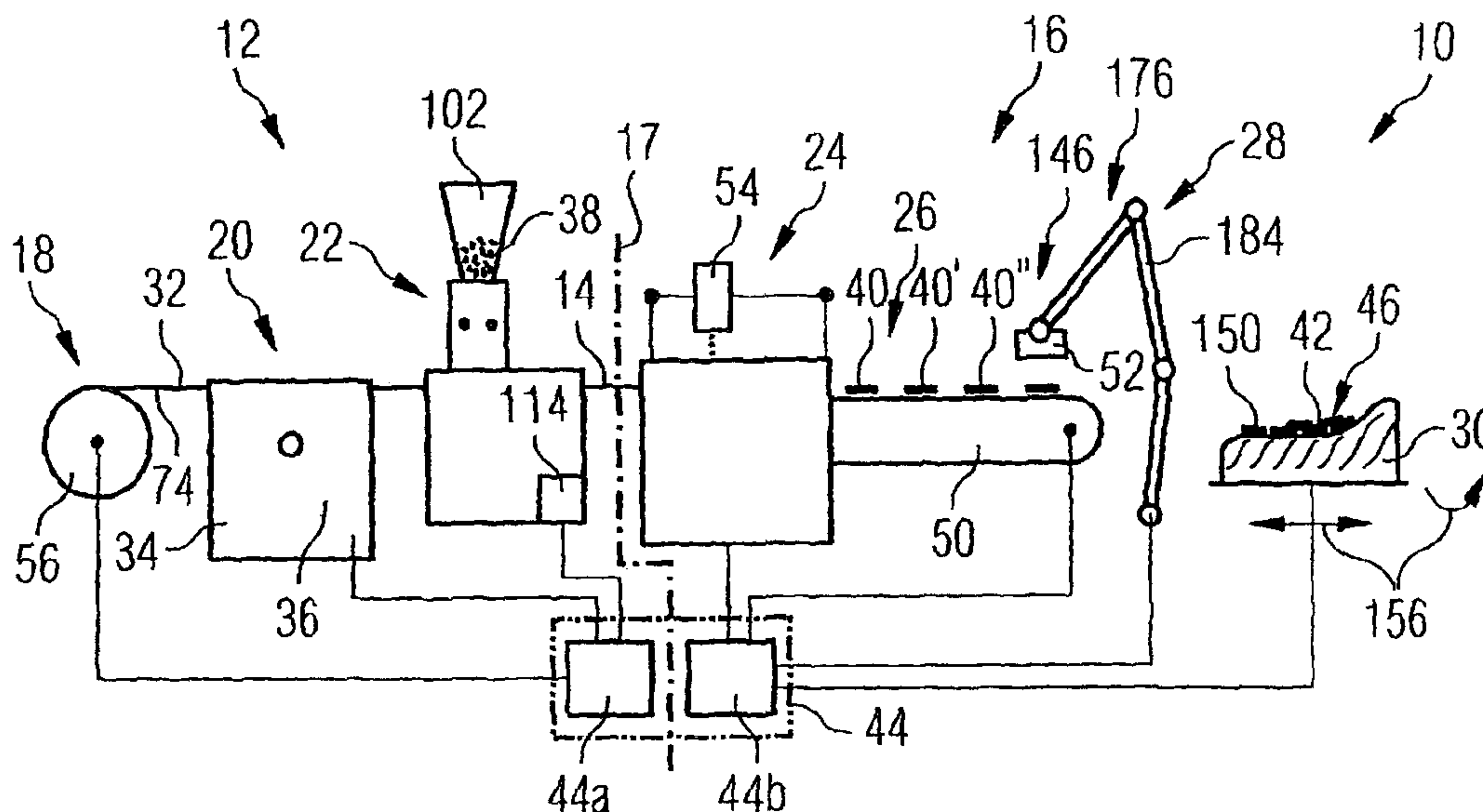




(86) Date de dépôt PCT/PCT Filing Date: 2008/03/13
 (87) Date publication PCT/PCT Publication Date: 2008/09/18
 (45) Date de délivrance/Issue Date: 2014/04/29
 (85) Entrée phase nationale/National Entry: 2009/09/10
 (86) N° demande PCT/PCT Application No.: EP 2008/053047
 (87) N° publication PCT/PCT Publication No.: 2008/110614
 (30) Priorités/Priorities: 2007/03/13 (DE10 2007 012 608.7);
 2008/03/03 (DE10 2008 012 255.6)

(51) Cl.Int./Int.Cl. *B29B 11/16* (2006.01),
B29C 70/38 (2006.01), *B65H 51/005* (2006.01),
D02J 1/18 (2006.01)
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(54) Titre : PROCEDE ET DISPOSITIF DE FABRICATION D'UNE PREFORME POUR UNE STRUCTURE EN MATERIAU RENFORCE PAR DES FIBRES ADAPTEE A DES FLUX DE FORCES
 (54) Title: METHOD AND DEVICE FOR PRODUCING A PREFORM FOR A FIBRE COMPOSITE STRUCTURE SUITABLE FOR POWER FLOWS



(57) Abrégé/Abstract:

The invention relates to a method and a device for producing a preform (42) for a fibre composite structure suitable for power flows. According to the invention, relatively short fibre band pieces (40, 40', 40'') are to be cut from a spread-out fibre band (14), laid in a pre-determined position, and fixed in said position by means of a binding material (38).



(12) NACH DEM VERTRAG ÜBER DIE INTERNATIONALE ZUSAMMENARBEIT AUF DEM GEBIET DES PATENTWESENS (PCT) VERÖFFENTLICHTE INTERNATIONALE ANMELDUNG

(19) Weltorganisation für geistiges Eigentum
Internationales Büro(43) Internationales Veröffentlichungsdatum
18. September 2008 (18.09.2008)

PCT

(10) Internationale Veröffentlichungsnummer
WO 2008/110614 A1

(51) Internationale Patentklassifikation:

B29B 11/16 (2006.01) **D02J 1/18** (2006.01)
B29C 70/38 (2006.01) **B65H 51/005** (2006.01)

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(21) Internationales Aktenzeichen: PCT/EP2008/053047

(22) Internationales Anmeldedatum:

13. März 2008 (13.03.2008)

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(25) Einreichungssprache:

Deutsch

(26) Veröffentlichungssprache:

Deutsch

(30) Angaben zur Priorität:

10 2007 012 608.7 13. März 2007 (13.03.2007) DE
10 2008 012 255.6 3. März 2008 (03.03.2008) DE

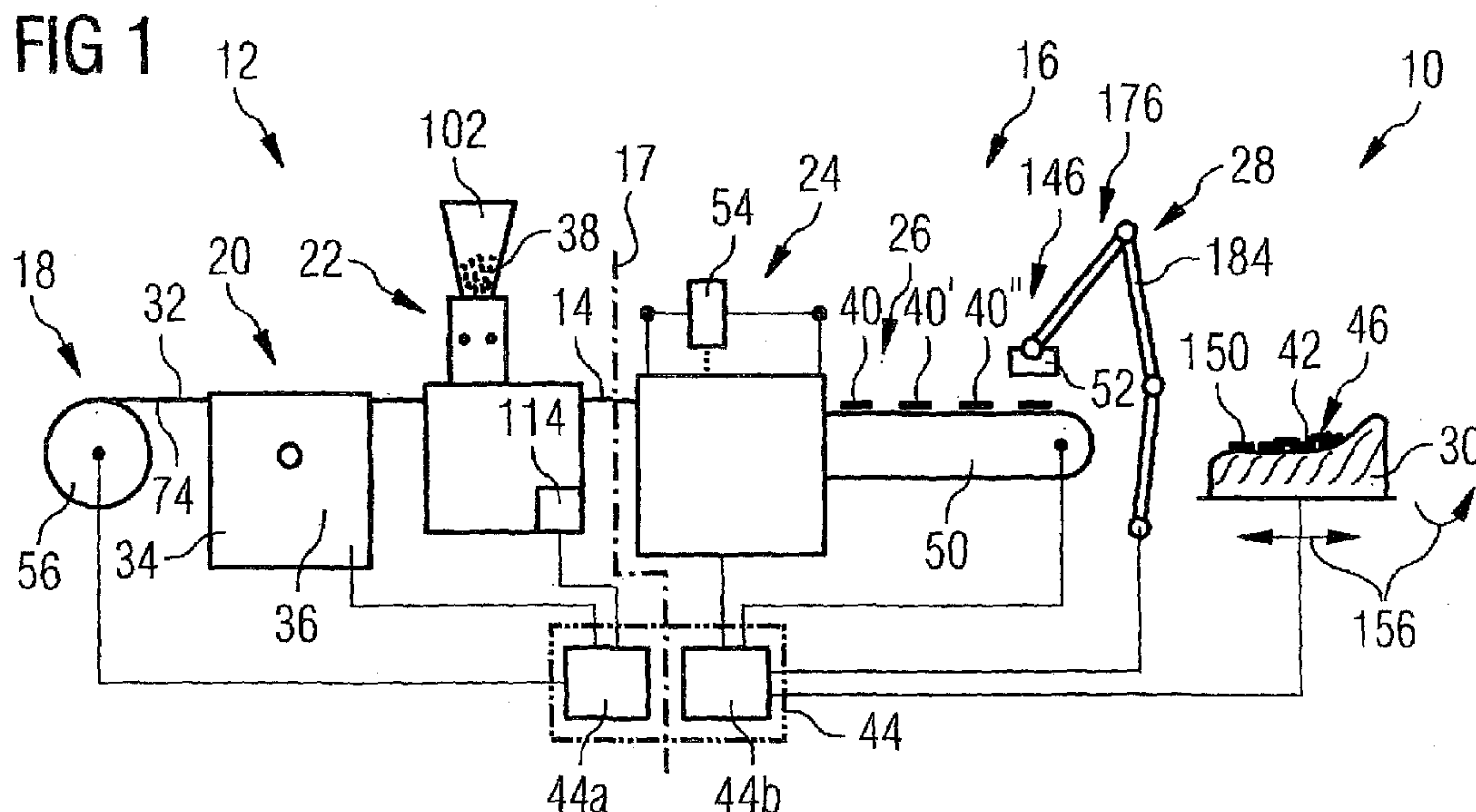
(81) Bestimmungsstaaten (soweit nicht anders angegeben, für jede verfügbare nationale Schutzrechtsart): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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[Fortsetzung auf der nächsten Seite]

(54) Title: METHOD AND DEVICE FOR PRODUCING A PREFORM FOR A FIBRE COMPOSITE STRUCTURE SUITABLE FOR POWER FLOWS

(54) Bezeichnung: VERFAHREN UND VORRICHTUNG ZUM HERSTELLEN EINER PREFORM FÜR EINE KRAFTFLUSSGERECHTE FASERVERBUNDSTRUKTUR



(57) Abstract: The invention relates to a method and a device for producing a preform (42) for a fibre composite structure suitable for power flows. According to the invention, relatively short fibre band pieces (40, 40', 40'') are to be cut from a spread-out fibre band (14), laid in a pre-determined position, and fixed in said position by means of a binding material (38).

(57) Zusammenfassung: Die Erfindung betrifft ein Verfahren und eine Vorrichtung zum Herstellen einer Preform (42) für eine kraftflussgerechte Faserverbundstruktur. Hierzu wird vorgeschlagen, von einem aufgespreizten Faserband (14) relativ kurze Faserbandstücke abzuschneiden (40, 40', 40''), an vorbestimmter Position zu verlegen und dort mittels eines Bindematerials (38) zu fixieren.

WO 2008/110614 A1

WO 2008/110614 A1

(84) **Bestimmungsstaaten** (soweit nicht anders angegeben, für jede verfügbare regionale Schutzrechtsart): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), eurasisches (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), europäisches (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Veröffentlicht:

- mit internationalem Recherchenbericht
- vor Ablauf der für Änderungen der Ansprüche geltenden Frist; Veröffentlichung wird wiederholt, falls Änderungen eintreffen

Method and Device for Producing a Preform for a Fibre Composite Structure Suitable For Power Flows

The invention relates to a process for manufacturing a preform for a load path aligned
5 fiber composite structure. The invention also relates to the use of such a process in the
manufacture of load path aligned fiber composite structures. Finally, the invention
relates to a device for carrying out the process.

At the construction of vehicles of all kinds, particularly at the construction of aircrafts
10 and spacecrafts, but also in other branches of industry such as mechanical engineering,
there is an increasing need for strong and yet lightweight, cost-efficient materials.
Especially fiber composite materials offer an outstanding lightweight construction
potential. The principle resides in the fact that particularly high-strength and stiff fibers
are embedded in a matrix in a load path aligned fashion, thus producing components
15 having outstanding mechanical properties by using previous techniques and having a
weight which at a comparable performance is typically 25% less than that of aluminum
structures and 50% less than steel structures. A drawback is the high material costs and
particularly the laborious and mainly manual fabrication.

20 Accordingly, there is a desire for an automated manufacture facilitating machine
positioning of the fibers in space. Nowadays, fiber-reinforced plastic materials are
characterized by an extremely high strength and stiffness at a low weight, particularly if
oriented long fibers, for instance carbon fibers, are used. They also have a high weight-
specific energy absorption potential and good fatigue characteristics.

25

Up to now this is achieved by endless fibers being incorporated in a matrix (e.g. epoxy
resin) in a load path aligned fashion. Depending on the direction of reinforcement,
anisotropic materials having direction-dependent mechanical properties can be
produced. For instance, a material can have characteristics which are different from
30 each other in the length and in the width of the material. Already today, a high

percentage of the structural weight in modern aircrafts and spacecrafts, is made up of fiber-reinforced plastic materials.

5 Currently, the most important manufacturing process is based upon the so-called prepreg technology. This technology involves positioning the reinforcing fibers in a parallel (unidirectional) fashion and embedding the fibers in a matrix. After a curing step, semi-finished products are produced which are rolled up as a thin layer. During processing, these layers are cut corresponding to the contour of the component and are laminated in a tool layer by layer and preferably by hand. Thereafter, curing takes place
10 under pressure and temperature inside an autoclave. The resulting components exhibit a very high light construction potential, but the manufacture is laborious and expensive. For this reason material searchers have for long dealt with the question in which way fibers can be positioned aligned to the load path and three-dimensionally and with a contour which matches the final contour of the component as closely as possible, in an
15 automated process.

To produce fiber composite structures with load path aligned fibers, so-called preforms as textile semi-products have been manufactured up to present for selected applications in addition to preregs. These are mostly two- or three-dimensional structures having a
20 load path aligned fiber orientation. Up to present endless fibers are placed in the load direction and prefixed by using means and techniques from textile engineering, normally sewing, knitting or the like. Examples of devices and processes for producing such preforms are disclosed in DE 30 03 666 A1, DE 196 24 912, DE 197 26 831 A1 and DE 100 05 202 A1.

25

From US 4,952,366 A1 a comparable process for manufacturing a preform and a composite structure from this preform is known, wherein a prepreg is reinforced with an endless fiber in order to produce the preform. During the transport of the prepreg the endless fiber is initially fixed to the prepreg through vacuum suction. Hence, a transport

of fiber layups on a conveyor belt in such a way that these fiber layups are drawn onto the conveyor belt by means of vacuum, is known from this prior art.

From DE 30 48 367 C1 a process and a device for spreading a fiber strand are known.
5 In this process the fiber strand is penetrated and fanned out as widely as possible by a convex surface.

From CH 450239 there are also known a process and a device for spreading a fiber strand. In this process the fiber strand is passed over fixed strips in a meandering
10 fashion. A guide surface of the strip is convexly bent in arc-shaped fashion.

From US 2002/0123819 A1 a system for automatic control of the spreading of a textile layer is known. The textile layer is composed of a plurality of fiber strands. This system includes a measuring device for measuring the position of the longitudinal edges of
15 each fiber strand, a width adjustment device for the individual adjustment of the width of each fiber strand, a position adjustment device for the adjustment of the position of each rope, and a control device for controlling the spreading operation in such a manner that the textile layer has a predetermined width and position. During this operation the fiber strands are pulled over bent rods.

20

From DE 695 00 513 T2 a segmented fiber laying head for laying and pressing fibers strands against a preform is known. Due to its segmentation the fiber laying head is elastic, so that the pressing force can be better adjusted for irregular moulds. The laying head includes a pressure roller by which individual long fiber strands can be pressed
25 against the preform. For forming the segmented fiber laying head this pressure roller is composed of many individual discs. Totally sixteen individual fiber strands are passed via fiber strand guides to the fiber laying head.

From EP 0 491 353 A1 a multiple axes fiber lay-up machine comprising a laying head
30 on a robot arm is known. This laying head includes a pressure roller by means of which

fiber strands can be compacted and pressed-on. The laying head processes a roving into a band and places the band onto a preform supported for rotation. The rovings are previously impregnated with resin. The individual elements are temperature-controlled, in order to adjust the adhesiveness of the resin for the respective processing step. In particular, the compacting roller can be heated for increasing the adhesiveness for the pressing-on operation. In this case, too the rovings are directly passed from a supply reel via fiber guides to the laying head.

From FR 2882681 there is also known a fiber lay-up machine for producing fiber-reinforced composite structures. The same includes a laying head for applying fiber strands. The laying head also includes a lay-up roller for the placement of the fibers onto a preform. Further the laying head, which is articulated to the end of a robot arm, is provided with means for applying resin to each fiber shortly before laying. Accordingly, a thermoplastic material as a binder can be applied by the head. The head also includes a cutting device for cutting the fibers strands to the desired lengths. This cutting device is arranged upstream of the device for applying resin. A transfer of the fiber strands from the cutting device to the lay-up roller takes place by means of air. In addition, a cooling device for cooling the fiber strands contacting the lay-up roller is provided for adjusting the adhesiveness. In the device for applying resin, heating elements can be provided to adjust the viscosity of the resin for the purpose of dosing and applying. The laying head is supplied with a plurality of fiber strands which are placed side by side and combined into a fiber band or fiber tape. For this purpose a transfer device is provided guiding the endless fiber strands from the supply reel up to the laying head.

From DE 103 01 646 A1 a filament or fiber laying as well as a process for its manufacture are known. In this process individual strand pieces of fiber strand material are laid without tension. This is performed by a plurality of combined laying and separation devices which in addition to the laying function for laying the individual fiber strand also have a separating function for separating the fiber strand piece. The laying and separation device is tubular and can have a certain spreading function by which a

fiber strand which originally has a round cross section is changed into a flat and more rectangular cross section. The laying normally takes place with parallel adjacent strand pieces. The fixing of the laid individual fiber strand pieces to the subsurface can be performed by clamping means having an additional spreading effect or by means of
5 gluing.

However, the known processes for manufacturing preforms are complicated concerning their implementation and process technique. Particularly for components where curved load path lines with a varying density are to be expected, it is not possible with previous
10 processes to manufacture a correspondingly load path aligned component. Particularly, the fibers cannot be oriented arbitrarily along defined curved paths and the fiber content cannot be locally varied.

Accordingly, it is an object of the invention to provide a process and a device for the
15 manufacture of textile semi-products for load path aligned fiber composite structures in which the fibers can be better and more easily adjusted to complicated load paths. Particularly, it is an object of the invention to provide a more simple process for the manufacture of a load path aligned component in which fibers can be oriented arbitrarily along defined curved paths and the fiber content can be locally varied.

In the process according to the invention a preform can be manufactured by first of all providing a flat fiber band. For this purpose and according to a preferred embodiment, a fiber filament bundle, preferably a roving, is spread to become flat.

- 5 According to a different embodiment of the process the flat fiber band is obtained by first of all providing a fiber band which is present as pre-impregnated semi-product. Pre-impregnated fiber semi-products are available for example in the form of prepregs or in the form of fiber semi-products impregnated with thermoplastic material. These semi-products can comprise unidirectional fibers, especially in the longitudinal direction of the
10 band, or also a fibrous fabric.

From this flat fiber band, which is present for example in the form of a spread bundle of fiber filaments or in the form of a semi-product pre-impregnated with a binder material, a fiber band piece – in the following also referred to as patch – is cut off at a predefined
15 length. Thereafter, the fiber band piece is taken up by means of a lay-up device and is placed at a predefined position. There the fiber band piece is fixed by means of a binder material. The cutting, placement and fixing of fiber band pieces is repeated, with the fiber band pieces being placed and fixed at different predefined positions. Preferably, this is performed in such a way that from the several patches which are fixed to each
20 other and/or to possible additional component parts of the preform the desired preform having a load path aligned fiber orientation is formed. In this way it is also possible for example to specifically reinforce also a part of a conventionally produced preform by patches being placed in a load path aligned fashion at positions which are particularly subjected to stress.

25

The invention, which could also be referred to as fiber patch preforming technology, enables the lay-up of short fiber pieces (patches) at the precise position by a special laying process. The required properties of the preform can be met through the orientation and the number of fiber pieces.

30

Cutting into short fiber pieces enables an orientation also along more strongly curved paths. Examinations have shown that despite the use of short fiber pieces instead of endless fiber structures a very high strength can be achieved – particularly because of the exact orientation and the better adaptability – thus considerably facilitating the lay-up process compared to the purely textile preforming methods.

By laying flat and short cut fiber pieces, the process according to the invention enables manufacturing load path aligned preforms. In preferred embodiments a fiber cutting tool cuts specially prefabricated binder-impregnated fiber bands or fiber bands from a previously binder-impregnated semi-finished material and delivers the same to a vacuum band-conveyor. There the fiber band pieces are separated and transferred to the lay-up device. The delivery of the fiber band pieces to a laying head of the lay-up device takes place smoothly via a combination of suction modules and blow off modules. In a preferred embodiment a heating device is provided on the laying head to heat the fiber band piece from ambient temperature during the transfer to its laying position and thus activate the binder. The laying head presses the fiber band piece onto the predefined position and moves away preferably by a blow off pulse. Thereafter the laying head returns to its initial position.

The technology according to the invention and/or its preferred embodiments allows the fully automated production of complex fiber preforms. Parameters like fiber content, fiber orientation and curve radii can be largely varied.

In the embodiment in which specially fabricated flat fiber bands are used, the binding material for fixing the fiber band piece is preferably applied to the fiber filaments, the binder material preferably being a thermally activated binder material, for example a thermoplastic material. Concerning the technical process, this can be easily implemented when the binder material is present and applied to the fiber filaments in the powder form and adheres there after a short time of heating. Though it is possible to apply the binder material during the transfer between the cutting operation and the

placement, it turned out that the technical process can be implemented more easily when the binder material is previously applied to the fiber filaments. A good distribution along with easy application is achieved when the binder material is applied to the bundle of fiber filaments between the spreading operation and the cutting operation.

5

In the embodiment in which pre-impregnated semi-products are used for the provision of the flat fiber band, prepregs or thermoplastic tapes are preferably used as the pre-impregnated semi-products. Thus it is not necessary to first provide the starting materials for delivering the fibers with a binding material. In fact the starting materials are already present in the initial form suitable for the process.

10

Patches from a thin fabric can be used as well. If fabric semi-products are used, fibers can be simultaneously laid in different fiber directions. For example, fabrics from fibers are formed in at least two different fiber orientations (e.g. 0° and 90°).

15

Especially by applying this easier fiber patch technology, it is possible to produce prototypes in a way similar to the rapid prototyping process. These components can then be tested with material properties which are reduced by a particular factor before employing more complicated manufacturing processes.

20

To enable also the production of complicated three-dimensional structures, it is further preferred that during the placement operation the fiber band piece is pressed onto a portion of a forming surface for the preform. This is preferably achieved by using on the laying head a laying die having an elastic pressing surface.

25

The shorter the fiber band pieces or patches which are cut the smaller the curvature radii that can be reproduced by a different orientation of fiber band pieces placed one behind the other in the fiber direction. Accordingly, for forming the fiber band piece, a cut-off length of less than about 20 cm, particularly less than about 10 cm is preferred.

30

When the fiber band pieces are very short, the requirements to the device for handling

the fiber band pieces become higher, especially the requirements to a cutting device which has to make cuts which are defined as precisely as possible while the distance is correspondingly shorter, and also the requirements to the laying device which has to lay a higher number of fiber band pieces for a given area of the preform. Accordingly,
5 approximately 10 mm are preferred as a lower parameter for the length of the fiber band pieces. These dimensional specifications can correspondingly vary depending on the size of the component to be produced.

According to the invention, a laying head of the lay-up device is – preferably
10 automatically – controlled in a manner such that it can reciprocate between at least one or more pickup positions where the individual fiber band pieces are picked up, and the positions respectively predetermined for the placement of the individual fiber band pieces.

15 To separate or to sufficiently space the fiber band pieces or patches from each other after the cutting operation, to allow the lay-up device to securely pick up the fiber band pieces individually and one after the other, a transfer by means of a transfer device is preferred having a transferring speed higher than the conveying speed for conveying the spread bundle of fiber filaments to a cutting device.

20

To precisely position the fiber band pieces, it is further preferred for the individual patches being held on the transfer device and/or the lay-up device, particularly on a laying head thereof. This can be done preferably with pneumatic forces, especially by a suction and blow off operation. Holding the patches by means of suction has the
25 advantage that the individual fiber band pieces, especially if the same are spread and individual filaments are preferably already pre-fixed by a binding material, can be supported flat and without warpings. The fiber band piece can be easily held thanks to its flat and, for instance, spread form.

A roving, particularly a carbon roving, is preferably used as a bundle of filaments which according to a preferred embodiment of the invention is spread in order to provide the starting material.

5 For example, the fiber band pieces or patches are placed in such a manner that they partly overlap in the rim zones, so that the fiber band pieces can be fixed to each other. On the other hand, overlapping of adjacent fiber band pieces is undesired under the aspect that superimposed fibers of adjacent fiber band piece may result in thickenings that can affect the strength. When the patches or fiber band pieces are cut off along arc-
10 shaped cutting lines, especially along circular arc-shaped cutting lines, a concave edge area can be obtained on one end and a complementary convex edge area on the other end of each fiber band piece. The fiber band pieces can then be placed next to each other with their correspondingly arc-shaped cutting edges adjacent to each other, whereby overlapping or gaps are minimized. Especially in a circular arc-shaped cutting
15 edge the fiber band pieces can be oriented closely adjacent to each other and with different fiber orientations to each other, without producing thickenings or overlapping.

The fixing of the fiber band pieces at their predetermined position and in their predetermined orientation in the preform can be achieved for example by way of left or
20 right neighboring fiber band pieces or by way of an additional ply of fiber band pieces applied in a staggered fashion, with the superimposed plies of fiber band pieces being fixed by means of a binder material or to further constituent parts of the preform, e.g. to a conventional fiber laying, especially in a case where the fiber patch technology for the local reinforcement of preforms is applied.

25

Accordingly, with the process according to the invention a preform in a kind of a patchwork lay-up can be achieved, with a tailored number and orientation of the individual patches.

Embodiments of the invention will be described in more detail by way of the attached drawings wherein it is shown by

- 5 Figure 1 a schematic overview of a device for manufacturing a preform for producing load path aligned fiber composite structures;
- Figure 1a a schematic view of an alternative embodiment of the device of figure 1 at a separation plane indicated by a chain line;
- 10 Figure 2 a schematic view of a pay-off device employed in a device according to figure 1 for paying off a bundle of fiber filaments processed in the device according to figure 1;
- 15 Figure 3 a schematic perspective view of a position sensor for use in a pay-off device of figure 2 and its characteristic curve;
- Figure 4 a perspective view of a spreading device for explaining the principle of operation of the spreading of a bundle of fiber filaments applied in a device according to figure 1;
- 20 Figure 5 a schematic perspective view of a spreading device for use in a device according to figure 1;
- 25 Figure 6a a schematic lateral view of a loosening device for use in a device according to figure 1;
- Figure 6b a schematic illustration of the principle of operation of the loosening device of figure 6a;

- Figure 7 a schematic lateral view of a binder impregnation device for use in a device for manufacturing a preform;
- Figure 8 a schematic lateral view of a combination of a cutting and laying device employed in one embodiment of a device for manufacturing a preform;
- 5
- Fig. 9/10 schematic illustrations of the principle of operation of the cutting device of figure 8;
- 10 Figure 11 a schematic view of predetermined paths for the placement of fibers by one of the devices according to figure 1 or figure 8;
- Figure 12 a series of fiber band pieces placed by the device according to figure 1;
- 15 Figure 13 a schematic view of a preform to be manufactured in a device according to figure 1 or figure 8;
- Figure 14 a schematic cross sectional view of a laying head for use in a laying device according to figure 1 or figure 8;
- 20
- Figure 15 a bottom view of the laying head of figure 14; and
- Figure 16 a detailed schematic perspective view of the laying device of figure 8.
- 25 Figure 1 shows an overall representation of a preform manufacturing device generally designated by reference number 10. This preform manufacturing device allows the fabrication of a complicated textile semi-product with load path aligned fiber filaments for manufacturing fiber composite structures in an easy manner even if the semi-product has a complicated structure. Such textile semi-products are called preforms.

The device is suited for processing different starting materials. These preforms are manufactured from individual short fiber pieces fixed by means of a binder material in the device according to figure 1. It is possible for these fiber pieces being previously cut off from a specially pretreated fiber filament strand or fiber band.

5

Another technique provides for these short fiber pieces being produced from a pre-impregnated semi-product. The pre-impregnated semi-product is provided as a fiber filament strand or fiber band already impregnated with a binder material, with the short fiber pieces being cut off from the fiber filament strand or fiber band. The preform manufacturing device can be divided up into a preparation module 12 for the possible preparation of the fiber band 14 and a cutting and laying module 16 for cutting-off and laying the fiber band pieces. A possible separation 15 between these module 12 and 16 is indicated by a chain line.

10

15

Figure 1 illustrates a first embodiment of such a cutting and laying module 16; a second embodiment of such a cutting and laying module 16 is illustrated in figure 8.

20

First of all the overall structure and the principle of operation of the preform manufacturing device 10 are explained with reference to figure 1. Thereafter the individual modules will be described with reference to the additional figures.

25

As can be seen from figure 1, the preform manufacturing device 10 includes a pay-off device 18, a spreading device 20, a binder impregnation device 22, a cutting device 24, a transfer device 26, a laying device 28 and a preform 30. These individual devices 18, 20, 22, 24, 26, 28 and 30 can each work independently and can also be used to serve their intended purpose without the respective other devices. The present disclosure hence comprises the respective devices 12, 16, 18, 20, 22, 24, 26, 28, 30 individually and alone.

The pay-off device 18 serves to supply a fiber filament strand, for example a roving 32. As described in more detail in the following, the pay-off device 18 is constructed in a manner such that the rovings 32 can be paid off without twisting. For manufacturing carbon fiber reinforced (CFC) components, a carbon roving is used in the illustrated
5 embodiment.

The spreading device 20 serves to spread the individual filaments of the rovings 32 as widely as possible, to provide a fiber band 14 as flat as possible from a number as small as possible of layers of individual filaments placed side by side. For this purpose the
10 spreading device 20 includes a spreading installation 34 and a loosening installation 36 as will be explained in more detail further down.

The binder impregnation device 22 serves to provide filaments of the fiber band 14 and/or individual fiber band pieces thereof with a binder material 38 serving to fix the
15 fiber band pieces in the preform. In the embodiment illustrated in figure 1, the binder impregnation device 22 forms a part of the preparation module 12 and is thus used to provide the spread fiber band 14 with binder material 38. In embodiments of the preform manufacturing device 10 which are not further illustrated, a binder impregnation device 22 can be additionally or alternatively associated to the cutting and laying module 16, to
20 then provide the fiber band pieces already cut off with binder material 38.

The cutting device 24 is constructed for cutting off pieces of a defined length from the fiber band 14 (fiber pieces). In the following the individual fiber band pieces are referred to as patches 40, 40', 40".
25

The transfer device 26 serves to separate the patches 40 and to transfer the same to the laying device 28.

The laying device 28 is constructed in such a way that it can pick up individual patches
30 40 and place them at predefined positions, in the present case on the preform 30. The

preform 30 serves to give the preform 42 a predetermined three-dimensional surface design.

The preform manufacturing device 10 further includes a control device 44 comprising several controls 44a, 44b. The control device 44 controls the individual devices or installations 12, 18, 20, 22, 26, 30 in a manner such that the preform 42 is formed from the individual patches 40 in the manner of a patchwork quilt.

Accordingly, the preform manufacturing device 10 allows the following process for manufacturing a preform 42 for a load path aligned fiber composite structure being carried out automatically:

In a preferred embodiment a bundle of fiber filaments present in the form of the rovings 32 is spread and provided with the binder material 38 which in the present embodiment is thermally activated.

According to a more simple technique, already pre-impregnated semi-products are provided in the form of a fiber band, so that the preparation module 16 needs not be used. This fiber band is already provided with a thermally activated binder material. The semi-product is a fiber band for example or a fiber fabric tape from prepreg or is present in the form of a thermoplastic tape.

In both techniques, the binder-impregnated or pre-impregnated fiber band 14 thus provided is then cut into pieces of a defined length, i.e. patches 40. The patches 40 are separated and transferred to the laying device 28. The laying device 28 places each patch at its respectively predefined position 46 on the preform 30, and presses the patch 40 onto the preform 30.

Accordingly, with this preform manufacturing device 10 a fiber patch preforming technology can be implemented which allows the exact positioning of short fiber pieces

through a special laying process. The required properties of the preform 42 can be achieved through the orientation and the number of fiber pieces. It is thus possible to orient fibers along defined curved paths and the fiber content can locally vary.

- 5 By the placement of spread, short-cut fiber band pieces – patches 40 – optimally load path aligned preforms 42 can be fabricated. A fiber cutting device 48 cuts the specially prefabricated binder-impregnated fiber bands 14 into short pieces and delivers the same to a vacuum band-conveyor 50 of the transfer device 26.
- 10 The delivery of the patches 40 from the vacuum band-conveyor 50 to a laying head 52 of the lay-up device 28 takes place smoothly through a combination of suction and blow-off modules. The laying head 52 heats the patch 40 during the transfer to its placement position and thus activates the binder material 38. The laying head 52 presses the patch 40 onto the predefined position and then moves away by a blow-off
- 15 pulse. Thereafter the laying head 52 returns to the initial position.

This technology allows the fully automatic production of complex fiber preforms. Parameters like fiber content, fiber orientation and curve radii can be largely varied.

- 20 In the embodiments illustrated herein, spread carbon fibers are used instead of textile semi-products for fabricating the preforms 42, or textile pre-impregnated semi-products are used as a starting material, which is specially cut, for fabricating the preforms 42. The length of the fibers is very short (only a few centimeters) compared to pre-
- 25 fabricated layings which use long fibers. By a specific positioning of the short fibers – in the patches 40 – high mechanical characteristics can be achieved which are similar to those of long fiber composites.

- The short fibers can be relatively precisely placed along complex load paths. Textile cuttings as previously used for manufacturing such preforms merely allow preferential
- 30 orientations being set. Thus with the technology herein described extreme geometric

shapes can be produced. The manufacturing process is fully automated, and thickness variations within a preform and/or modified fiber volume contents can be achieved.

In the embodiment of the preform manufacturing device 10 illustrated in figure 1, a laser 5 54 is used as a fiber cutting tool 48 within the cutting and laying module 16. The laser is process-controlled and is precisely movable with respect to the fiber band 14. Further in figure 1, a robot arm is indicated as a mechanical laying system 184 for moving the laying head. The preform 30 can be precisely moved and rotated in a defined fashion relative thereto, in order to produce complex 3D structures of preforms 42 in a simple 10 way.

In summary, a principle of the embodiment of the fiber patch preforming technology herein described is based on spreading carbon fiber rovings 32 as widely as possible, coating them with binder powder and cutting them into pieces of a defined length, so- 15 called patches 40, by employing a novel cutting technique.

A principle of a further embodiment of the fiber patch preforming technology is based on cutting pre-impregnated semi-finished fiber bands into pieces of a defined length, patches 40, by using this cutting technique. 20

In both embodiments, these patches 40 are then picked up by specific laying device 28, placed at a predefined position and fixed by means of the binder material 38. This enables the production of most varying component geometries and fiber architectures.

25 In the preferred fabrication process spread fibers are used. Fiber spreading forms a basis for avoiding local accumulations of fiber ends within the later composite material, since the same cause stress concentrations which in the worst case may result in a failure of the component. Spreading reduces the thickness of the rovings 32. Thus more continuous fibers can reach the zone of influence of a fiber end and compensate peaks 30 of stress. Further, in an overlapping placement, the step or shoulder on the cutting end

of a roving 32 is reduced. In a non-spread roving such a step or shoulder could be as high as 250 μm and could cause a deflection of the carbon fiber situated on top of it from the load path direction. Additionally, a zone rich in resin could be formed there, negatively affecting the strength of the material.

5

To carry out the spreading operation as effectively as possible, twisting of the roving 32 shall be avoided, since filaments running transversely could again constrict a spread roving. The tension within the roving 32 in its spread state should be constant, since the spreading width and the spreading quality could be influenced by tension differences.

10

The pay-off device 18, which is described in more detail in the following with reference to figure 2, serves to enable delivery of a roving 32 in a non-twisted state from a supply reel 56 and to compensate the oscillating movement of the roving 32 during its withdrawal from the supply reel 56. For this purpose the pay-off device 18 comprises a

15 movable support 58 of the supply reel 56 which is so designed that the supply reel 56 will correspondingly join up the position of the part of the roving 32 just being paid off, so that the pay-off position remains as constant as possible.

For this purpose, the support 58 comprises a carriage 62 supported along a linear

20 guideway 60. The carriage 62 is movable by means of stepping motors and, in the illustrated embodiment, by means of a drive screw 64 in the direction of the rotation axis of the supply reel 56. The carriage 62 is driven by a motor 66 with an integrated control. A sensor 68 monitors the current position 70 of the roving 32 and thus controls the rotation of the motor 66.

25

A photodiode 72 which is illustrated in figure 3 together with its characteristic curve serves as a sensor 68. A diode line of the photodiode 72 registers the shadow of the roving 32 and outputs the position via an amplifying circuit (not further shown) as an analog signal. The center of a shadow corresponds to a particular voltage as a function

30 of the position. The analog signal is transmitted as a bipolar tension signal to the control

of the motor 66, with 0 Volt corresponding to the center of the sensor. Additionally, the sensor 68 is exposed to a flash from an IR-LED spotlight at a particular frequency, for example 10 KHz, to prevent the measuring signal from being influenced by ambient light. This sensor 68 is optimized for the special requirements of a pay-off operation compensating the position of the roving 32 on the supply reel 56 and also allows still further adjustments such as the displacement of the center and the adjustment of the bending. The combination of a spatial resolution photodiode 72 and a controlled servo motor 66 has the advantage that the counter movement is caused in dependence of the current speed of movement of the roving 32. Relatively low-speed compensation movements are caused at low pay-off speeds, whereas high pay-off speeds cause correspondingly fast counter movements. This enables the roving 32 being unreeled mainly oscillation-free as a flat band or tape 74. On the end of the pay-off device 18 the roving 32 passes in an S-like movement around two little reels 75 - in the present case two waisted stainless steel reels which additionally calm final oscillations. Differently from the way illustrated in figure 1, the pay-off device 18 can also be operated completely autonomously, i.e. independently of the remaining modules and normally only requires power supply, e.g. an electrical connection.

After the pay-off device 18 the roving 32 passes a spreading line in the spreading device 20.

As already mentioned above, the spreading device 20 comprises the spreading installation 34 which is shown in more detail in figure 5 and the function principle thereof is described with reference to figure 4.

Figure 4 shows the basic layout of a conventional spreading principle already known from DE 715801 A. Here a fiber strand 14 successively passes a bent rod 76 and thereafter a straight rod 78. In the conventionally known radius spreaders illustrated in figure 4, the combination of a straight rod and a bent rod provides for a pulling force which acts on the fiber being redirected. Now also a force acts through which the fiber is

pressed onto the bent rod. At the highest point of deflection the filaments are subject to the highest force. This force decreases with an increasing distance from this point. This means that the filaments can evade the load if they move outwardly on the bent rod. But the result of the spreading operation depends on the pulling force acting on the fiber, the friction between fiber and rod, the position of the rods relative to each other and the curvature of the rod. If the curvature is extreme, the difference of the forces acting between the highest point and an outward position is so big that the surface friction of the rod does no longer play a part. The filaments would abruptly move outwardly, i.e. the roving 32 would slip off or split. If the curvature is insufficient, the spreading ratio would be too small.

For this reason, the radius spreader illustrated in figure 4 is not suitable for the industrial processing of rovings 32 to prepare the same for the preform fabrication on an industrial scale. In particular, defects in the roving 32 such as twisting, gaps or folds would cause the spread material to slip off or split.

With the spreading installation 34 illustrated in figure 5 the problems concerning the quality of the material of rovings or of other fiber filament bundle intended to be spread, in that the roving 32 or the fiber filament bundle is newly placed again and again onto at least one convexly bent spreading edge. For this purpose the spreading installation 34 includes at least one convexly curved spreading edge 80 which moves relative to the roving 32 or any other bundle of fiber filaments by at least one component direction perpendicular to the longitudinal extension of the roving 32 or any other bundle of fiber filaments, so that the same is placed under tension onto the convexly curved spreading edge 80 and thereafter moves away vertically from the roving 32 or the bundle of fiber filaments by at least one direction component, so that the bundle of fiber filaments becomes detached from the spreading edge 80.

In its practical configuration the at least one spreading edge 80 is formed on a radial projection 82 on a rotary shaft 84.

In the preferred construction according to the embodiment illustrated in figure 5, at least two edges, at least one of which being constructed as a convexly curved spreading edge 80, is movable from opposite directions towards the roving 32 or the bundle of fiber filaments. For this purpose this embodiment provides two rotary shafts 84, 86
5 having radial projections 82. The rotary shafts 84, 86 rotate in mutually opposite directions.

In addition to first radial projections 82, where the convexly curved spreading edges 80 are formed, a preferred embodiment also provides second radial projections 88
10 terminating in straight edges 90. A spreading device is thus provided in which at least one convexly curved spreading edge 80 and at least one straight spreading edge 90 can move from opposite directions towards the roving 32 or the bundle of fiber filaments until the roving 32 or the bundle of fiber filaments is spread between the edges 80, 90 in the manner similar to that illustrated in figure 4. The edges 80, 90 can also be returned
15 in the opposite direction to relieve the roving 32 or the bundle of fiber filaments.

In the embodiment according to figure 5, this is particularly easily implemented in that several wings 94 forming the radial projections 82, 88 are formed on the rotary shafts 84, 86 driven in the opposite directions by means of a gear mechanism 92. The wings
20 94 substantially extend in the axial direction and the edges 80 or 90 are formed on their radially outermost regions. A wing 94 comprising the straight edge 90 is followed in the circumferential direction by a wing comprising a convex radially outwardly curved spreading edge 80, and this wing is in turn followed by a wing 94 comprising a straight edge 90 and so on.

25

In a different embodiment, the edges of all wings 94 are constructed as radially outwardly curved spreading edges 80. By the arrangement on moving elements that move in the opposite directions, in the present embodiment the two rotary shafts 84, 86, the fibers are each spread between two oppositely curved spreading edges 80.

30

In this way the spreading installation 34 is constructed as a so-called wing-type spreader which provides for a repeated placement of the rovings 32 on the spreading edges 80. Additionally, a finishing layer on the roving 32 or on the bundle of fiber filaments is broken open by the alternating bending operation, and the filaments 100
5 can move independently from each other.

The spreading installation 34 in the spreading device 20 constructed as a wing-type spreader is followed in the conveying direction of the rovings 32 by a loosening installation 36 which in the present embodiment is constructed as a suction chamber
10 according to the so-called Fukui principle. The suction chamber 96 can be of a type which is described in US-A-6 032 342. The loosened and pre-spread roving 32 is drawn into the suction chamber 96 by a strong laminar air stream 98. Air is caused to flow around the individual filaments 100 so that the filaments can relatively easily slide one above the other. Further the suction chamber 96 is able to compensate minor
15 fluctuations in the tension of the rovings 32.

At the production of plastic fibers the bundles of filaments are frequently freely guided and passed through eyelets. During this operation, parts of the filaments 100 can twist around the remainder of the bundle and cause constrictions of the rovings already at the
20 time of manufacture. After the reeling of the bundle of filaments on a roving reel these defects are hardly visible, because the bundle of filaments is reeled up in a flat condition. But after the bundles of filaments have been loosened in the spreading installation 34 roving parts running in the transverse direction can be clearly seen. This effect can cause gaps and displacements within the roving 32 which negatively
25 influence the spreading quality.

To achieve a spreading pattern which is as homogeneous as possible, an embodiment of the invention which is not explicitly shown provides for a multistep spreading operation, in which the spreading ratio is stepwise increased. For this purpose a first
30 spreading installation 34 and a first loosening installation 36 for spreading the roving 32

to a first width, for example a value between 8 and 16 mm, are provided. This is followed by a next step comprising a further spreading installation 34 having a larger width and a further loosening installation 36 having greater dimensions than the first spreading installation and the first loosening installation, in order to effect spreading to a larger width, for example to a value between 20 and 35 mm.

Thereafter, the roving 32 is present in form of a wide, thin band, i.e. the fiber band 14.

In the further process, this fiber band 14 is still provided with a small amount of the binder material 38.

Theoretically, only three filaments are placed one on top of the other in a 12k roving which is 30 mm wide and perfectly spread. In this case a diameter of the filaments of 7 μm and the highest packing density have been assumed. But in reality a roving still includes spreading defects that may locally cause thicker areas and thus a higher number of filament ends.

The impregnation of the thus spread rovings 32 with binder material 38 takes places in the binder impregnation device 22, the principle thereof is illustrated in figure 7. The basic principle of the binder impregnation device 22 is similar to that of a powder shaker of a kind described for example in US-A-3 518 810, US-A-2 489 846, US-A-2 394 657, US-A-2 057 538 or US-A-2 613 633. Accordingly, this powder shaker comprises a funnel 102 with a roller 106 having radial raised portions 104 moving past the exit of the funnel.

In the illustrated embodiment said roller 106 is a knurled steel roller which is transports the powder with its rough surface. This roller 106 is in turn treated by a brushing roller 108 removing the powdery binder material 38 from the roller 106 and sprinkling the same onto the fiber band 14 passing under the roller 106.

Between the fiber band 14 and the application mechanism a voltage U can be applied, so that the powder will electrostatically adhere to the fiber band 14 like in a powder coating process.

- 5 The transfer roller 106 and the brushing roller 108 are driven by two separate electric motors 110 and 112 to enable free adjustment of the sprinkling parameters. Control takes place through a control unit 114 which can be a part of the control device 44.

To avoid the powder from becoming blocked thus causing jamming of machine parts,
10 the funnel 102 is not rigidly fixed to the remainder of the binder impregnation device 22, but is supported on a holder 116 which allows compensating movements. An advantage of the holder 116 is that the funnel 102 can oscillate during operation thus automatically shaking the powder downwards. The powder is sprinkled in an amount which can be exactly dosed onto the surface of the roving 32 which moves past under the funnel at a
15 defined speed of 3 to 6 m/min for example. Excessive powder falls into a collection container (not shown) outside of the roving 32 and can be recycled to the process at a later time.

Measurements have shown that the amount of binder material applied by sprinkling is
20 almost a linear function of the rotating speed of the roller 106.

The binder impregnation device 22 also includes a heating installation 118 serving to fix the powder particles of the binder material 38 melting at heating temperatures to the surface of the filaments 100.

25

In the illustrated embodiment the heating installation 118 comprises a heating line which is about 100 to 500 mm long. The preferred embodiment of the heating installation 118 is equipped with radiant heaters, in the present case infrared radiant heaters 120. The heating power of the heating installation 118 can be precisely set through the control
30 unit 114.

The binder particles are slightly melted and adhere to the fiber surface.

Thereafter – as illustrated in figure 1a – the finished fiber band 14 can be reeled up on a
5 special film reel 121 and stored for later use.

According to a further technique which can also be implemented with this device, a fiber
band 14 is used which is already present in the form of pre-impregnated semi-product
and is delivered for example on a reel 121. This technique does not use the preparation
10 module 12. This technique uses for example prepregs or thermoplastic tapes which are
already present in the form of a fiber band or have been brought into a band form by
means of a separating installation not further shown. For this reason it is not necessary
to first impregnate the fibers with a binder thus saving labor and time compared to the
above-described technique which is more complicated because of the extra preparation,
15 even though it is more preferable with respect to the final result. Also thin fabric
materials can be used which are also available in the form of semi-products and are
correspondingly pre-impregnated. Such a technique, which is less expensive, can be
employed for example as preliminary stage in the product development of test products
before more complicated production processes are used for making products with better
20 material properties, if the tests were successful.

In the embodiment illustrated in figure 1, the fiber band 14 provided as a semi-product
or specially prefabricated is supplied to the cutting installation where it is cut into the
patches 40, 40', 40" and thereafter laid by the laying device 28.

25

Figure 1a shows an embodiment with separate modules 12, 16 and the use of film reels
121 as an example for intermediate storage. The modules 12, 16 in this form could also
be situated in different production sites.

Figure 8 illustrates in more detail a second embodiment of the cutting and laying module 16. In the embodiment according to figure 8 the cutting device 24 comprises a fiber cutting tool 122 having a knife system 124 and a counter roller 126 and at least one or, as in the present case, several transport rollers 128.

5

The knife system 124 can be operated in dependence of the rotating speed of the counter roller 126 and/or the transport rollers 128, for cutting patches 40 of a defined length.

10 In particular, the knife system 124 includes a coupling mechanism (not further illustrated) coupling a drive unit of the knife system 124 with the drive unit of the rollers 126, 128.

In the illustrated example the knife system 124 is provided with a cutting cylinder 130
15 which, as a radial projection, includes at least one and in the present case several cutting edges 132. In the illustrated embodiment the cutting cylinder 130 can be coupled by a coupling means not further shown to the drive unit of the counter roll 126 in such a manner that the cutting edges 132 move with the same peripheral speed as the surface of the counter roller 126.

20

The cutting device shown in figure 8 and in more detail in figure 9 accordingly comprises a coupled cutting system 134 in which two pairs of transport rollers 128 and a rubberized counter roller 126 are driven by means of a motor not further shown via a central form-locking transmission, for example a toothed belt (not shown). The transport
25 rollers 128 feed an endless fiber band – in the present case particularly the spread fiber band 14 – and direct the same over the counter roller 126 rotating at the same speed.

Above the counter roller 126 a cutter bar 136 is in the waiting position.

If a cut is to be made, an electromagnetic clutch couples the cutter bar 136 into the
30 movement of the cutting system. At the contact point the cutter bar 136 and the counter

roller 126 have the same rotating speed. The material to be cut is broken by a knife blade 138. Thereafter the cutter bar 136 is decoupled and stopped for example by means of an electromagnetic brake (not shown). The second pair of transport rollers 128 removes the cuttings.

5

The coupled cutting system 134 enables the cutting of spread fiber bands without distortion. The cutting act or the cutting length can be adjusted computer-controlled during operation.

10 The brake system (not explicitly shown) provides for a permanent locking of the cutting cylinder 130 when the clutch is not active. The coupling and braking operations take place via a common changeover relay (not shown) thus excluding failure caused by program errors. A sensor system (not further shown), for example an inductive proximity switch, registers the position of the knife and provides for a braking effect on the knives
15 in a horizontal position. If the connected control unit, for example the control unit 44, outputs a cutting command, the cutting cylinder 130 is coupled, accelerates and makes a cut. If at this time the cutting cylinder 130 has the same peripheral speed as the counter roller 126, as provided in this embodiment, the knife blade 138 is not bent or deformed resulting in an endurance of the knife which is much higher than that of a
20 simple vertical knife. After the cutting operation the cutting cylinder 130 is decoupled and decelerated and held at the same position as at the beginning. The cutting length is programmed in control software.

Figure 10 schematically illustrates the flow of the cutting system control. As shown in
25 figure 10, the cutting cycle is predetermined in dependence of the feeding speed of the cutting system. The minimum cutting length results from the dimension of the cutting cylinder 130 and the counter roller 126 and is within a range for example of the width of the spread fiber band 14. The maximum cutting length is theoretically unlimited.

In both illustrated embodiments of the cutting and laying module 16, after leaving the cutting device 24, the patches 40, 40', 40" are transferred to the transfer device 26 which removes the patches 40, 40', 40" from the cutting device 24 at a transporting speed which is higher than the conveying speed of the fiber band 14 to the or in the cutting device 24. Thus the patches 40, 40', 40" are separated and sufficiently spaced from each other. The transfer device 26 comprises a holding system to hold the patches 40, 40', 40" against the transfer device and a delivery system to deliver the patches 40, 40', 40" to the laying head 52 of the laying device 28.

10 The holding system and the delivery system are here implemented in the form of a vacuum band-conveyor 50. A large-volume suction chamber 140 distributes the suction force of a vacuum source not further shown, for instance a suction blower, over the entire transfer device 26. A band comprising many through pores, for example a polypropylene band, is passed over a perforated metal sheet 142 covering the suction chamber 140.

The transfer device 26 is driven through its coupling to a conveyor unit of the cutting device 24. In the illustrated embodiment, the vacuum band-conveyor 50 is coupled to the form-locking transmission driving the transport rollers 128 and the counter roller 126. A corresponding transmission ratio, e.g. a transmission ratio of 1:2, provides for a sufficiently large distance between the patches 40, 40', 40". At the end of the transferring distance a suction-type blow-off chamber 144 is situated and driven by a pneumatic vacuum module. The suction-type blow-off chamber is in operation as long as a fiber piece – patch 40 – is passed over the suction-type blow-off chamber 144. As soon as the laying die is at a predetermined delivery position 146, a blow-off pulse is output at the right moment to deliver the patch 40 to the laying head 52.

The laying head 52 attracts the patch 40 by suction, heats and transfers it with a predetermined orientation to its predetermined position.

As illustrated in figure 11, during this operation the patches 40, 40', 40" are placed onto the preform 30 along predetermined curved paths 148. Pos. 150 indicates patches laid with a corresponding orientation along these curved paths 148 and their overlapping. In the overlapping zones the patches 40 are fixed to each other by the binder material 38
5 heated by the laying head 52.

The cutting device shown in figure 1, in conjunction with a laser 54 (or any other kind of beam cutting technique) even allows the production of complicated shapes of cutting edges. Figure 12 illustrates a particularly preferred shape of cutting edges, with the
10 cutting edges 152, 154 being curved in a complementary fashion convexly or concavely with respect to each other. The oppositely directed cutting edges 152, 154 on each patch are curved in a circular arc fashion. Thus the cutting edges 152, 154 of patches 40, 40', 40" that are arranged one behind the other can be placed very close to each other without producing gaps or thickenings even if the patches 40, 40', 40" are angled.
15 In this way a lay-up is possible with the fiber pieces constantly tightly abutting and having a corresponding fiber orientation also along small curvature radii of the paths 148. The fixing of the patches 40, 40', 40" can be effected by overlapping with adjacent patches or those arranged above or underneath (not shown).

20 In this manner it is possible to produce even very complicated preforms 42 like those indicated for example in figure 13. In this example, short fiber pieces according to the patchwork type make up a preform 192 for a load path aligned fiber composite structure for a window funnel of an aircraft or spacecraft for example. The patches 40, 40', 40" are oriented corresponding to the load paths.

25

Concerning the technical process, the illustrated annular shape can be achieved by defined rotatable preform 30 as indicated by the arrows 156 in figure 1.

Now, the laying device 28 and its laying head 52 of the embodiment of the cutting and laying module 16 illustrated in more detail in figure 8 will be further explained with reference to the figures 14 to 16.

- 5 The laying head 52 has the function to pick up a fiber piece or patch 40, 40', 40" and to transfer the same to the respective next predetermined position 46 on the preform 30 requiring lay-up of a patch 40, 40', 40". For this purpose the laying head 52 includes a holding device. While other holding devices are also conceivable, the holding device in the illustrated example is constituted by a suction device 158 which makes picking up
10 the patches from the transfer device 26 easier.

Further, it is advantageous to activate the binder material 38 with which the picked-up patch 40 is provided, during the transfer by means of the laying head 52. For this purpose the laying head 52 includes an activation system for activating the binder
15 material 38. The configuration of the activation system depends on the binder material which is used. For example, if a binder material is used which is activated by an additive, the laying head comprises means for adding the additive. In a different embodiment not further illustrated, an instantly activated binder material such as an adhesive is supplied only during the transfer of the patch on the laying head. In this
20 case the laying head includes means for the addition of binder material. For use in the above-described preform manufacturing device employing a thermally activated binder material 38, the activation system is constructed as a heating device 160 in the illustrated embodiment.

- 25 It is further preferable for the laying head 152 being able to lay-up the patch 40, 40', 40" even against complicated three-dimensional surface architectures of the perform 30. To this end, the laying head 52 includes a pressing device 162 suitable for pressing the transferred patches 40 against different surface architectures. The pressing device 162 includes in a preferred construction a flexible surface 164 where the patch 40 can be

held by means of a holding device. Further preferably, the flexible surface 164 is formed on an elastic carrier 166.

Figure 14 shows a cross sectional view of a laying die 168 of the laying head 52 combining the holding device, the activation system and the pressing device. The laying die 168 shown in figure 14 accordingly comprises the suction device 158, the heating device 160 and the pressing device 162 with the flexible surface 164 on the elastic carrier 166.

Figure 15 is a bottom view of the flexible surface 164.

If the fiber patch preforming technology (FPP) is applied, the laying die 168 enables fiber pieces (patches) which are binder-impregnated and cut into defined geometries being precisely placed at the intended position according to a laying pattern (for example the laying pattern shown in figure 11). The laying die 168 is a central component of the laying technology and can be used also in other geometrical variations. For example, square or roller-shaped laying dies are also conceivable.

In the concrete embodiment according to figure 14, the laying die 168 is configured as a silicone die. The surface adaption of the silicone die is similar to pad printing, although the present field of application is completely different.

The laying head 168 can quickly and gently pick up and transfer fiber cuttings to the defined location through an integrated suction – suction device 158. During the transfer, a heater – heating device 160 – integrated in the contact surface – flexible surface 164 – heats up the material and thus activates the binder – binder material 38 – on the fiber cutting. The fiber cutting is pressed onto the surface, with the soft die material adjusting to the surface geometry. When the laying die 168 moves away from the surface, a blow-off pulse is output, the binder material 38 is cooled and the fiber material remains where it has been placed.

The laying die 168 enables the production of fiber patch preforms 42.

5 In figure 14, the elastic carrier 166 – elastic pressing body – is represented including an air distribution 170 which forms a part of the suction device 158. The part of the suction device 158 which is not illustrated is provided with the usual pneumatic sources and pneumatic controls (not shown). Further, the flexible surface 164 is represented as an elastic heating surface 172 including suction and blow-off channels 174.

10 The elastic carrier 166 is seated on a coupling plate 4 which is provided with removable fixing elements (not shown) for fixing the laying head 168 to a positioning device 176 (see figure 16).

15 Further, a thermo element 178 is provided as a control element of the heating device 160. A highly flexible electrical power line 180 connects the thermo element 178 to the elastic heating surface 172.

Figure 15 shows a suction surface – flexible surface 164 – including the suction and blow-off channels 174.

20

The use of the laying die 168 as well as further details of the laying device 28 will be described in the following in context with its use in the preform manufacturing device 10.

25 In the fiber patch preforming technology individual fiber patches 40 are arranged to form a three-dimensional preform 42, 192. To achieve this, the layout plan is implemented by applying a suitable laying technique. The laying device 28 is delivered the binder-impregnated and cut fiber patches 40 from the vacuum band-conveyor 50 associated with the cutting device 24 and places the fiber patches 40 onto a surface, at a cycle which is as quick as possible. In the illustrated embodiment the fiber patches 40, 40', 40''
30 are placed onto a surface of the preform 30.

The patches 40, 40', 40" shall be pressed onto the forming surface to produce a robust preform 42. The laying die 168 shall be as soft as possible to adjust to a three-dimensional surface with uniform force. For this configuration it is further preferred that
5 shortly before the placement of the patches a certain amount of heat can be provided for activating the binder material 38. For this purpose the flexible surface 164 includes the heating device 160 which influences the mechanical properties of the die material as less as possible. Similar to the vacuum band-conveyor 50, a two-dimensional fixing of the filigree fiber patches 40 is beneficial. For this purpose the flexible surface 164 also
10 has a suction function.

The manufacture of the laying die 168 is similar to the manufacture of printing pads known from printing engineering. For the manufacture of printing pads a series of special silicones are available which are able to resist for a long time the permanent
15 alternating mechanical loads. From these silicones a silicone rubber is selected which meets the additional requirements caused by the heating device 160 and the contact with the binder material 38 as perfectly as possible. Since the laying die 168 has incorporated a heater, tests have been made with regard to the temperature stability of the die material. In this case it is advantageous for the laying die 168 being able to
20 resist permanent temperatures of up to 200°C. A softener for the silicone material is selected corresponding to these requirements.

For heating the lay-up surface of the laying die 168 various heating devices 160 can be used, among others also electric heating devices, fluid circuits or hot air. Concerning the
25 fabrication technique, the variant comprising an electric heating device 160 is the most convenient to implement and simultaneously offers the possibility of a high heating power and an exact temperature setting.

To not influence the flexibility of the carrier 166, the electric power lines 180 are
30 advantageously formed by means of carbon fiber yarn. The high flexibility of such a fiber

yarn prevents the flexible surface 164 from becoming stiff. Also, such a fiber is able to stand several 100,000 load cycles.

The thermal conductivity of the elastic carrier 166 can be increased by admixing
5 thermally conductive material to the silicone.

For instance, with a moiety of the thermally conductive material of about 10-30 percent by weight the thermal conductivity of the flexible surface is sufficiently high, so that a heating element of the heating device 160 and the flexible surface 164 can be kept at
10 almost the same temperature.

The suction and blow-off channels 174 are integrated in the flexible surface 164 of the laying die 168 and join each other inside the laying die 168 through a chamber 182. In the chamber 168 an absorbing suction fleece (not shown) is inserted preventing
15 collapsing when subject to the pressure load of the laying die 168.

To avoid electrostatic charging, the flexible surface 164 is advantageously made of a flexible material having antistatic properties.

20 The mechanical lay-up system of the laying device 28 will still be explained in the following with reference to figure 16.

The mechanical lay-up system 184 illustrated in figure 16 serves to move the laying die 168, in order to transfer fiber patches 40 from the cutting device 24 to the predefined
25 position 46. The mechanical lay-up system 184 allows a rapid laying cycle and an adjustable lay-up angle.

As explained above, the patch 40 is delivered in contactless fashion from the vacuum band-conveyor 50 to the laying die 168. For this purpose the control device 44 outputs a
30 blow-off pulse of the suction/blow-off chamber 144 of the vacuum band-conveyor 50

after a preset delay time and in dependence of the cutting command. The patch 40 is delivered via an air path of a few millimeters (about 0.5 – 10 mm) to the aspiring laying die 168. Thereafter, the movement cycle of the mechanical lay-up system 184 commences.

5

The mechanical lay-up system 184 comprises a translational drive for the transfer of the laying die 168 from the pick-up position to a position above the predetermined position. In the illustrated embodiment of the mechanical lay-up system 184 the first drive unit is constituted by a horizontal pneumatic cylinder 186. This horizontal pneumatic cylinder
10 186 is adapted to move the laying die 168 from its pick-up position to the placement position. A second drive unit constituted by a vertical pneumatic cylinder 188 presses the laying die 168 onto the surface, preferably at a pressure that can be adjusted.

During the displacement, the surface of the die is permanently kept at an adjustable
15 temperature, so that the binder can activate its adhesiveness. As soon as the patch 40 contacts the surface the binder material 38 cools down and becomes solid. Then, under the control of the control device 44, the blow-off pulse in the suction device of the laying die 168 is output causing the laying die to move away and thereafter return to its initial position. Here the separating properties of the silicone are beneficial, because there is
20 not any binder material 38 remaining on the die.

By means of a third drive unit, which in the illustrated embodiment is constituted by a stepping motor 190 including a spline shaft system 191, the laying die 168 can be rotated. Accordingly it is possible to even produce traces of inclined patches 40 without
25 requiring the entire laying head (e.g. the laying die 168 including the mechanical lay-up system 184) being rotated.

To achieve an economic laying process a very high cycle time of more than two laying operations per second has been planned. Five laying operations per second or even
30 more are performed for example. With a patch length of 60 mm and using a 12k roving,

a fiber throughput of theoretically 14.4 g/min is achieved. If it is intended for instance to cover one square meter with fiber patches 40 having the thickness of a biaxial laying (approximately 500 g/m²), the preform manufacturing device 10 would require 35 minutes. Shorter times are possible by using several laying devices 28 in conjunction with several robots working together on one surface.

Because of the relatively low achievable speeds, the FPP technique in its currently presented form is still mainly applied for the reinforcement of other types of preforms and for thin-walled and complex components, for example the reinforcement of the rims of holes in multi-axial layings or fabrics. A window funnel, the preform 192 thereof is shown in figure 13, could also be produced with a very thin wall and with a defined fiber layer.

Certain types of preforms require less degrees of freedom in a FPP system – preform manufacturing device 10. If it is only reinforcement profiles that are to be produced, the individual modules could be simplified and combined into one production line. Modules which are not required could be omitted. Alternatively, the device could be separated in several modules including intermediate storage of the semi-finished material.

This would help to reduce system costs and to increase productivity.

The cutting and laying module 16 herein described is suitable for processing spread binder-impregnated dry fiber bands produced in a preparing module 12 on one side and pre-impregnated semi-finished fiber bands 14, for example prepreg or thermoplastic tapes, on the other side. Prepreg and thermoplastic tapes can be normally processed in the same way as binder-impregnated dry spread rovings. In all three cases the adhesiveness of the patches 40, 40', 40" is activated by heat. The individual steps of the process of the preferred embodiment of the processes are identical: reeling off, cutting, separating, picking up, heating and placement (in the order as mentioned).

However, different binder materials used have different activating temperatures. Prepreg is sticky already at room temperature (about 20°C). The binder material 38 which is preferably used in the preparation module develops its adhesiveness at approximately 100°C to approximately 120°C. Thermoplastic material with which
5 thermoplastic tapes are impregnated even involve higher temperatures, depending on the structure of the thermoplastic material that is used.

In the preform manufacturing device 10 and particularly in its cutting and laying module 16 the working temperature or ambient temperature is adjustable by means of at least
10 one temperature adjustment device not further shown. This temperature adjustment device can be associated with the building in which the device 10 and/or the cutting or laying module 16 are situated.

This assures in a case where different binder materials are used that the adhesiveness
15 is activated only at the level of the laying die 168. For example, if prepregs are used, the surroundings are air-conditioned. Work is then particularly performed at cooling temperatures lower than 0°C, preferably at freezing temperatures lower than 10°C, for example about -18°C. Through the heated laying die 168 the previously deep-frozen patch 40, 40', 40" is heated approximately to room temperature.

20

The laying die 168 includes an additional temperature range approximately corresponding to room temperature or lower than room temperature and up to approximately 200°C. As long as binder material can be activated in this temperature range, it can be processed in the device illustrated herein.

List of reference numbers

	10	preform manufacturing device
	12	preparation module
5	14	fiber strand
	16	cutting and laying module
	18	pay-off device
	20	spreading device
	22	binder impregnation device
10	24	cutting device
	26	transfer device
	28	laying device
	30	preform
	32	roving
15	34	spreading installation
	36	loosening installation
	38	binder material
	40, 40', 40"	patch (section of a fiber band; fiber band pieces)
	42	preform
20	44	control device
	46	predefined position
	48	fiber cutting system
	50	vacuum band-conveyor
	52	laying head
25	54	laser
	56	supply reel
	58	support
	60	linear guideway
	62	carriage
30	64	drive screw

	66	motor
	68	sensor
	70	position
	72	photodiode
5	74	flat band
	75	little reel
	76	bent rod
	78	straight rod
	80	spreading edge
10	82	first radial projection
	84	rotary shaft
	86	rotary shaft
	88	second radial projection
	90	straight edge
15	92	gear mechanism
	94	wing
	96	suction chamber
	98	laminar air stream
	100	filaments
20	102	funnel
	104	radial raised portions
	106	roller
	108	brushing roller
	110	electric motor
25	112	electric motor
	114	control device
	116	holder
	118	heating device
	120	infrared heating radiator
30	122	fiber cutting system

	124	knife system
	126	counter roller
	128	transport roller
	130	cutting cylinder
5	132	cutting edges
	134	coupled cutting system
	136	cutter bar
	138	cutting blade
	140	suction chamber
10	142	perforated metal sheet
	144	suction/blow-off chamber
	146	delivery position
	148	curved paths
	150	overlapping patches
15	152	cutting edge
	154	cutting edge
	156	mobility of the preform – multidimensional
	158	suction device
	160	heating device
20	162	pressing device
	164	flexible surface
	166	elastic carrier
	168	laying die
	170	air distribution
25	172	elastic heating surface
	174	suction and blow-off channels
	175	coupling plate
	176	positioning device
	178	thermal element
30	180	electric power line

	182	chamber
	184	mechanical lay-up system
	186	horizontal pneumatic cylinder (first drive unit)
	188	vertical pneumatic cylinder (second drive unit)
5	190	stepping motor (third drive unit)
	191	spline shaft system
	192	window funnel preform

Patent Claims

1. Process for manufacturing a preform (42) for a load path aligned fiber composite structure, comprising the following order of steps:
 - a) providing a flat fiber band (14) in a feeding direction,
 - c) cutting off a fiber band piece (40, 40', 40") from a free end of the flat fiber band (14) such that the free end of the fiber band (14) is cut completely through to form a strip of fiber band (14),
 - e) picking up the fiber band piece (40, 40', 40") at a predetermined pickup position by means of a laying device (28),
 - f) placing the fiber band piece (40, 40', 40") at a predefined position,
 - g) fixing the fiber band piece (40, 40', 40") by means of a binder material (38),wherein the steps c) through f) are repeated for the placement and fixing of additional fiber band pieces (40, 40', 40") at other predefined positions and wherein the steps e) and f) are carried out by means of a laying head (52) of the laying device (28) which automatically moves from the at least one pickup position to a first predefined position for the placement of a first fiber band piece (40) and back to said one or to one of several predetermined pickup positions for picking up a second fiber band piece (40') and then to a second predefined position for the placement of the second fiber band piece (40').
2. Process according to claim 1, characterized in that a binder material (38) activated by heat is used and the cut-off fiber band piece (40, 40', 40") is heated for carrying out step g).
3. Process according to claim 2, characterized in that the laying head (50) is heated in order to activate the binder material (38).

4. Process according to claim 3,
wherein the laying head (50) is heated during its movement between the pickup position and the predefined position.
- 5 5. Process according to any one of claims 1 to 4,
characterized in that in step f) the fiber band piece (40, 40', 40") is pressed against a portion of a forming surface (30) for the preform (42), in order to give the fiber band piece (40, 40', 40") a desired three-dimensional surface architecture.
- 10 6. Process according to claim 5,
characterized in that the pressing against the forming surface (30) is carried out by means of an elastically deformable receiving surface (164) of the laying head (52), with the fiber band piece (40) being held tightly to and in a condition lying flat against the receiving surface, during the laying and pressing operations.
- 15 7. Process according to any one of claims 1 to 6,
characterized in that in step c) for producing the fiber band piece (40, 40', 40") a piece of less than about 20 cm is cut off.
- 20 8. Process according to any one of claims 1 to 6,
characterized in that in step c) for producing the fiber band piece (40, 40', 40") a piece of less than about 10 cm, is cut off.
- 25 9. Process according to one of any one of claims 1 to 8,
characterized in that the fiber band piece (40) is pneumatically held against the laying head (52) during the laying operation.

10. Process according to any one of claims 1 to 9, characterized in that in step f) the placed fiber band piece (40, 40', 40") is released from the laying head (52) by means of pneumatic pulse.
- 5 11. Process according to any one of claims 1 to 10, characterized by the step to be carried out between step c) and step e):
d) transferring the fiber band piece (40, 40', 40") from a cutting device used for carrying out step c) to the pickup position of the laying device.
- 10 12. Process according to claim 11, characterized in that the transfer speed in step d) is higher than a conveying speed of the flat fiber band (14), in order to subsequently separate fiber band pieces (40, 40', 40") that have been cut off from each other.
- 15 13. Process according to claim 11 or 12, characterized in that for being transferred said fiber band piece (40,40', 40") is pneumatically held against a band-conveyor (50).
14. Process according to claim 13,
20 characterized in that the fiber band piece (40, 40', 40") is delivered from the band-conveyor (50) to the laying head (52) through a pneumatic pulse.
15. Process according to any one of claims 1 to 14,
25 characterized in that that fiber band pieces (40, 40', 40") are placed with their fiber direction oriented along predefined curved paths (148).
16. Process according to any one of claims 1 to 15,
30 characterized in that a different number of fiber band pieces (40, 40', 40") are placed on different sections of the preform (42), in order to achieve different fiber contents in the sections of the preform (42).

17. Process according to any one of claims 1 to 16,
characterized in that
in step c) the fiber band piece (40, 40', 40'') is respectively cut along an arc-
shaped cutting line.
18. Process according to claim 17,
characterized in that in step f) fiber band pieces (40, 40', 40'') are placed one
behind the other without overlapping, with mutually complementary circular arc-
shaped cutting edges (152, 154).
19. Process according to any one of claims 1 to 18,
characterized in that step a) comprises a1) spreading a bundle of fiber filaments
(32) into a flat fiber band (14).
20. Process according to claim 19,
characterized by a step to be carried out anytime between
step a1) and f):
b) applying the binder material (38) to the fiber filaments (100).
21. Process according to claim 20,
characterized in that step b) is carried out prior to step c).
22. Process according to any one of claims 19 to 21,
characterized in that in step a) the filaments (100) of a roving (32) are spread.
23. Process according to claim 22,
wherein the roving (32) is a carbon roving.

24. Process according to any one of claims 1 to 18,
characterized in that step a) comprises
a2) providing a flat fiber band (14) from a semi-product pre-impregnated with a
binder material.
- 5
25. Process according to claim 24,
characterized in that the pre-impregnated semi-product is a prepreg.
26. Process according to claim 25,
10 characterized in that at least the steps c) and e) are carried out at a temperature
below 20°C.
27. Process according to claim 25,
15 characterized in that at least the steps c) and e) are carried out at a temperature
below 10°C.
28. Process according to claim 25,
characterized in that at least the steps c) and e) are carried out at a temperature
below 0°C.
- 20
29. Process according to claim 24,
characterized in that the pre-impregnated semi-product is a thermoplastic tape.
30. Process according to any one of claims 24 to 29,
25 characterized in that the pre-impregnated semi-product consists of a pre-
impregnated fiber fabric.
31. Process according to claim 30,
30 characterized in that the fiber fabric is made from fibers oriented in at least two
different directions.

32. Process according to claim 30 or 31,
characterized in that in step a2) comprises cutting of the pre-impregnated fiber
fabric into a band shape.

5

33. Process according to any one of claims 24 to 32,
characterized in that a semi-finished product is used which is impregnated with a
binder material (38) that is activated by a temperature change, and that the cut-
off fiber band piece (40, 40', 40") is heated and cooled in the course of the
process.

10

34. Process according to any one of claims 24 to 32,
characterized in that a semi-finished product is used which is impregnated with a
binder material (38) that is activated by a temperature change, and that the cut-
off fiber band piece (40, 40', 40") is heated in the course of the process.

15

35. Process according to any one of claims 24 to 32,
characterized in that a semi-finished product is used which is impregnated with a
binder material (38) that is activated by a temperature change, and that the cut-
off fiber band piece (40, 40', 40") is cooled in the course of the process.

20

36. Use of a process according to any one of claims 1 to 35, for manufacturing a load
path aligned fiber composite structure constructed with a preform (42)
manufactured by means of the process.

25

37. Device (10) for carrying out the process according to any one of claims 1 to 36, comprising:
a cutting device (24) for cutting off a flat fiber band (14) into several fiber band pieces (40, 40', 40"),
5 a laying device movable relative to the cutting device, for picking up and placing individual fiber band pieces (40, 40', 40") with a predetermined orientation at a predefined position, and
a control device (44) configured for controlling the laying device (28) in such a manner that the fiber band pieces (40, 40', 40") are oriented along predetermined
10 paths (148),
wherein the laying device (44) is movable from at least one predetermined pickup position (146) to different predefined positions and back, in order to pick up the fiber band pieces (40, 40', 40") cut by the cutting device (24) at the at least one pickup position and place the same at the predefined position.
- 15
38. Device according to claim 37,
characterized by a spreading device (20) for spreading at least one roving (32) to form the flat fiber band (14).
- 20
39. Device according to claim 38,
characterized by at least one convexly curved spreading edge (80) movable with at least one direction component perpendicular to the longitudinal extension of a bundle of fiber filaments (32) to be spread relative to the bundle of fiber filaments, so that the bundle of fiber filaments (32) is placed under tension onto the
25 convexly curved spreading edge (80) and thereafter be removed again from the bundle of fiber filaments (32) with at least one direction component perpendicular to bundle of fiber filaments (32), in order to release the same from the spreading edge (80).

40. Device according to claim 39,
characterized in that the at least one spreading edge (80) is formed on a radial
projection (82) rotatable on a rotary shaft (84).
- 5 41. Device according to claim 37,
further including at least two edge portions, at least one thereof is formed as a
convexly curved spreading (80), and which is moved from opposite directions
towards the bundle of fiber filaments (32).
- 10 42. Device according to claim 41,
characterized in that two rotary shafts (84, 86) having radial projections (82) are
provided, with said rotary shafts (84, 86) rotating in mutually opposite directions.
43. Device according to claim 42,
15 characterized in that several wings (94) forming the radial projections (82, 88) are
formed on the rotary shafts (84, 86) which are mutually oppositely driven, said
wings (94) substantially extending in the axial direction and having the edge
portions (80, 90) formed on their radially outermost regions.
- 20 44. Device according to claim 43,
wherein the rotary shafts (84, 86) are mutually oppositely driven by means of a
gear mechanism (92).
45. Device according to any one of claims 41 to 44,
25 characterized in that several edge portions serving to spreading are configured
as convex radially outwardly curved spreading edges (80), with edge portions
which are to be placed one after the other on the bundle of fiber filaments (32)
are arranged on mutually oppositely moving movement elements in such a
manner that the fibers is respectively spread between two oppositely curved
30 spreading edges (80).

46. Device according to any one of claims 39 to 45,
characterized in that the spreading device (20) includes a loosening device (36)
for loosening the spread bundles of fiber filaments (32) arranged in the feeding
direction of the bundle of fiber filaments (32) behind a spreading installation (34)
5 comprising the at least one spreading edge (80).
47. Device according to claim 46,
characterized in that the loosening device (36) comprises a suction chamber
(96).
10
48. Device according to any one of claims 37 to 47,
characterized by a binder material impregnation device (22) adapted for applying
binder material (38) to filaments (100), for fixing the fiber band pieces (40, 40',
40").
15
49. Device according to claim 48, characterized in that the binder material
impregnation device (22) is associated with the spreading device (22) to apply
binder material (38) to the filaments (100) of the spread fiber band (14).
- 20 50. Device according to claim 48 or 49,
characterized in that the binder material impregnation device (22) is configured
for applying powdery binder material (38).
51. Device according to any one of claims 37 to 50,
25 characterized by a transfer device (26) by which the cut-off fiber band pieces (40,
40', 40") are separated and transferred to the laying device (28).

52. Device according to claim 51,
characterized in that the transfer device (26) comprises a vacuum band-conveyor
(50) for transferring thereon fiber band pieces (40, 40', 40") in a fashion adhering
to the band-conveyor by applying suction pressure.
- 5
53. Device according to claim 51 or 52,
characterized by a combination of suction and blow-off modules (140, 142, 144,
174) adapted for smooth delivery of fiber band pieces from the transfer device
(26) to the laying device (28).
- 10
54. Device according to any one of claims 37 to 53,
characterized by at least one heating device (160) for activating the binder
material (38) applied to the filaments (100).
- 15
55. Device according to claim 54,
characterized in that the heating device (160) or at least one of several heating
devices is arranged on the laying head (52) for heating picked up fiber band
pieces.

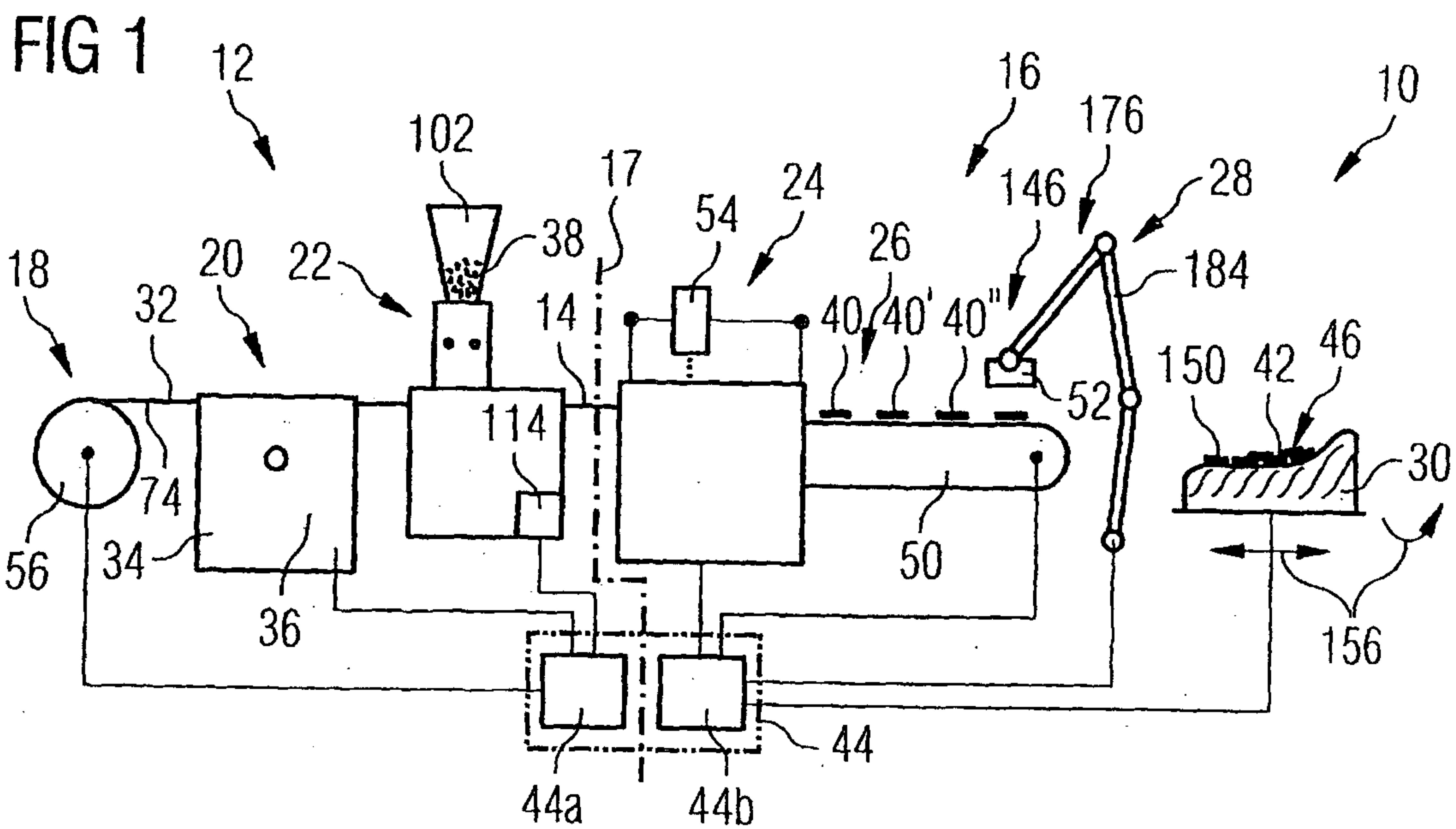


FIG 1a

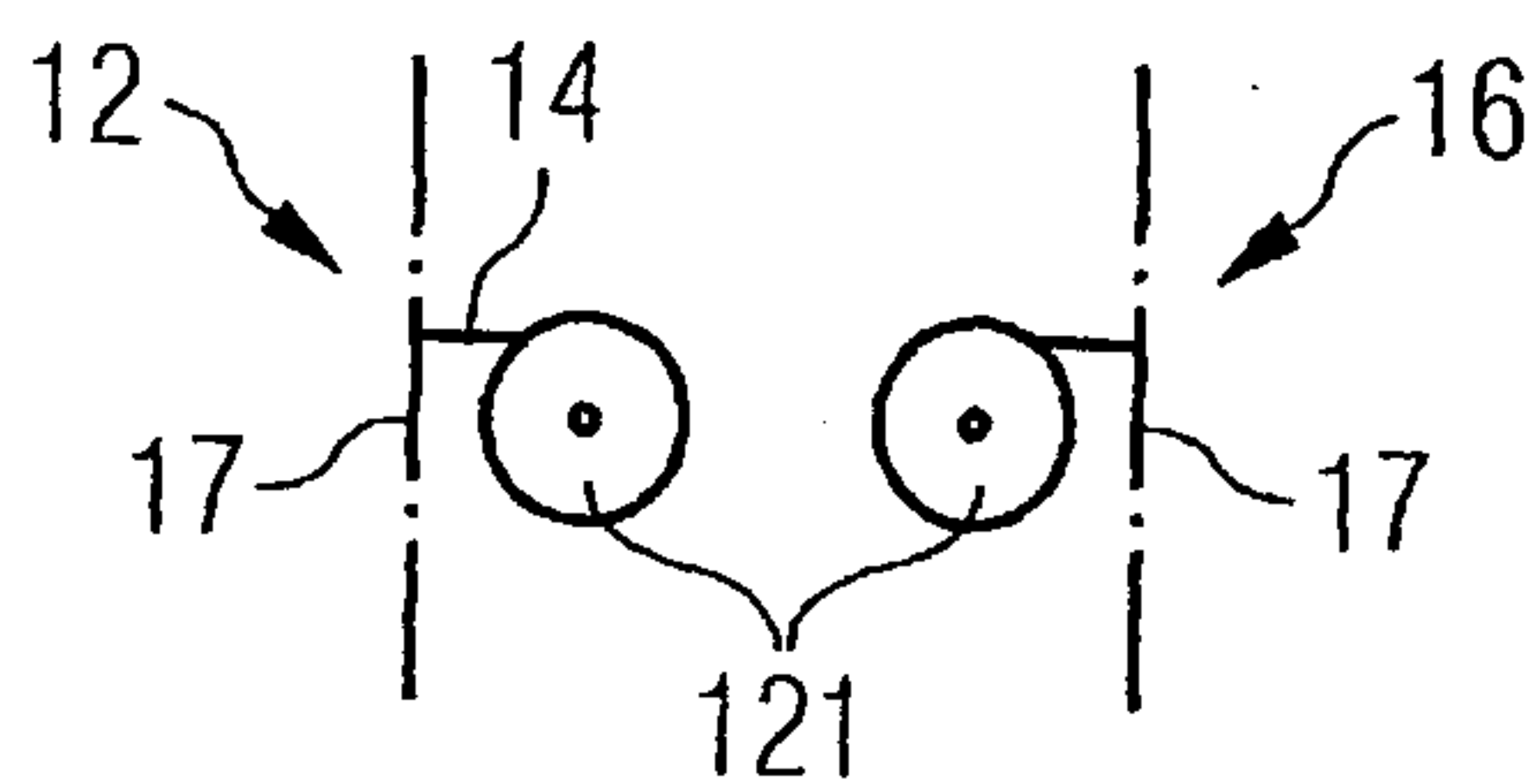


FIG 2

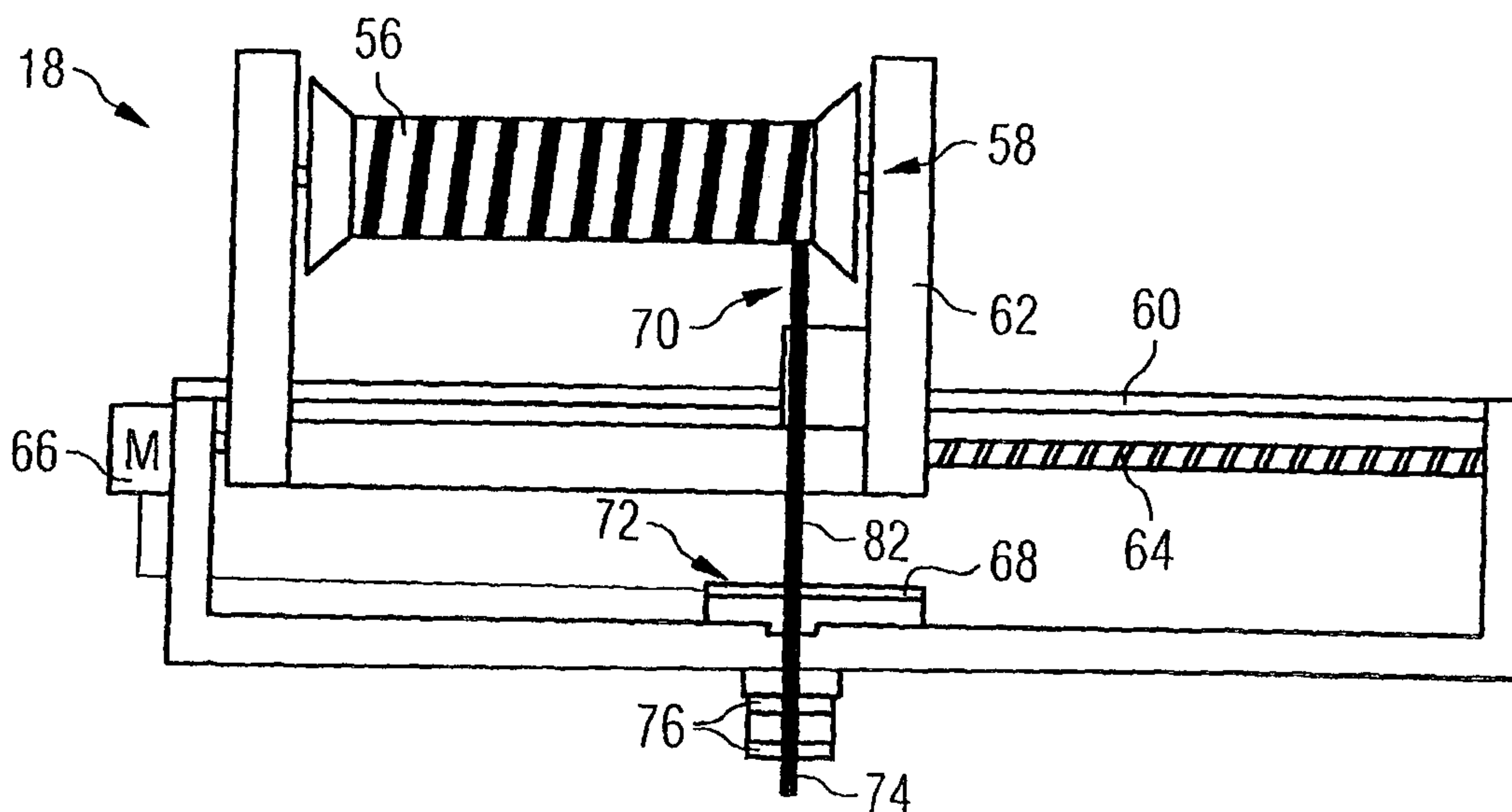


FIG 3

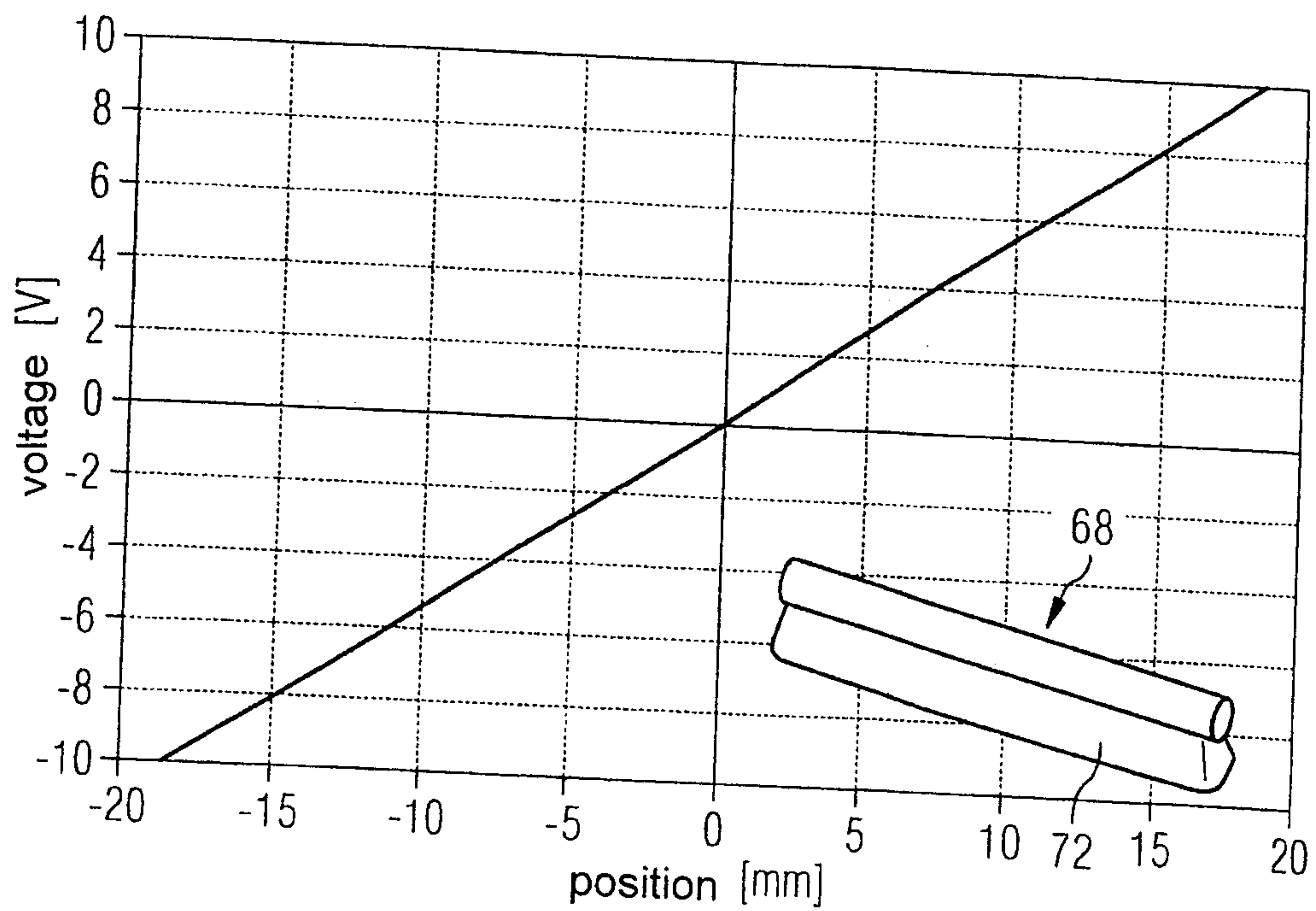


FIG 4

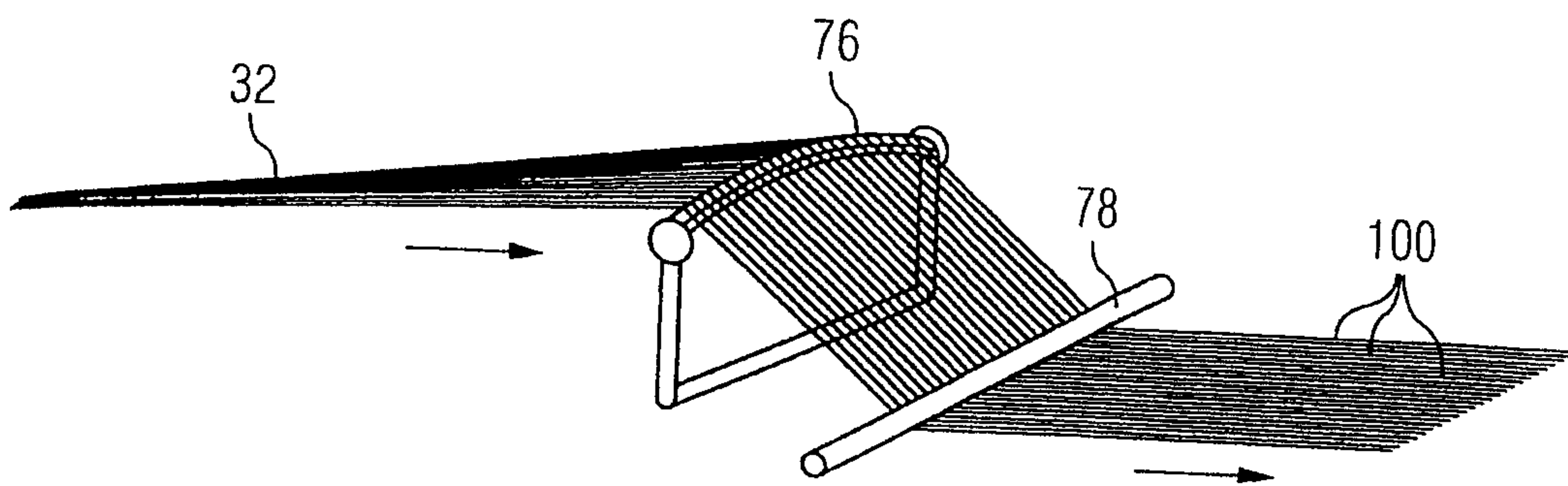


FIG 5

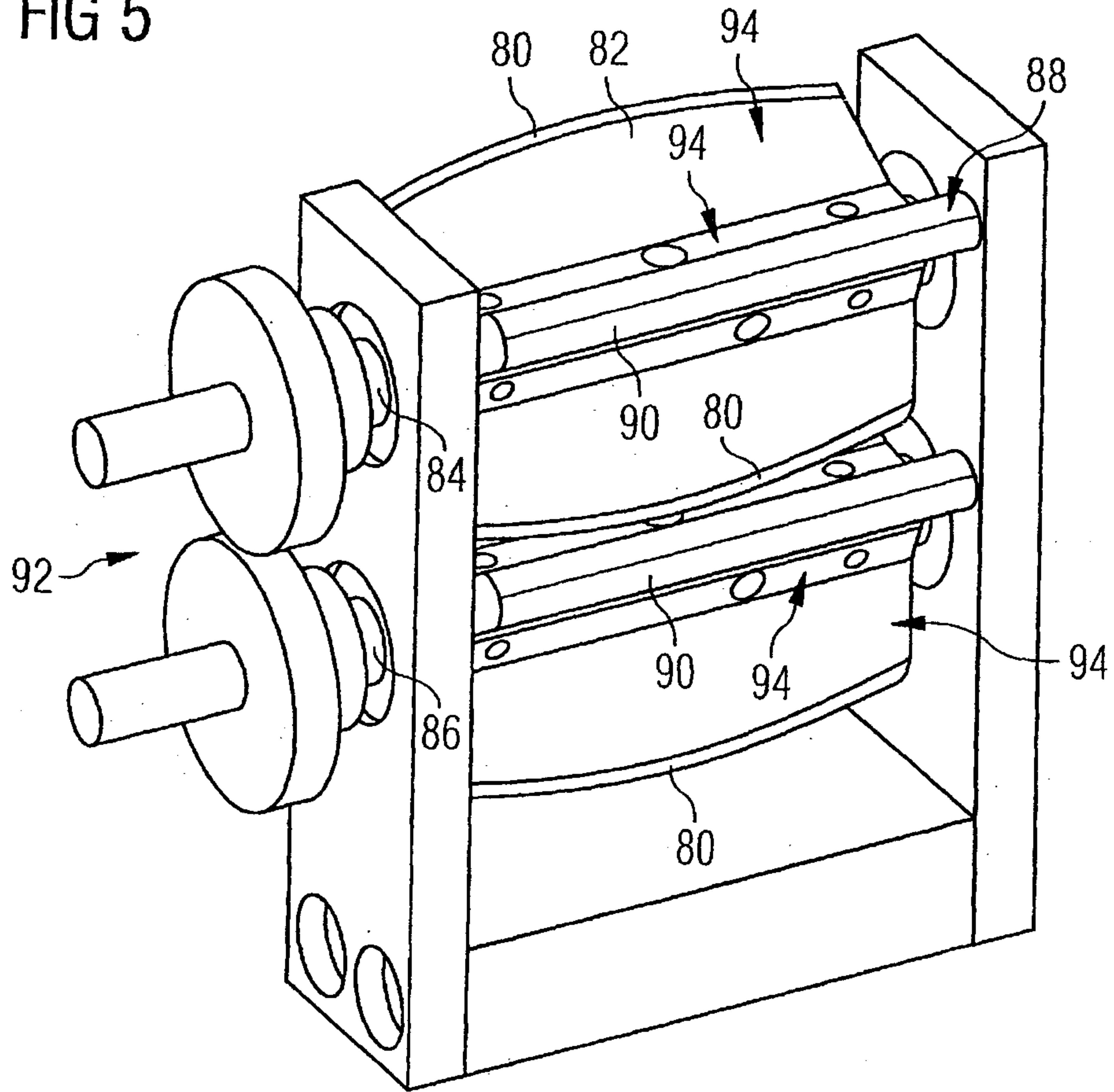


FIG 6a

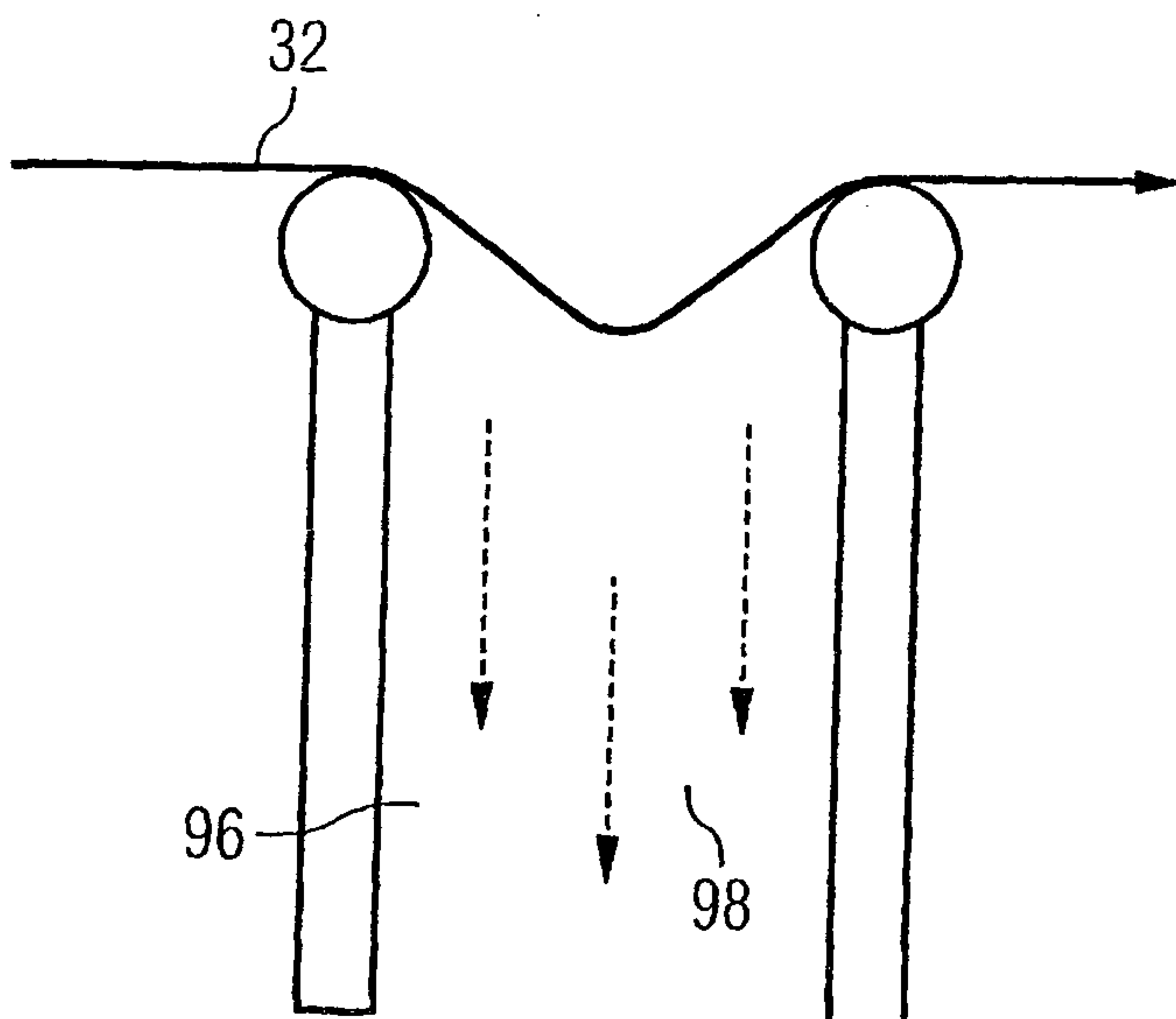


FIG 6b

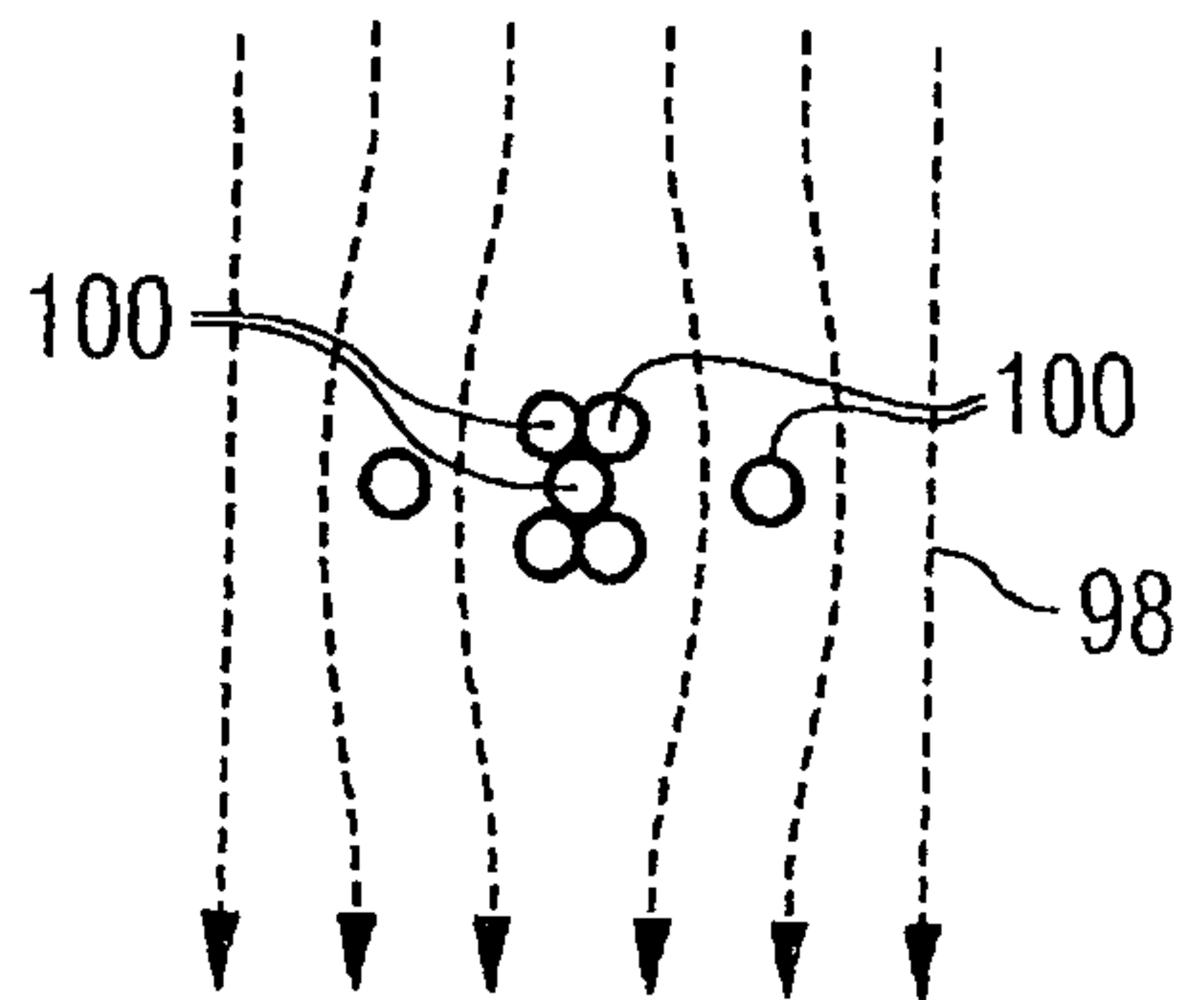


FIG 7

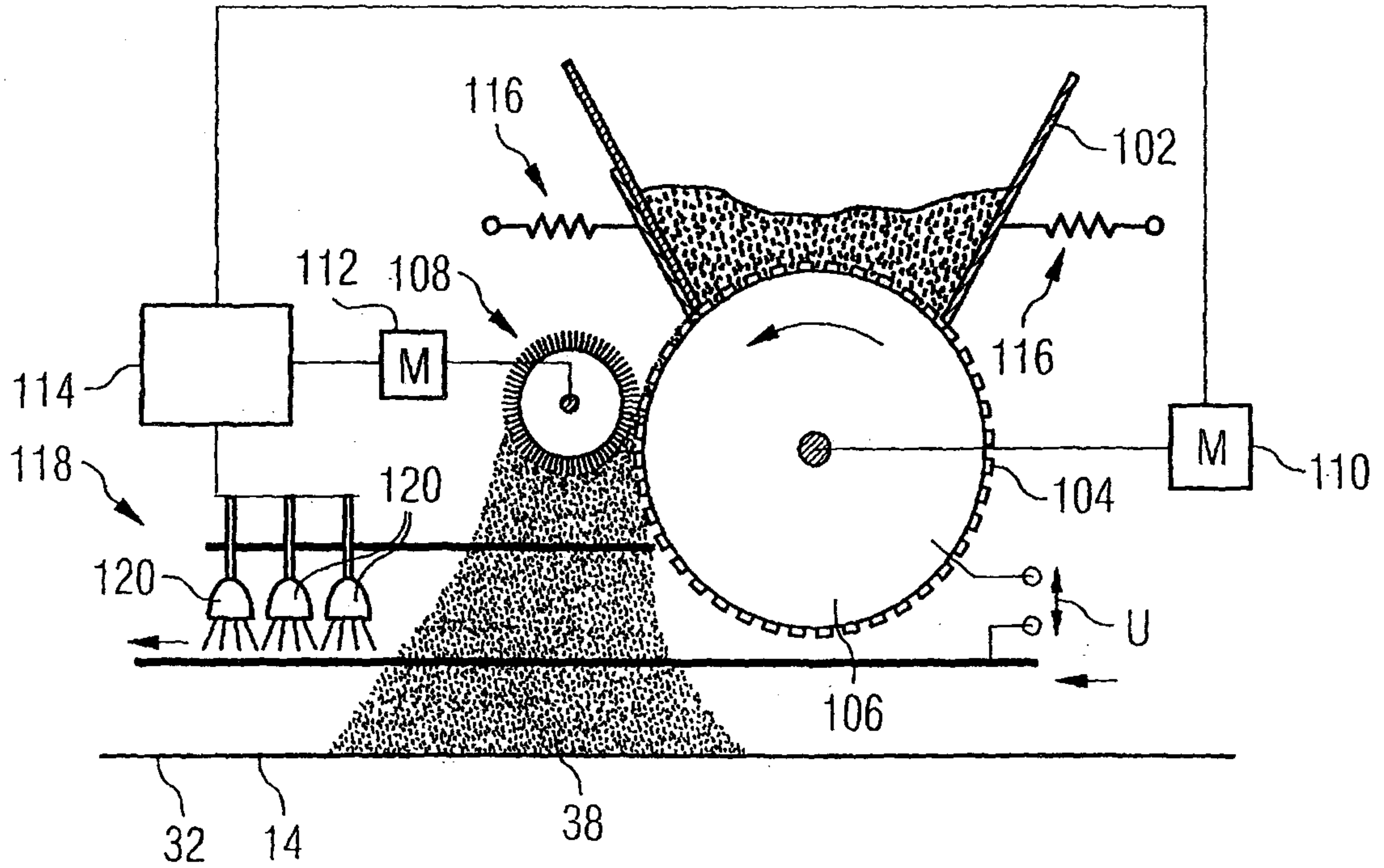
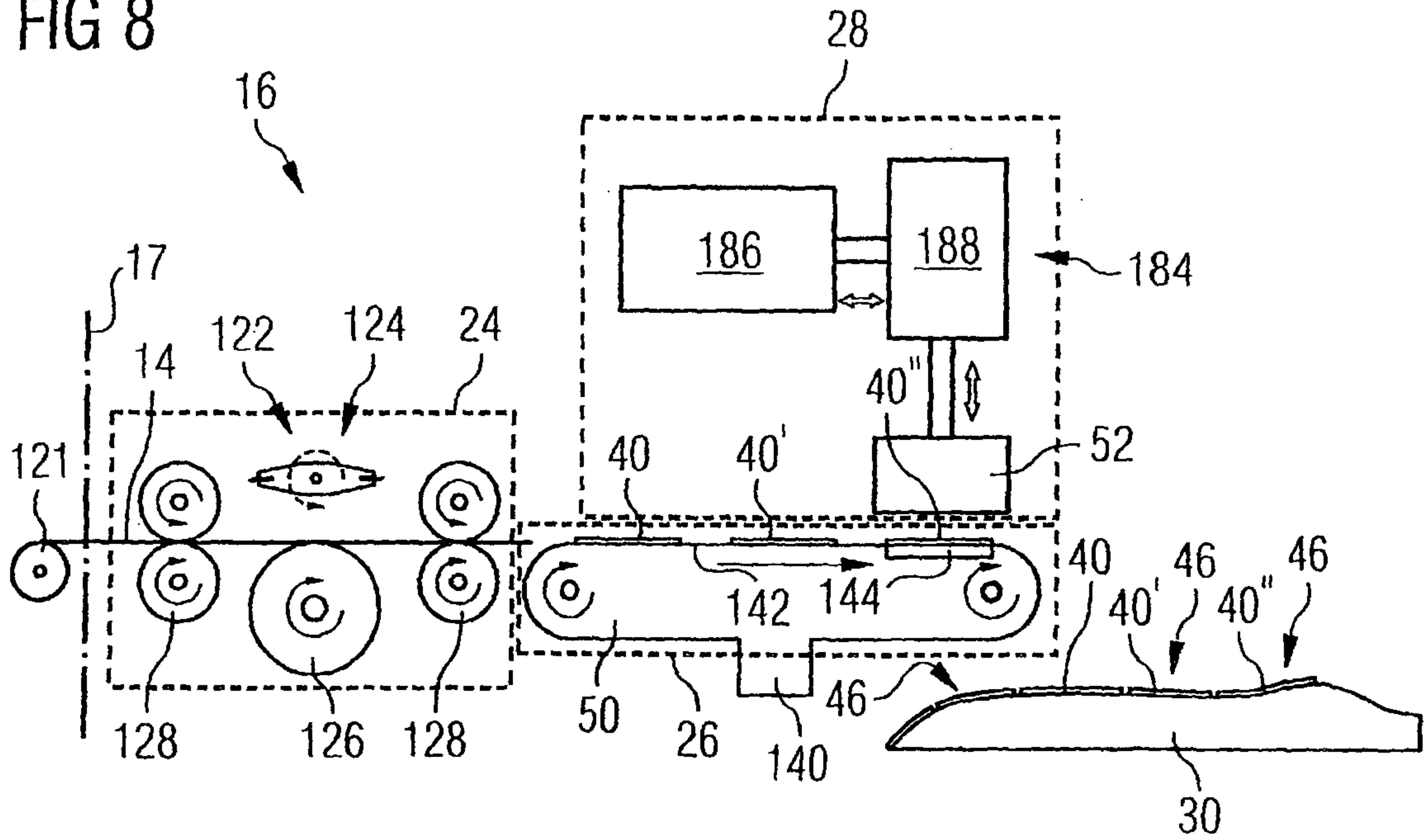


FIG 8



5/8

FIG 9

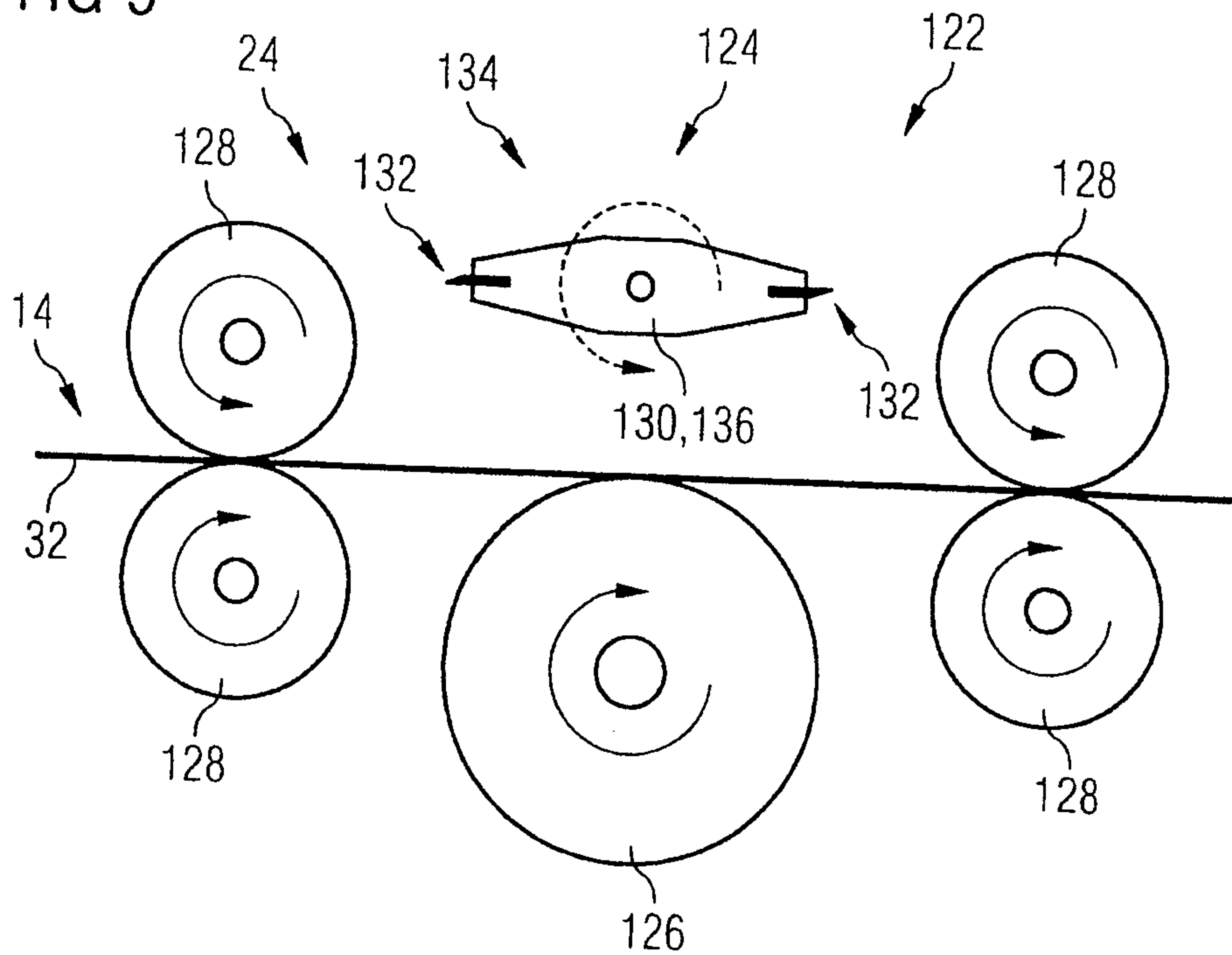


FIG 10

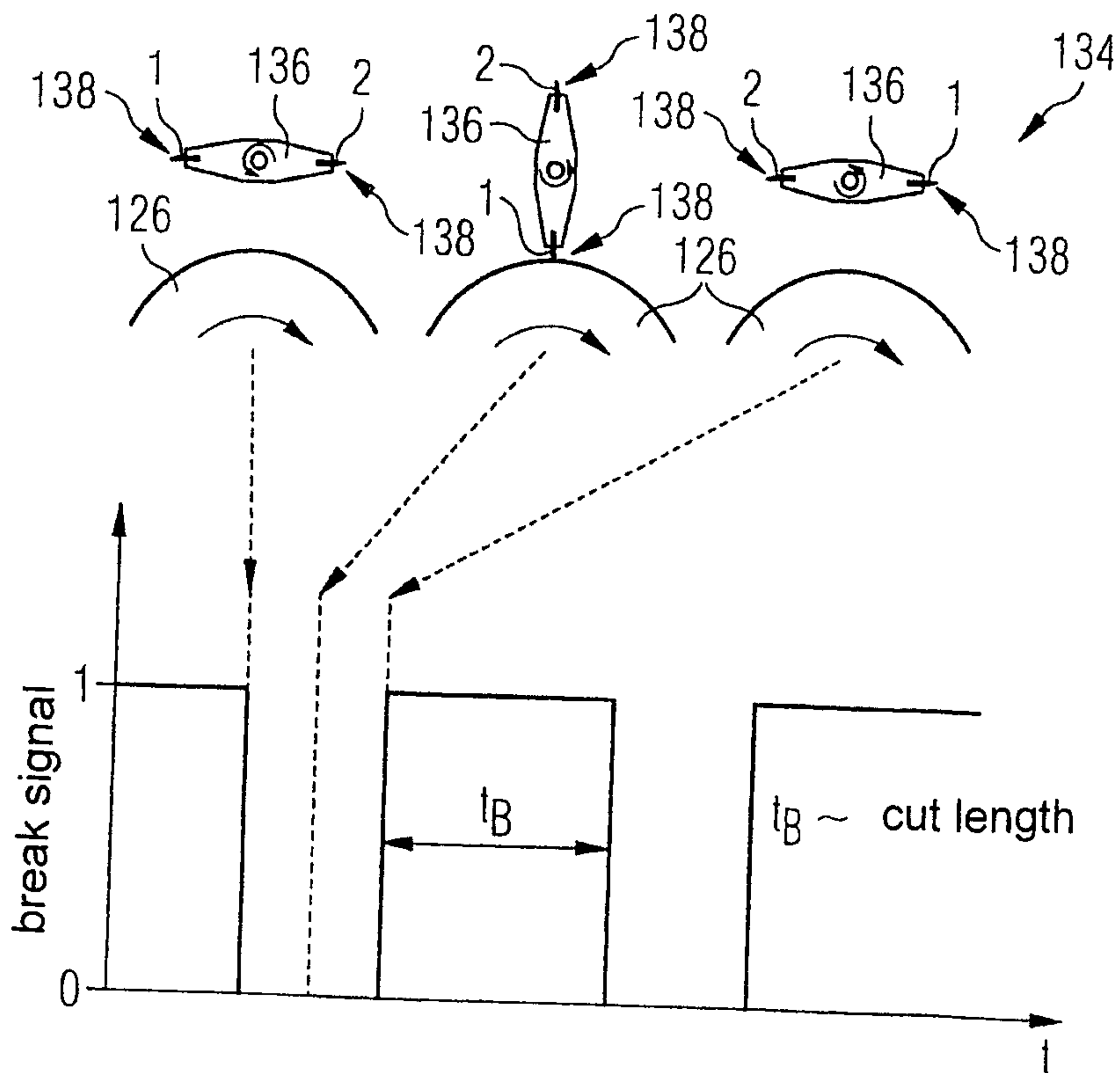


FIG 11

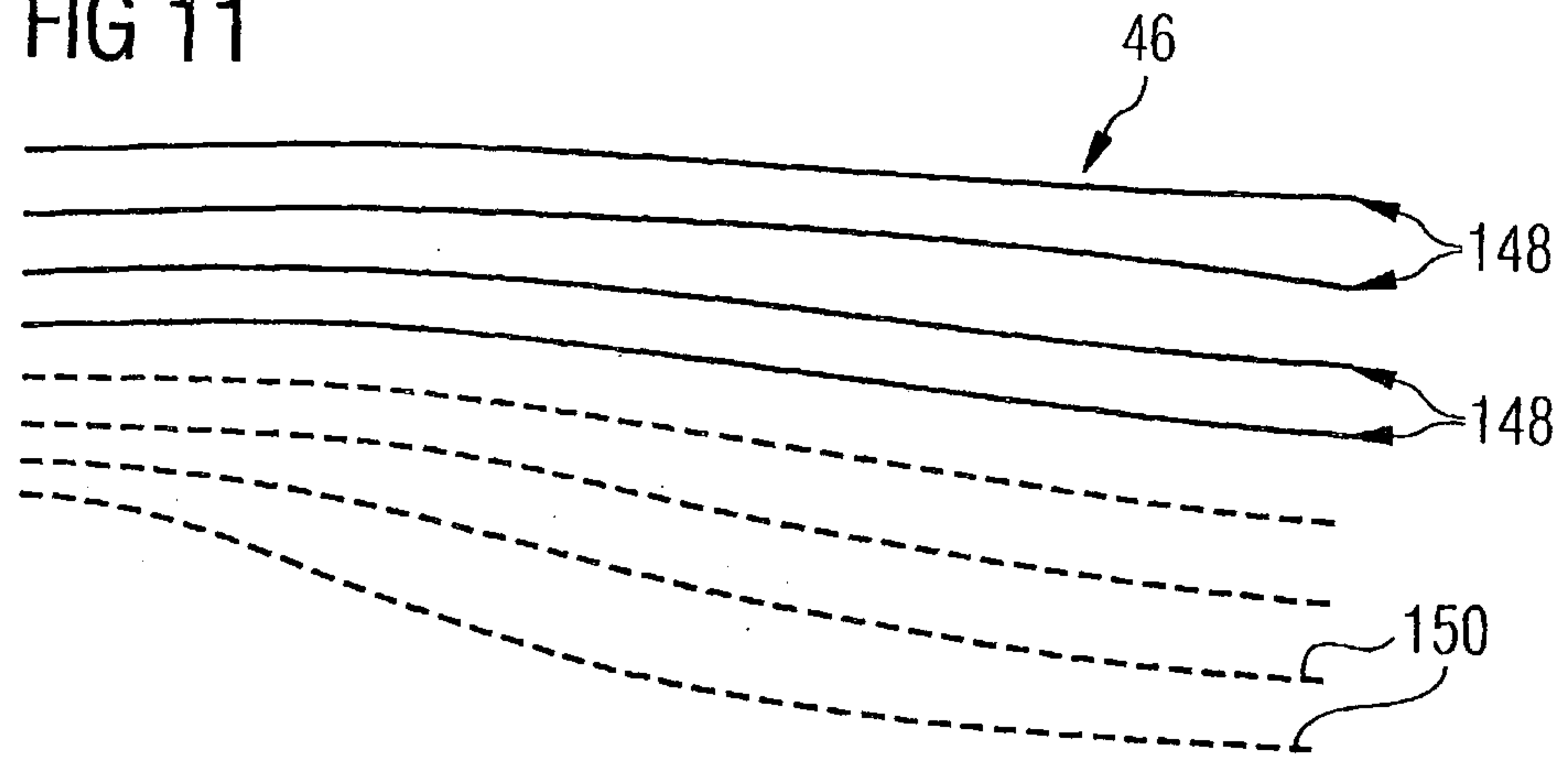


FIG 12

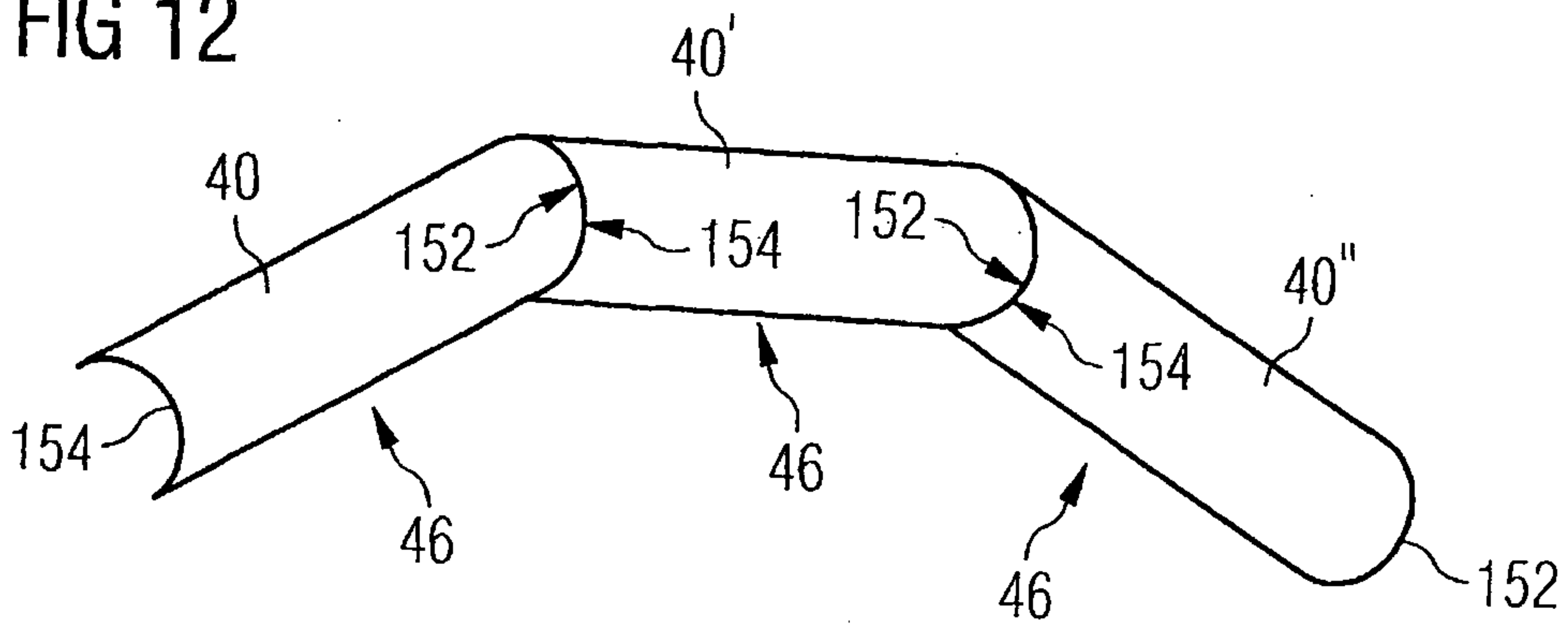


FIG 13

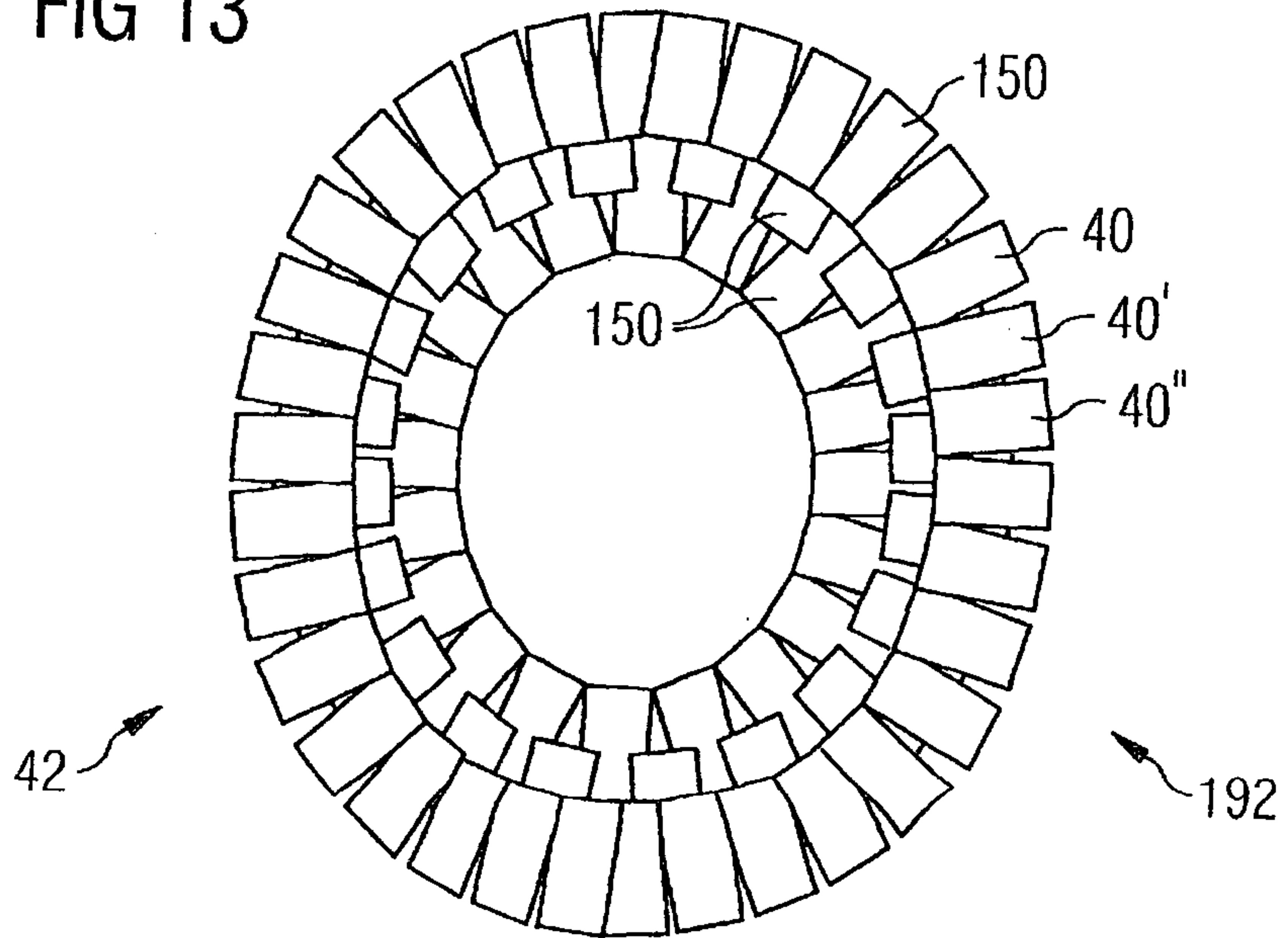


FIG 14

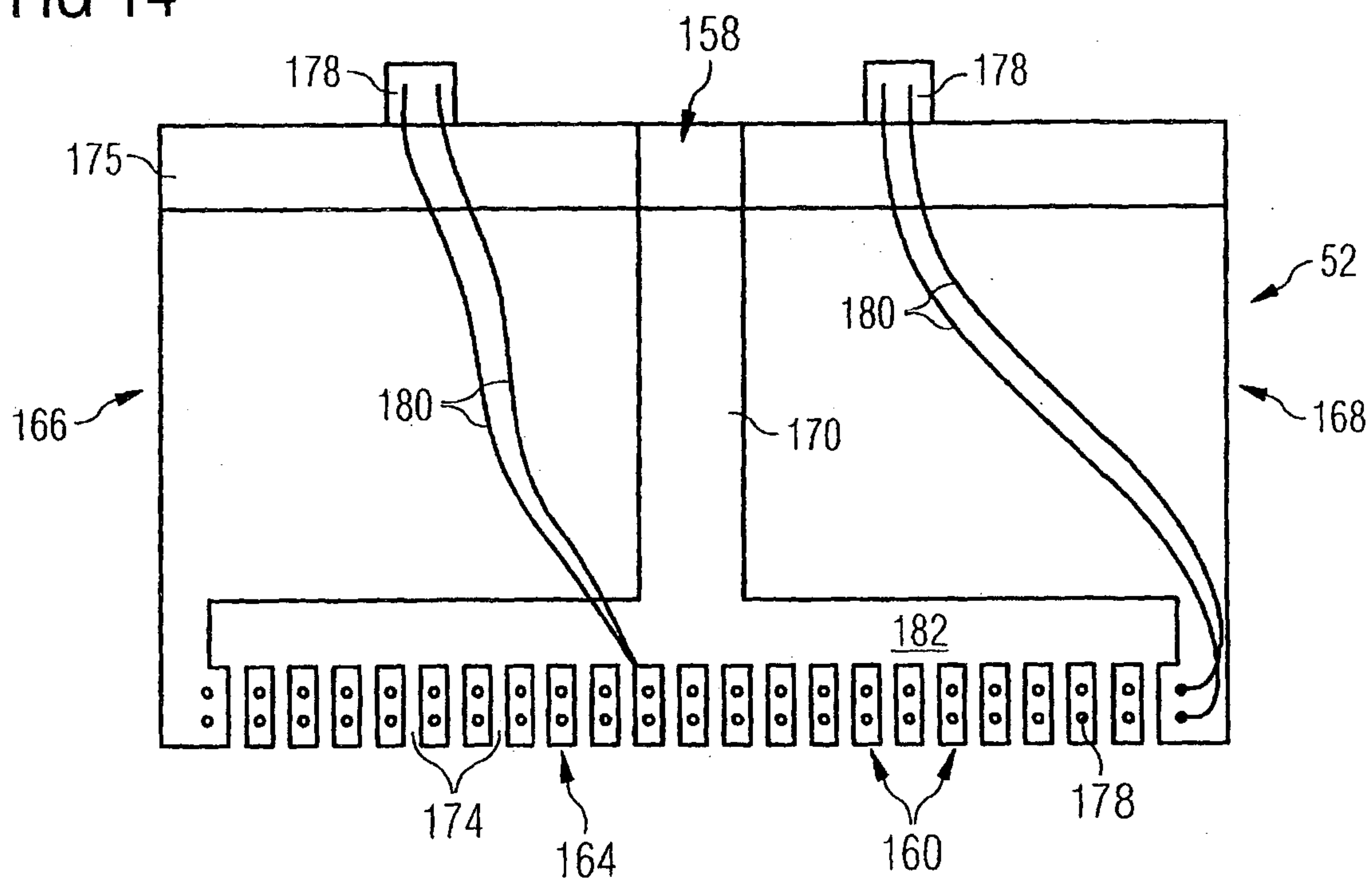


FIG 15

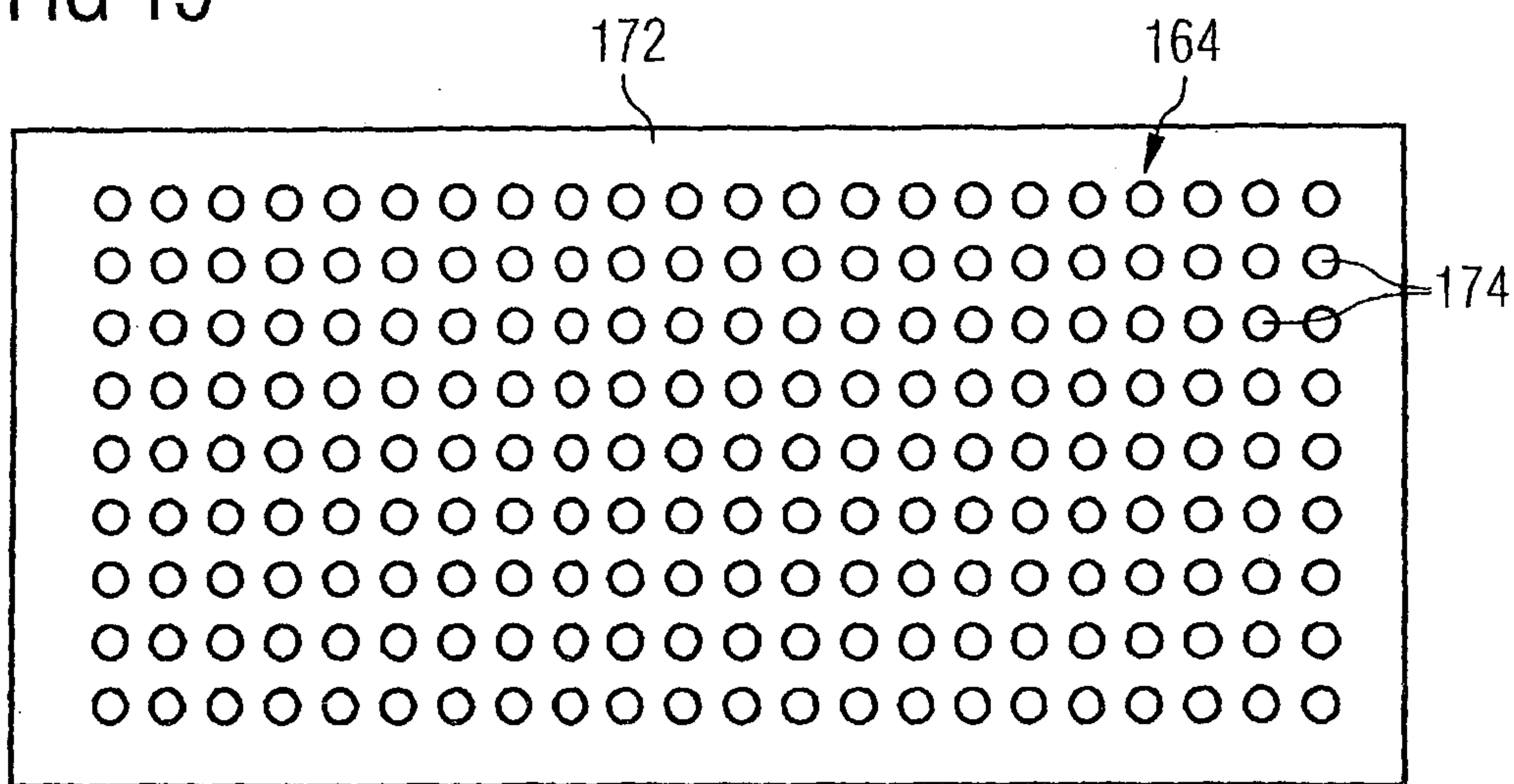


FIG 16

