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(54) Title: LINEAR ELECTRONIC TRANSDUCER

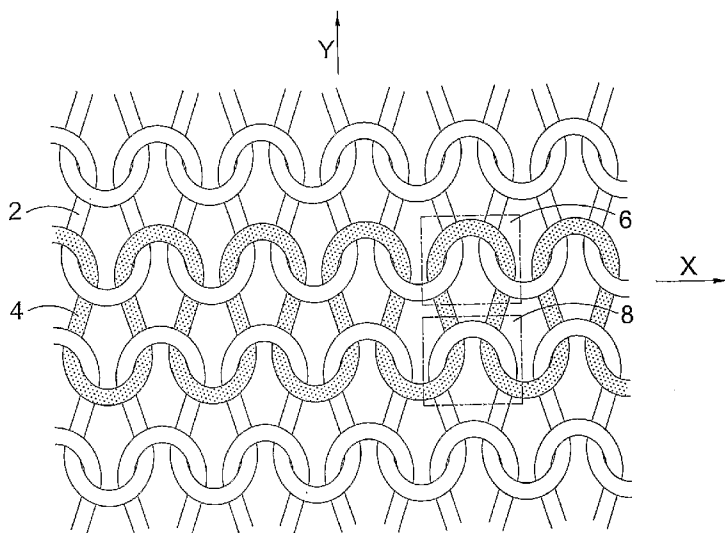


Figure 1

(57) **Abstract:** An electronic transducer comprises a knitted structure extendible in two dimensions defined by its courses and wales. An electro-conductive yarn (4) defines at least one single course in the structure adjacent non-conductive yarns (2), and is to be part of a circuit providing an indication of an electrical characteristic of the yarn. When unextended in either direction, successive loops of the stitches including the electro-conductive yarn are in engagement. Extension of the structure in the course direction separate loops forming the stitches, and extension in the wale direction urges the loops together. The structure can be used in methods of registering extension of the structure in either or both of the course and wale directions.

WO 2009/093040 A1

### Linear Electronic Transducer

This invention relates to electronic transducers, and particularly to such transducers incorporated into a knitted structure. Such knitted transducer devices are disclosed in International Patent Publication No: WO 2004/100 784, the disclosure whereof is hereby incorporated by reference. The device disclosed in this publication comprises a knitted structure having at least one transduction zone knitted with electrically conductive fibres. Deformation of the knitted structure results in a variation of an electrical property of the transduction zone. By monitoring these variations, it is possible to obtain an indication of deformation of the knitted structure. When incorporated into a garment, particularly one worn close to the skin, bodily movements can be monitored.

The present invention is also directed at electronic transducers comprising knitted structures. However, transducers of the invention focus on individual yarns in the structure, and specifically changes in an electrical characteristic of one or more knitted courses as a consequence of the structure being extended or stretched. According to the invention the transducer comprises a knitted structure of stitches arranged in courses, extendible in two dimensions defined by the courses and wales to distort the geometry of the stitches. Extension in the course dimension separates the legs of the stitches; extension in the wale dimension urges the legs of the stitches together. At least one electro-conductive yarn defines a single course in the knitted structure, which is otherwise created from non-conductive yarns, to form a single electrically conductive course of stitches with electrically non-conductive adjacent stitches. The course may be part of a circuit that provides an indication of an electrical characteristic of the course. The structure will have a relaxed or unextended condition, in which successive loops of the stitches including the electro-conductive yarn will be in engagement. With such engagement alternate stitches of the electrically conductive yarn are short circuited, and the resistance or other characteristic of the electro-conductive yarn course will reflect this. While the characteristic is typically resistance,

it might be piezoelectric, capacitive or inductive. This enables the creation of localised linear transducer within a knitted fabric structure.

When a structure embodying the invention is extended or stretched in the course direction the touching loops of the electro-conductive yarn or yarns disengage and separate, thereby breaking the short-circuits between them and altering its or their electrical characteristics. When the structure is stretched or extended in the wale direction, the loops remain in engagement and the extent of contact is increased. This will also alter the electrical characteristics of the yarn or yarns. For example, the electrical resistance of the yarn or yarns will increase upon the structure being stretched or extended in the course direction to disengage or separate adjacent loops. It will remain unaltered, or reduce in response to stretching or extension in the wale direction. In this sense then, such a fabric can function as a two-way stitch.

The non-conductive yarns in knitted structures forming transducers according to the invention are normally low modulus yarns, typically elastomeric in order to enhance the performance characteristics of the linear transducer. When knitting structures with such yarns, they will normally be substantially stretched with the consequence that in the resultant structure the stitches are contracted such that successive loops along a course of stitches are in engagement or jammed. This will draw successive loops of the conductive yarn also into engagement, with the consequences outlined above.

If the non-conductive yarns of the knitted structure are non-extendible, then the structure can be formed more loosely, and the engagement or otherwise of successive loops in the conductive yarn determined positively by the extension of the structure in one or other of the course and wale dimensions. Such a structure, or that described above comprising elastomeric yarns, could be integrated in a square, rectangular or shaped knitted panel frame in which movement of opposite sides towards and away from each other determines whether the successive loops are in engagement.

Transducers of the invention will of course be used in combination with electrical circuitry for monitoring changes in the electrical characteristic of the electro-conductive yarn. The electrical circuitry can include a display and/or a memory for keeping a record of the monitored changes. As noted above, the electrical characteristic will typically be electrical resistance, but other characteristics can also be monitored, particularly if the knitted structure includes electro-conductive yarns in yarn courses

spaced from one another, extensions in each of the course and wale direction can be very accurately monitored.

Transducers embodying the invention can be incorporated in garments such as training vests which are used to monitor body or respiratory movements. Another particular garment in which the transducer can be useful is a belt or strap which can be used to focus on a particular area or region of the body.

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

Figure 1 is an enlarged view showing details of stitches in a knitted structure;

Figure 2 is a view similar to that of Figure 1 showing details of a knitted structure in which adjacent loops of a yarn in a course are touching;

Figure 3 is a view similar to that of Figure 1 showing details of a knitted structure in which adjacent loops of a yarn in a course have been separated by stretching in the X direction;

Figure 4 is a view similar to that of Figure 1 showing details of a knitted structure in which adjacent loops of a yarn in a course have been brought together by stretching in the Y direction;

Figure 5 is a similar enlarged view showing details of a knitted structure comprising elastomeric yarns; and

Figure 6 shows how a knitted structure embodying the invention may be incorporated in a waistband or belt.

Knitted structures consist of stitches which are arranged in rows and columns. Rows are generally called courses, and extend in the same direction as that of the knitting yarn, indicated at X in Figure 1. The columns or wales extend in the perpendicular direction, indicated at Y in Figure 1.

A knitted structure in a transducer according to the invention is made up of a number of non-conductive yarns 2 with an individual conductive yarn 4 extending along a single course as shown in Figure 1. Successive courses of yarn are interlinked by loops forming stitches in which there are defined two specific binding areas 6 and 8. As shown in Figure 1, the upper binding area 6 is at the distal end of a loop formed in the yarn 4, which extends through downwardly directed neighbouring loops in the adjacent

non-conductive yarns 2. In the lower binding area 8 the arrangement is similar, with the downwardly extending loops being defined by the conductive yarn 4, held by the upwardly extending loop from the adjacent lower non-conductive yarn 2.

The fabric structure shown in Figure 1 is relatively loose, and the yarns are substantially non-extensible. The yarns are though, fully flexible. As a consequence, when the structure is extended in the Y direction the structure will contract in the X direction. The result is engagement between the outer flanks of adjacent loops in each yarn, and particularly of those loops in the conductive yarn 4. This engagement creates an electrical short circuit of alternate lengths of yarn, thereby altering its electrical characteristics, and particularly the electrical resistance between the ends of the yarn on either side of the fabric structure. If the structure is then extended in the direction X, then the effect is reversed with the loop flanks being withdrawn from one another and with that withdrawal, the removal of any short circuits created thereby. Any electrical current passing through the conductive yarn must then travel the full length of the yarn, whose effective resistance is thereby increased.

A tightly knitted fabric of non-extensible yarns can be created with a relaxed structure of the kind illustrated in Figure 2. As can be seen, successive loops in the yarn of each course of stitches are touching. If one (4) of the yarns shown was electrically conductive, then its electrical characteristics will be influenced by the contact and the points of contact between successive loops. Its measured resistance for example will be reduced relative to that of its full length by an amount determined by the location of the points of contact in the loops. In effect, there will be a short circuit across each loop.

If the fabric of Figure 2 was extended in the course direction (X in Figure 1), then each loop will be extended as shown in Figure 3. The points of contact shown in Figure 1 will disengage, and an electric current in the conductive yarn 4 must use its full length, including all the loops. Its measured electrical resistance will correspondingly increase, and by an amount that can be easily monitored. Extension of the fabric by a predetermined amount sufficient to disengage the contact points can therefore be registered. Other electrical characteristics, such as piezoelectric, capacitative or inductive can also be monitored to register different degrees of extension.

If the fabric of Figure 2 was extended in the wale direction (Y in Figure 1), then each loop will be extended as shown in Figure 4. As a consequence, the length of the conductive yarn 4 carrying current and therefore its measured resistance will be further

reduced relative to that of its full length. The change will of course be progressive, enabling the amount of extension to be monitored, not just the passage beyond a predetermined amount. It will be appreciated that if the fabric of Figure 2 was subject to extension in both the course and the wale direction, then extension in one of these directions will affect the monitoring of an electrical characteristic of the conductive yarn as a consequence of extension in the other. Monitoring circuitry can of course accommodate this, and in some circumstances monitor both extensions, for example by simultaneously monitoring different electrical characteristics of the yarn.

A knitted structure embodying the present invention can be created using a conductive yarn in combination with low modulus non-conductive yarns such as single or double covered elastomeric yarns or monofilament or multifilament elastomeric yarn. In such a structure, because the low modulus yarn would be stretched during the knitting process, the knitted structure would naturally contract to bring adjacent flanks of the loops in respective stitches into intimate contact with each other. Such stitches are called jammed stitches, and a section from such a structure is illustrated in Figure 5. This structure can effectively only be stretched or extended in the X direction. Thus, in its natural or relaxed state as illustrated, the electrical characteristic of an electro-conductive yarn 4 defining one of the courses in the structure will be that at which the juxtaposed flanks of adjacent loops are in close engagement, short circuiting alternate lengths of yarn as described above. Its electrical resistance for example will be reduced relative to that of the total length of the yarn without the short circuits. When the structure of Figure 5 is stretched in the course direction X, the touching flanks are separated, and the overall resistance of the conductive yarn 4 between its ends is increased.

The knitted structure of Figure 5 comprising the same low modulus or elastomeric yarns has uniform and predictable extension characteristics. As a consequence, when a single conductive yarn 4 is incorporated in the structure as described above, the point at which its electrical characteristic changes as a result of the separation of touching flanks can be accurately associated with a particular extension of the structure in the course direction X.

Transducers embodying the invention can be used in a number of applications where accurate monitoring identification of movement is required. This is of particular value in performance, sports and medical applications where it is needed to monitor

respiration or physical movement around joints for example. It can though, also be useful to monitor cyclic testing of mechanical constructions.

Figure 6 illustrates a belt or strap incorporating a transducer 10 embodying the invention as shown. The transducer makes up the entire width of the belt, and must thereby accommodate any extension of the belt length. An adjustment mechanism 12 enables the belt to be fitted and adapted to the wearer such that it closely follows the respective body contours enabling extensions and contractions to be monitored.

Within the transducer 10, a single conductive yarn 4 extends within a structure comprising non-conductive yarns. At either lateral end of the transducer, the yarn 4 is connected to conductors 14 extending to a recorder box 16 which monitors changes in one or more electrical characteristics of the conductive yarn 4 within the transducer. The conductors 4 will be fixed in the body of the belt which, apart from the transducer 10, is substantially non-extensible. The control box 16 will be mounted on and slidable relative to the non-extensible belt sections. The recorder box 16 will include the requisite circuitry and power source such as a small battery, none of which is shown. It can also include a display panel to provide a visible indication of extensions and contractions of the belt as a whole. It can also be coupled to a remote recorder for monitoring these changes, either directly or through a wireless connection.

The invention has been described using a single conductive yarn in a knitted structure of non-conductive yarns. However, it will be appreciated that a plurality of conductive yarns may be used; either individually, or in parallel or in series.

Various different yarn materials may be used in knitted structures embodying the invention. Suitable non-conductive and non-extensible yarns (as per Figure 1) are made from any natural and/or man-made fibres, such as cotton, wool, PE, PP, PA, Aramids etc. Preferred low modulus or elastomeric non-conductive yarns are monofilament or multifilament PU (Lycra, Spandex etc), single or double covered Lycra or Spandex. Suitable conductive yarns can be plain metal yarns such as stainless steel yarns, carbon yarns and all metal coated yarns. Suitable coated yarns consist of polyethylene multi-filaments, each coated with a nano layer of silver, copper, nickel or gold.

**CLAIMS:**

1. An electronic transducer comprising a knitted structure of stitches arranged in courses and wales, and extendible in two dimensions defined by the courses and wales to distort the stitches, extension in the course dimension separating loops forming the stitches and extension in the wale dimension urging the loops together, wherein an electro-conductive yarn defines at least one single course in the structure adjacent non-conductive yarns, in which, when unextended in either dimension successive loops of the stitches including the electro-conductive yarn are in engagement, which yarn is adapted to be part of a circuit for providing an indication of an electrical characteristic of the yarn.
2. A transducer according to Claim 1 wherein the non-conductive yarns are low modulus yarns.
3. A transducer according to Claim 2 wherein the non-conductive yarns are elastomeric yarns.
4. A transducer according to Claim 2 or Claim 3 wherein the non-conductive yarns are extended in the knitting process, whereby stitches in the knitted structure are jammed with successive loops of stitches including the electro-conductive yarn urged against one another.
5. A transducer according to any preceding Claim wherein the electrical characteristic of the electro-conductive yarn is resistance.
6. A transducer according to any of Claims 1 to 4 wherein the electrical characteristic of the electro-conductive yarn is piezoelectric.
7. A transducer according to any of Claims 1 to 4 wherein the electrical characteristic of the electro-conductive yarn is capacitive.
8. A transducer according to any of Claims 1 to 4 wherein the electrical characteristic of the electro-conductive yarn is inductive.
9. A transducer according to any preceding Claim in combination with electrical circuitry for monitoring changes in said electrical characteristic.
10. A garment incorporating a transducer according to any preceding Claim as an integral part thereof.

11. A garment according to Claim 9 in the form of a belt.
12. A method of registering the extension of a knitted structure in the direction of its courses, in which structure an electro-conductive yarn defines at least one single course in the structure adjacent non-conductive yarns and has a predetermined electrical characteristic when the structure is in a reference condition, wherein extension of the structure in the course direction causes successive loops in the stitches of the electro-conductive yarn to separate, the method comprising monitoring the electrical characteristic for a change indicative of a given said extension.
13. A method according to Claim 12 wherein, in said reference condition successive loops in the stitches of the electro-conductive yarn are in engagement.
14. A method of registering the extension of a knitted structure in the direction of its wales, in which structure an electro-conductive yarn defines at least one single course in the structure adjacent non-conductive yarns and has a predetermined electrical characteristic when the structure is in a reference condition, wherein extension of the structure in the wale direction causes successive loops in the stitches of the electro-conductive yarn to come together, the method comprising monitoring the electrical characteristic for a change indicative of a given said extension.
15. A method according to Claim 14 wherein, in said reference condition successive loops in the stitches of the electro-conductive yarn are spaced from each other.
16. A method according to Claim 13 or Claim 15 wherein said electrical characteristic is resistance and said given extension is that at which successive loops in the stitches of the electro-conductive yarn respectively disengage or come together.
17. A method according to Claim 16 wherein said given extension is that at which a preset number of successive loops in the stitches of the electro-conductive yarn respectively disengage or come together.

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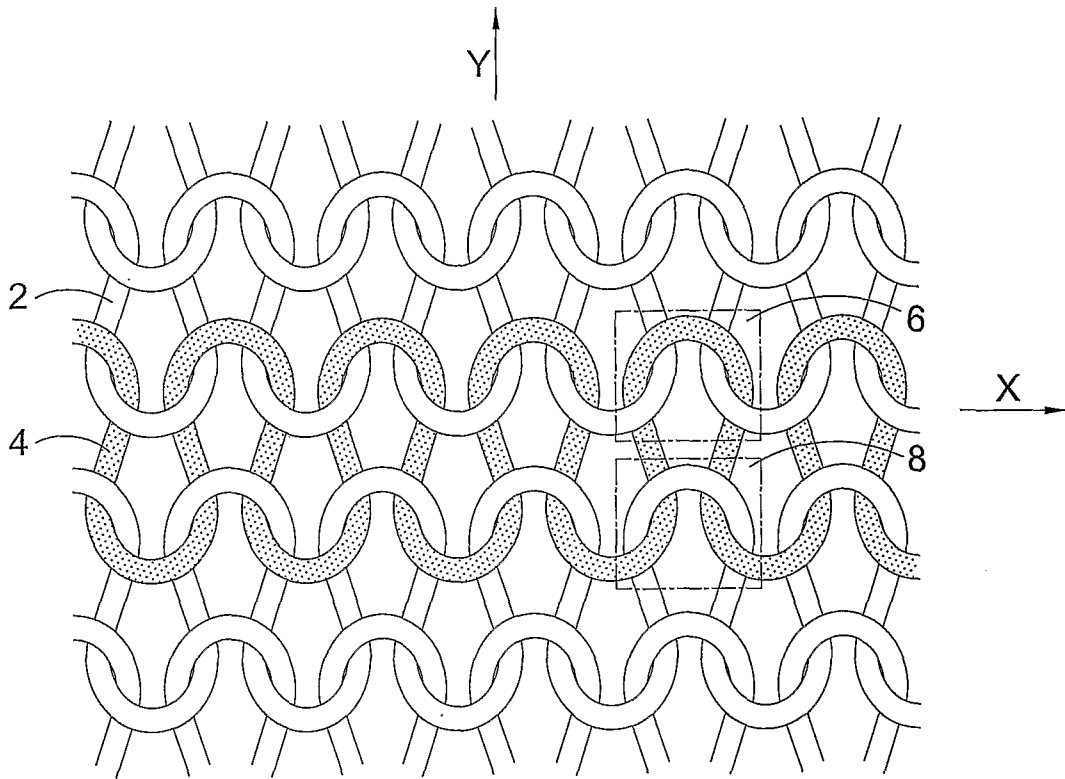


Figure 1

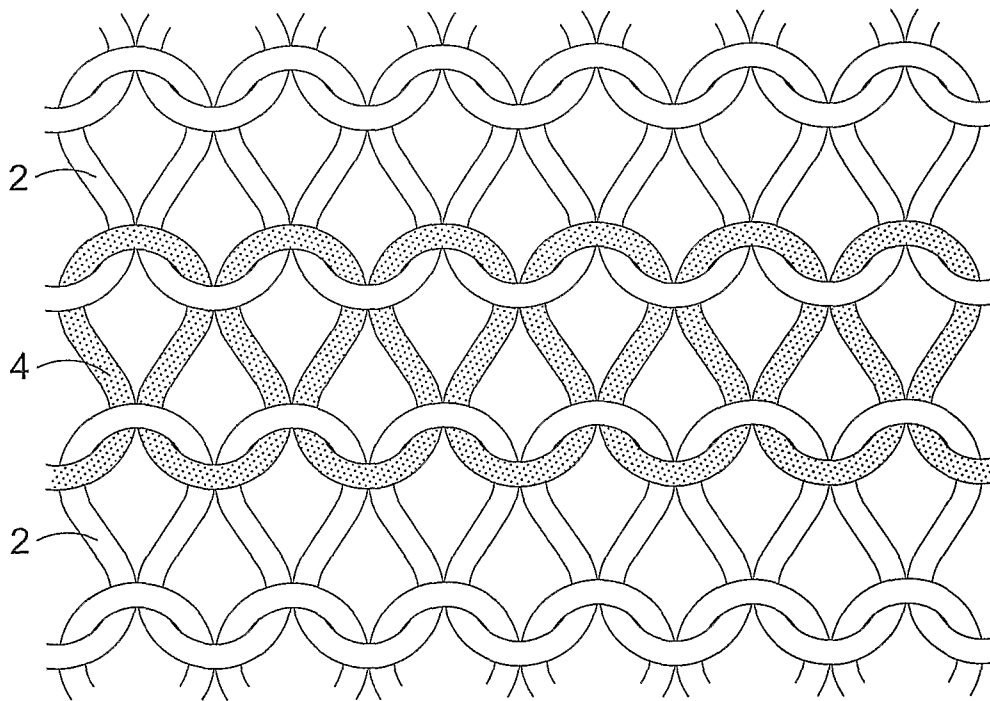


Figure 2

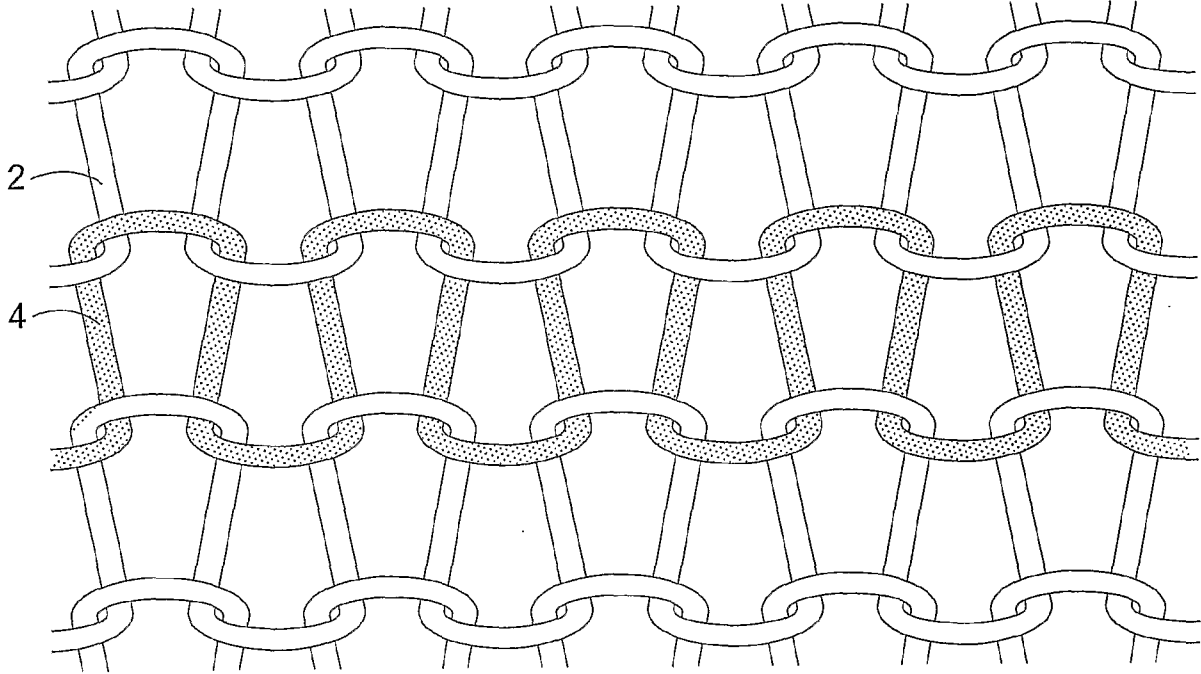


Figure 3

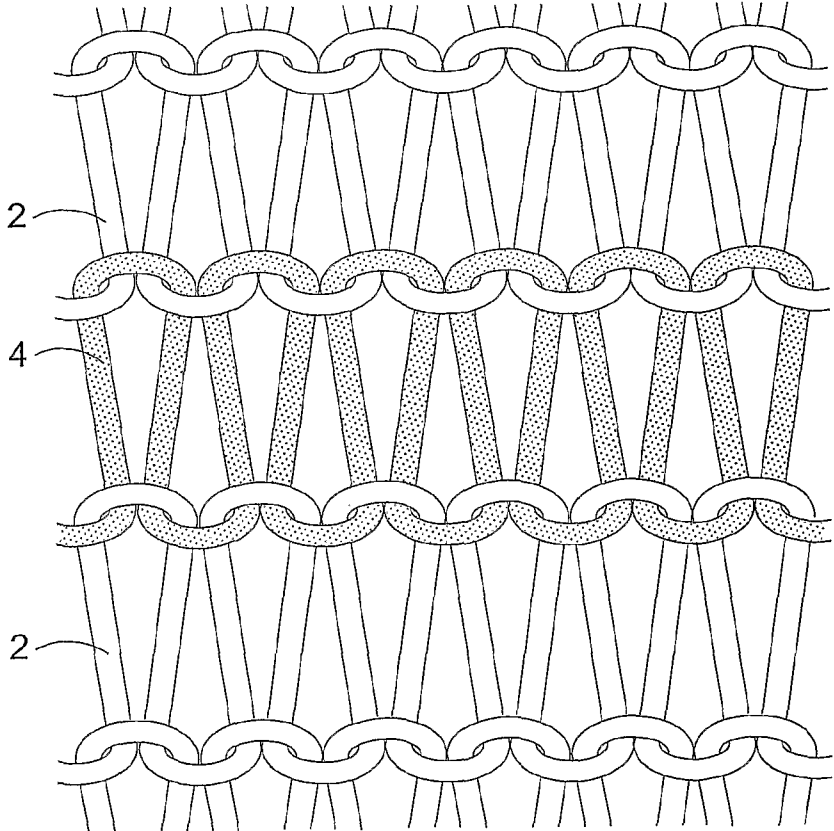


Figure 4

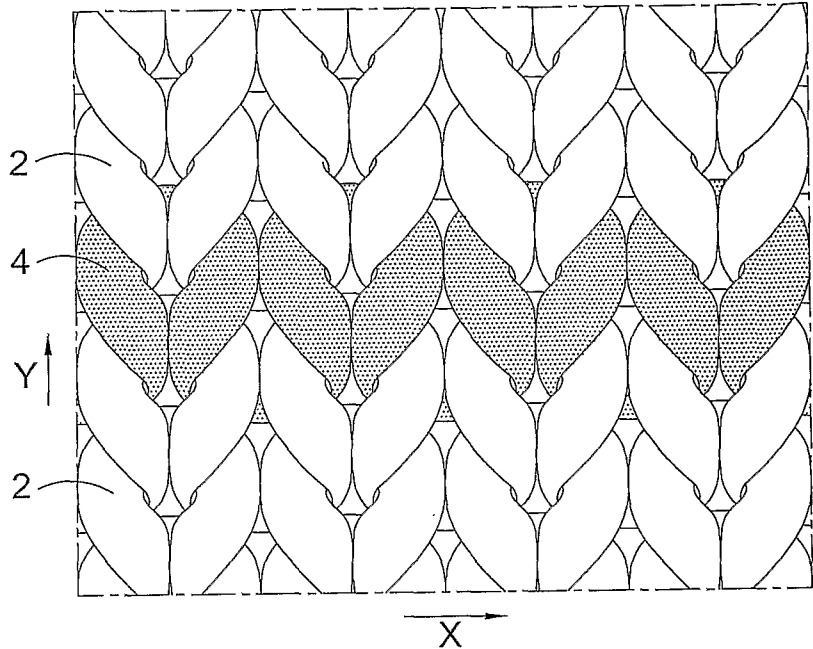


Figure 5

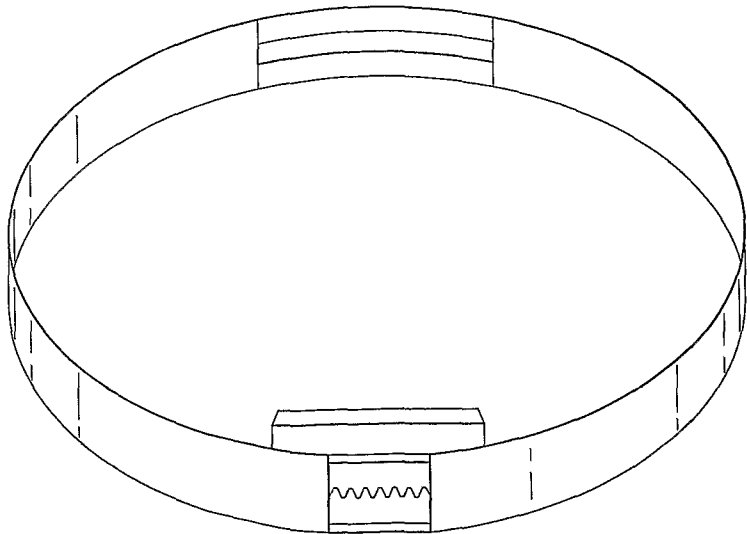


Figure 6

# INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2009/000195

**A. CLASSIFICATION OF SUBJECT MATTER**  
INV. D04B1/14      D04B1/24

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)  
D04B

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

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

EPO-Internal

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X  A	DE 10 2004 038636 A1 (MEDI BAYREUTH WEIHERMUELLER & [DE]) 16 February 2006 (2006-02-16) the whole document -----	1-11  12, 14
X  A	WO 2007/050650 A2 (SENSATEX INC [US]; SHARMA VIKRAM [US]) 3 May 2007 (2007-05-03) paragraph [0056]; figure 3a -----	1-11  12, 14
A	WO 2004/100784 A2 (UMIST VENTURES LTD [GB]; UNIV MANCHESTER [GB]; DIAS TILAK [GB]; BEATTI) 25 November 2004 (2004-11-25) cited in the application the whole document -----	1, 9-10, 12, 14
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Further documents are listed in the continuation of Box C.

See patent family annex.

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- \*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
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Date of the actual completion of the international search

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## INTERNATIONAL SEARCH REPORT

International application No

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2005/053532 A1 (MILIOR S P A [IT]; PARADISO RITA [IT]) 16 June 2005 (2005-06-16) the whole document -----	1, 9-10, 12, 14

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Information on patent family members

International application No

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