-10-13), pages 577-581, XP019881783, ISSN: 1432-0630, DOI: 10.1007/S00339-010-6066-5 1 Introduction 2.1 Materials and manufacture of coaxial actuator figures 1, 2 -----	1-9
Y	US 4 384 230 A (WISNER) 17 May 1983 (1983-05-17) column 8, lines 41-68 figure 8 -----	1-9

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IT2015/000077

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004217671 A1	04-11-2004	US 2004217671 A1	04-11-2004
		US 2008022517 A1	31-01-2008
		US 2009184606 A1	23-07-2009
		US 2010263181 A1	21-10-2010
		US 2011025170 A1	03-02-2011
US 2002130673 A1	19-09-2002	NONE	
US 4384230 A	17-05-1983	NONE	