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(54) Benævnelse: **Vindenergianlæg med ringgenerator**

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The present invention relates to a device for producing a stator of a synchronous machine.

One known method for producing stator windings in generators comprises the use of what are called preformed coils. These preformed coils are individual windings of the stator winding which are already adapted in their form to the grooves and groove spacings of the stator, and which are first of all laid individually in the grooves and then connected together.

However, wind energy systems are always exposed to high loads during operation. With increasing wind speed, the output of the wind energy system increases, but at the same time so does the mechanical load. As a result, the stress on the wind energy system from a mechanical and electrical point of view increase [sic] substantially simultaneously. At high wind speeds, the mechanical stress on the installation is high, and at the same time a great deal of electrical energy is generated, so the stress on the electrical components is high as well.

In this case, the generator of the wind energy system, which is subjected to mechanical and electrical stresses, is under particular stress. This combination results in problems if e.g. as a result of high generated electrical currents the temperature in the region of the generator is likewise high and as a result of mechanical stress connections between individual components are subjected to vibrations. If a small amount of play, or loosening, also occurs as a result of the thermal expansion, the mechanical stresses here may lead to a defect or even to damage.

If this failure relates to the stator winding or a phase thereof, this phase at least is inoperative for energy production. Furthermore, an additional asymmetrical load is produced in the generator, since this phase behaves as if in no-load operation as a result of the interruption. Mechanical damage due to detached and freely movable components such as connecting sleeves is not even taken into account in this case.

For a stator of a generator, wound in a six-phase configuration, with 72 poles, there are 432 preformed coils, which are connected together by 864 connection points. These connection points are usually configured as screw, clamping or soldered connections.

Taking into account statistical probabilities (no matter how small), as a result of the high number of connection points and the permanent load changes, even if the connection between the preformed coils is produced with care a considerable source of failure is present here. Only one stator is taken into account in the preceding considerations. The mass production aspect makes the actual probability of such failure clear.

GB 2 149 595 A or US 4,318,019 A disclose an alternator of a passenger vehicle or of a wind energy system, wherein the stator in each case has an uninterrupted winding. US 5,881,778 A relates to an alternator of a passenger vehicle and to a method for producing this alternator.

US 4,318,019 A discloses a generator of a wind energy system.

It is therefore an object of the present invention to devise a device for producing a stator of a synchronous machine in which these problems discussed above are at least reduced.

This object is achieved by a device for producing a stator of a synchronous machine according to Claim 1.

The synchronous machine has a rated output of several hundred kW. On the inner and outer periphery, grooves for receiving a stator winding which are spaced apart from each other are formed on the stator. The winding is wound continuously without interruption. The device for producing a stator has a bearing device for the stator in which the stator is held vertically. The diameter of the stator is several metres.

In order to be able to compensate for current displacement effects in the individual windings, the windings are produced from at least two conductor bundles, with a plurality of conductors which are insulated from each other being present in each conductor bundle. These conductor bundles are laid in a specified order in grooves of the stator, and the order is changed at likewise specified distances, so that in alternation each of the conductor bundles is affected by these effects as uniformly as possible. Due to this uniform influencing of all the conductor bundles of a phase, it is possible to dispense with compensation measures.

In order to facilitate the handling of the stator during production of the winding and to create a situation which is beneficial in terms of occupational physiology, the stator is held in a bearing device in which the grooves are at a beneficial working height for producing the winding and permits [sic] rotation of the stator in the circumferential direction by a desired amount. This can preferably be done using a motor-driven drive.

Furthermore, at least one supporting device for supporting at least one coil with winding wire is provided. This supporting device permits the handling of the winding wire, e.g. in the form of conductor bundles, the length of which is calculated according to the invention such that the phase can be wound continuously on the stator. The length of the conductor bundles required for this results in a considerable weight, which can no longer be handled manually.

In each case two drums with winding wire are handled in pairs, in order thus to be able to handle both conductor bundles simultaneously, and one supporting device bears three pairs of the drums with winding wire, so that using such a supporting device a three-phase system with two conductor bundles per phase in each case can be wound on the stator.

The drums with the winding wire are arranged pivotably about a central axis of rotation of the supporting device. This arrangement makes it possible to compensate for twisting of the conductor bundles which results from the turning of the stator in the holding device by the drums being correspondingly turned along with them on the supporting devices.

Further advantageous embodiments of the invention are set forth in the dependent claims.

The invention will be described in greater detail below with reference to [in] the figures. Therein:

Fig. 1 shows a simplified stator of an annular generator in a holding device;
Fig. 2 is a cross-section through a conductor bundle;
Fig. 3a shows part of the stator grooves with conductor bundles laid therein;
Fig. 3b shows part of the stator grooves with conductor bundles laid therein;
Fig. 3c shows a known construction of a stator winding;
Fig. 3d shows a construction of a stator winding;
Fig. 4 shows a simplified supporting device according to the invention in a side view;
Fig. 5 is a front view of a supporting device; and
Fig. 6 shows the arrangement of supporting devices and stator for producing a stator winding.

In Fig. 1, reference numeral 10 designates the stator, which has grooves 12 running in the axial direction on the inner periphery. This is the most frequent structural form of a generator. The rotor (not shown) is located within the stator 10. This structural form is referred to as an internal rotor. Alternatively, the grooves 12 in the case of what is called an external rotor, in which the rotor encompasses the stator 10, may be provided on the outer periphery of the stator. The grooves 12 are shown enlarged in the figure. The stator 10 is held in a holding device 14 which stands on the ground and thus holds the stator 10 and in particular the grooves 12 at a height which forms an operating position which is beneficial in terms of occupational physiology.

Since such a stator 10 of an annular generator has a diameter of several metres and accordingly a great weight, the stator 10 is rotatably mounted on pivot bearings 16 and can be turned by a desired amount e.g. in the direction of the arrow in order to bring the grooves 12 to be machined into a desired position. This turning of the stator 10 can of course take place using a drive motor (not shown).

Fig. 2 illustrates a conductor bundle 20 which consists of a plurality of individual conductors 22 which are laid as a bundle in the grooves (reference numeral 12 in Fig. 1). In this case, the individual conductors 22 are insulated from each other by a coating.

The formation of conductor bundles 20 consisting of individual conductors 22 has the advantage that these conductor bundles are not fixed in their cross-sectional form, but changeable, so that they on one hand are guided through a relatively narrow groove opening, but on the other hand then by appropriate deformation can very largely fill the broader groove cross-section, in order to achieve a good filling factor for the groove (reference numeral 12 in Fig. 1).

Fig. 3a shows an unwound section of the inner periphery of the stator 10. The grooves 12 are arranged horizontally next to one another here. In the grooves 12 are laid the conductor bundles, which are illustrated here in simplified manner as circular conductor bundles 20. In each case two of these conductor bundles 20 are combined to form one winding of a phase. This is illustrated in the figure by crosspieces 24 which connect two of the conductor bundles 20 in each case. Accordingly, corresponding to the illustration in this figure two windings of a phase are laid in each groove. For a better overview, the individual conductor bundles are numbered from bottom to top with numbers 1 - 4. To distinguish the individual phases of the six-phase system illustrated here, these are marked below the groove with the designations P1 - P6.

In the figure, it can easily be recognised that the conductor bundles 1 and 2 always form the first winding, while the conductor bundles 3 and 4 always form the second winding, which is laid in the corresponding groove 12.

In Fig. 3a, viewed starting from the left, the phases P1 - P6 are illustrated next to one another in a rising order and the order of the conductor bundles is indicated by the reference numerals 4, 3, 2, 1. After the groove 12 with the phase P6, this phase sequence repeats again starting with P1. In the second groove 12 with the phase P5 illustrated in this figure, the order of the conductor bundles 20 is now changed. Although the first winding arranged at the bottom in the groove 12 still consists of the conductor bundles 1 and 2, the order of these is however transposed. Likewise, the second winding still consists of the conductor bundles 20 designated 3 and 4, but these are likewise transposed in their order. The phase P6 arranged next to then again has the already known sequence of conductor bundles.

The phases P1 - P6 are illustrated once again in the right-hand part of this figure. In addition to the transposition of the conductor bundles 20 of phase P5 designated 1 and 2 or 3 and 4 respectively, here likewise the conductor bundles of phase P3 are illustrated transposed. Of course, here too the conductor bundles 20 designated 1 and 2 form the first winding and the conductor bundles 20 designated 3 and 4 form the second winding of this phase, but again the position of the conductor bundles is transposed within the winding.

The reason for this transposition becomes discernible if it is explained that the magnetic lines of force run not only in the longitudinal direction of the legs 26 which laterally delimit the grooves 12, but also through the grooves between two legs 26 with different polarity. This results in a current displacement in the individual conductor bundles 20 depending on the position thereof in the groove 12.

If the position of the conductor bundles is then transposed at certain intervals, both conductor bundles 20 of a winding are correspondingly alternately subjected to this effect, so that given a suitable selection of the transposition position and frequency both conductor bundles 20 of a phase are subjected to this effect approximately uniformly, so that no compensating currents of note resulting from non-uniform exposure flow, and thus the maximum possible current can be emitted by the generator.

Fig. 3b therefore shows the representation of the stator grooves with stator windings or stator conductors laid therein, it being possible to recognise that the stator grooves are very largely filled with the windings, and the direction of current flow in the conductors (arrow head, arrow cross) also being able to be recognised. Furthermore, the arrangement of the phases is changed compared with Fig. 3a, in order also better to make clear the change in the sense of winding. The illustration according to Fig. 3b however also makes it clear that more than 80%, preferably more than 95%, of the entire space of the stator groove is filled up with windings and thus the proportion of air in the stator groove is extremely low.

Fig. 3c shows part of a conventionally produced winding, but without the stator and the grooves in which the winding is laid being illustrated. The winding in this case is formed from preformed coils 40, which have two windings 41, 42. These windings 41, 42 are illustrated offset relative to each other in order to be better recognisable. In the groove (not shown in this figure), they are of course arranged exactly one above another.

Three preformed coils 40 of a phase are illustrated. The spacing results from the fact that preformed coils of the other phases of the stator are arranged in alternation between preformed coils of this phase, but are not illustrated in the figure. The preformed coils 40 of a phase can be connected to each other by soldered joins or screw/clamping connections or similar techniques.

These connections illustrated in Fig. 3c are potential sources of failure.

Fig. 3d shows the embodiment of a continuously wound phase. Here too, corresponding to the illustration in Fig. 3b, again part of the winding of a phase is illustrated. In this case, the individual windings 41, 42 are likewise illustrated offset relative to each other, in order to make clear the type of embodiment.

In this embodiment, it can immediately be recognised that the transitions illustrated as a potential source of failure in Fig. 3b are eliminated with this invention. No interruption can therefore occur any longer at the transitions between the individual winding portions.

Fig. 4 shows a supporting device 30 for the conductor bundles which are used as winding wires in a side view. An L-shaped base frame 31 provides a secure footing for the entire supporting device 30. A supporting plate 32 is connected to the base frame 31 via a pivot bearing 33. On the supporting plate 32 there are fastened supporting arms 34 which run from the centre of the supporting plate 32 from a specified portion towards the periphery of the supporting plate 32 and extend a specified length substantially horizontally away from the supporting plate 32.

To these horizontally extending portions of the supporting arms 34 there are rotatably fastened drums 36 with the conductor bundles which are used as winding wire.

Between the vertical portion of the supporting arm 34 running parallel to the supporting plate 32 and the horizontally extending portion thereof there is provided a pivot bearing (not shown). This pivot bearing cooperates with a drive 35 and permits turning of the horizontal portion of the supporting arm 34 about its longitudinal axis together with the drums 36 arranged thereon. As a result, twisting which occurs upon winding the stator winding between the conductor bundles of this winding can be counteracted.

Fig. 5 shows a front view of this supporting device 30. Here a base frame 31 which tapers from the base towards the tip is illustrated. Two cross-members 38 and 39 are provided to increase the stability.

On the base frame 31, the supporting plate 32 is arranged rotatably, on the supporting plate 32 there are arranged three supporting arms 34 offset in each case by the same angle (120°), on the substantially horizontally extending cantilevers of which in each case two drums 36 for the conductor bundles are fastened. Due to the rotatable mounting of the supporting plate 32 and the drums 36 fixedly connected thereto via the supporting arms 34, turning can be carried out by a second motor 37.

When producing the winding on the stator 10, each conductor bundle 20 is laid in a groove 12, is bent over at the end of the groove 12 in the winding overhang and guided up to a new groove 12, extending in parallel, in the winding overhang. Then the conductor bundle 20 again is bent over such that it can be laid in this groove 12. At the exit from this groove 12, the conductor bundle 20 is again bent over in the winding overhang such that it can be guided to the next groove 12. As a result, corresponding turning is of course yielded in the conductor bundle 20 extending towards the drum 36 as well.

The drums 36 are arranged in pairs on the horizontal portions of the supporting arms 34. Since these horizontal portions can be rotated about their longitudinal axis by the drives 35, the drums 36 are turned along with them. In this manner, twisting of the conductor bundles can be counteracted by turning the corresponding supporting arm 34.

A second drive 37 is arranged between the base frame 31 and the supporting plate 32, and permits rotation of the supporting plate 32 with all the supporting arms 34 and drums 36 arranged thereon, in order likewise to carry out the rotation of the stator 10 in the stator holder 14 and in this manner to avoid twisting of the conductor bundles.

Fig. 6 shows, in simplified manner and without conductor bundles between the supporting devices 30 and the stator 10, the arrangement of two supporting devices 30 and a stator 10 which is to be wound. The stator 10 is mounted in a holding device 14 and rotatable in the circumferential direction (direction of the arrow). Since each of the supporting devices 30 likewise has rotatably mounted drums 36, these can jointly carry out or implement the turning of the stator by corresponding turning. By providing two supporting devices 30 with three pairs of drums in each case, six phases can therefore be wound on a stator simultaneously.

It is obvious that the present invention can be applied not only to annular generators for wind energy systems, but in principle to any synchronous machine, it having to be made clear that these are not miniature machines, but machines which have a considerable spatial extent and which routinely have connected loads of several hundred kW or more under certain circumstances. For example, a rated output of more than 500 kW is typical for an annular generator of a wind energy system, and even generators with a rated output of more than 4 MW are already being tested and will be used in the future. The stator of the synchronous machine described alone weighs several tonnes, and for annular generators of over 4 MW even more than 50 tonnes under certain circumstances.

Patentkrav

1. Indretning til fremstilling af en stator af en synkronmaskine med flere 100 kW nominaleffekt, ved hvilken der ved den indre eller ydre omkreds med afstand fra hinanden er udformet noter til optagelse af en statorvikling, hvor viklingen er viklet gennemgående uden afbrydelser, hvor statorens diameter udgør flere meter, med
en lejeindretning for statoren, i hvilken statoren holdes stående, og
mindst et drev til at dreje statoren i lejeindretningen i sin omkredsretning.

2. Indretning ifølge krav 1,
kendetegnet ved en bæreindretning, der er adskilt fra lejeindretningen (14), til fastholdelse af mindst en tromle med viklingstråd.

3. Indretning ifølge krav 2,
kendetegnet ved en parvis indretning af flere tromler, hvor parrene af tromlerne er anbragt i en ensartet afstand fra hinanden langs med en tænkt omkreds.

4. Indretning ifølge et af de foregående krav,
kendetegnet ved en bæreindretning, der er anbragt på hver endeflade af statoren.

5. Indretning ifølge et af de foregående krav,
kendetegnet ved et antal af parrene af tromlerne lig med antallet af de faser, der skal vikles på statoren.

6. Indretning ifølge krav 5,
kendetegnet ved, at hver af bæreindretningerne hver især bærer halvdelen af tromlen.

7. Indretning ifølge et af de foregående krav,
kendetegnet ved en bæreplade, der er anbragt i det væsentlige vertikalt, og bærearme, der forløber fra bærepladens centrum og ud, til optagelse af tromlerne.

8. Indretning ifølge krav 7,
kendetegnet ved en drejelig lejring af bærepladen.

9. Indretning ifølge krav 8,
kendetegnet ved et drev til at dreje bærepladen i omkredsretningen.

10. Indretning ifølge et af kravene 7-9, **kendetegnet ved,**
at tromlerrne er anbragt på en i det væsentlige horisontalt forløbende sektion af bærearmene (34), og at den horisontalt forløbende sektion er udformet drejelig omkring sin langsgående akse.

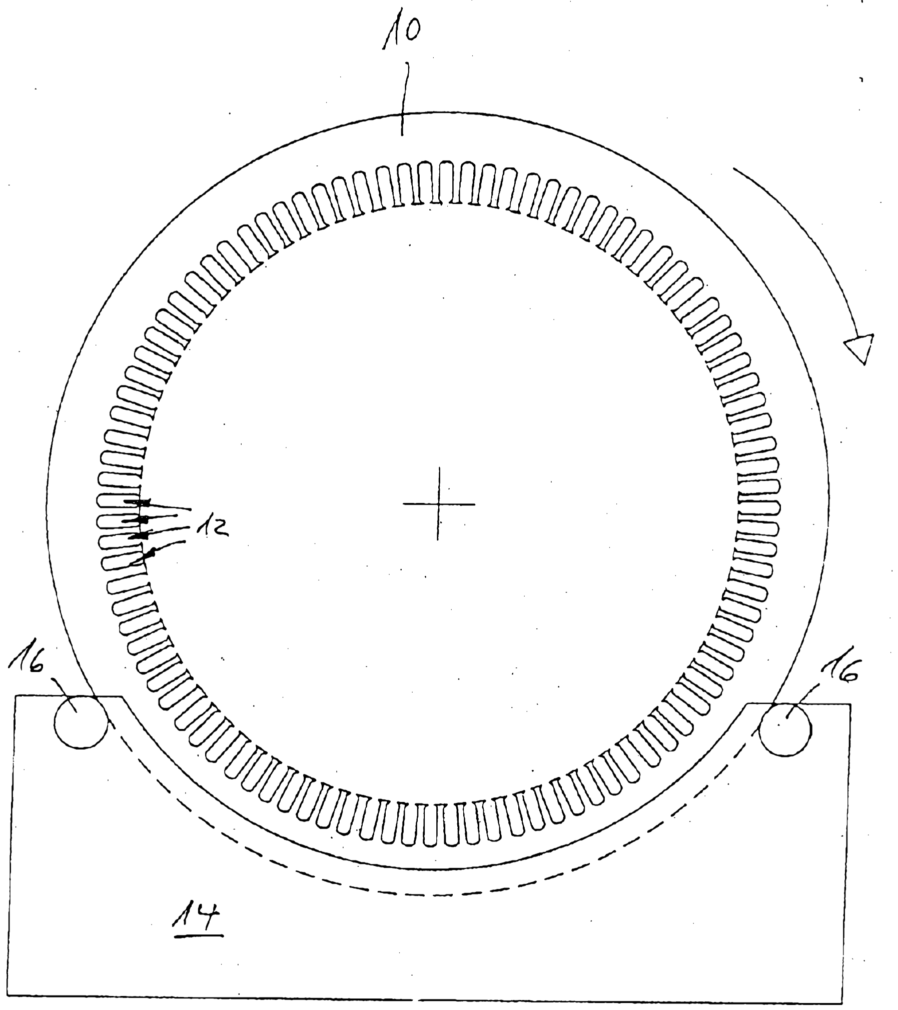

Fig. 1

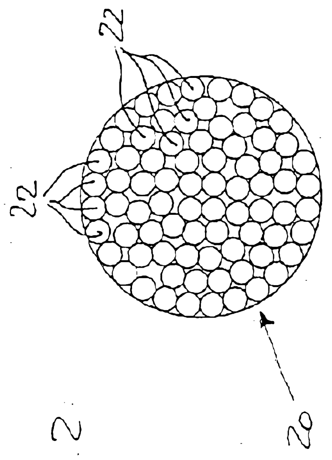

Fig. 2

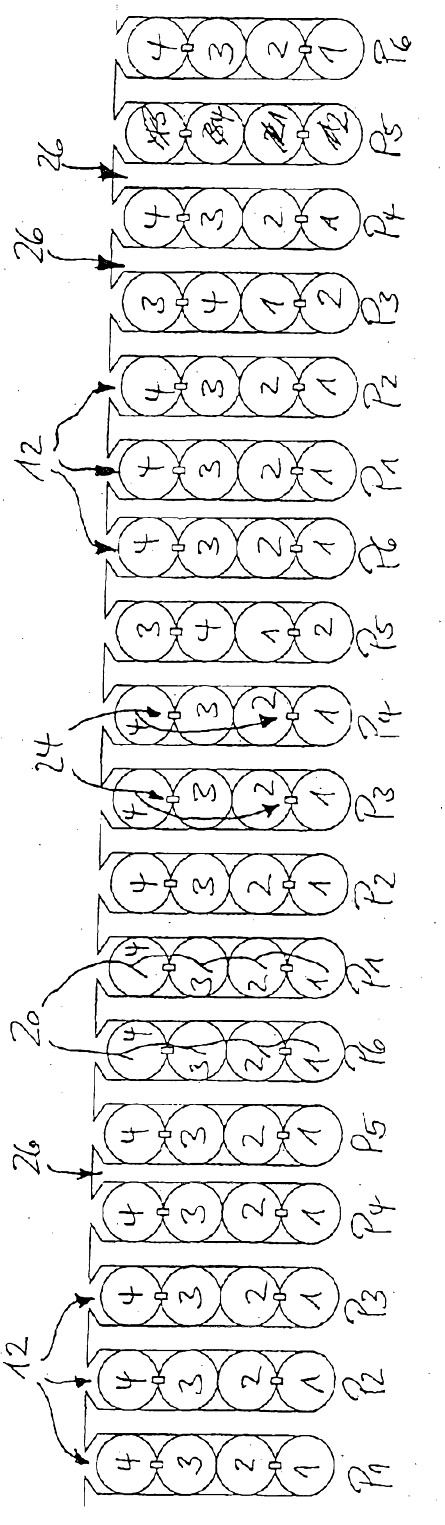

Fig. 3a

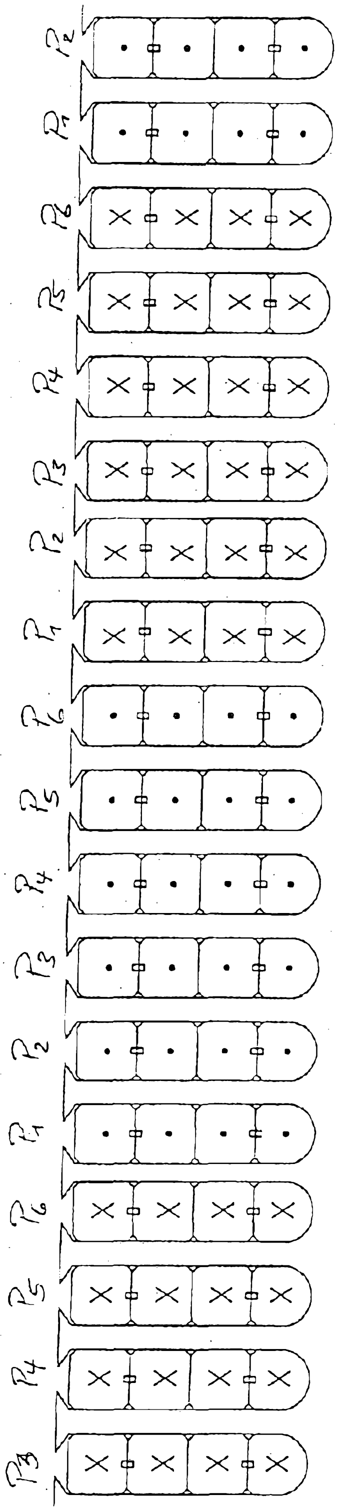

Fig. 36

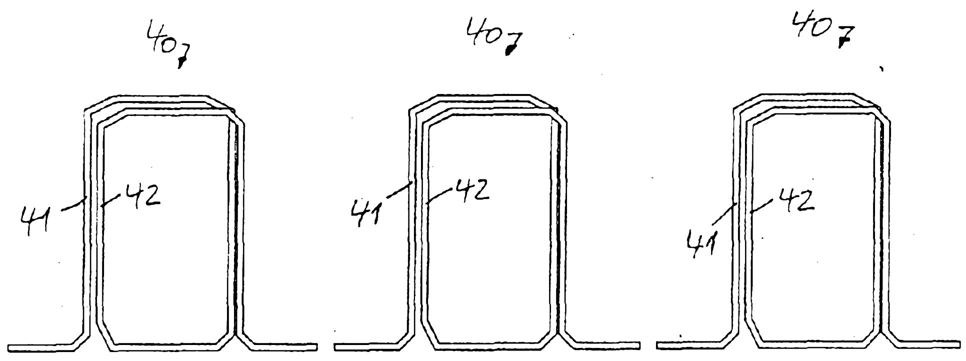

Fig. 3c

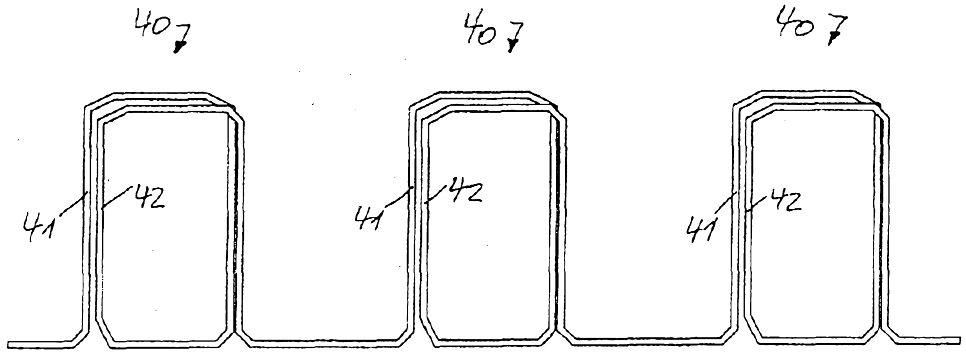

Fig. 3d

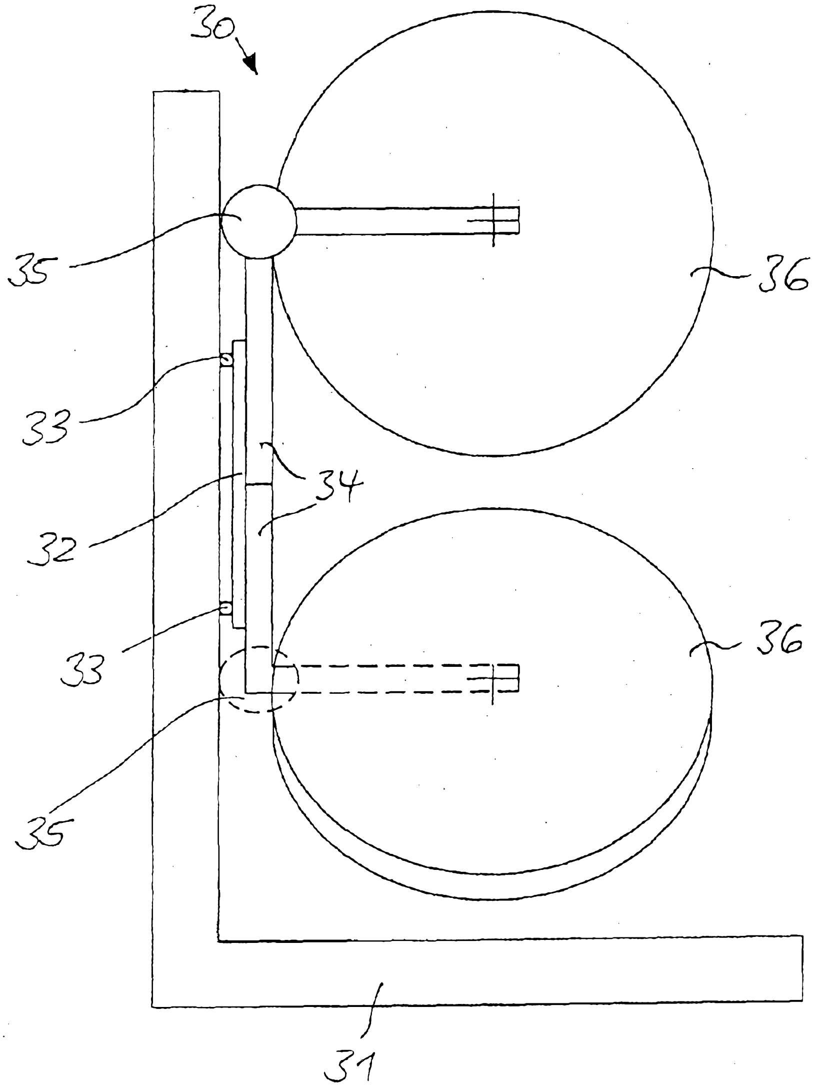

Fig. 4

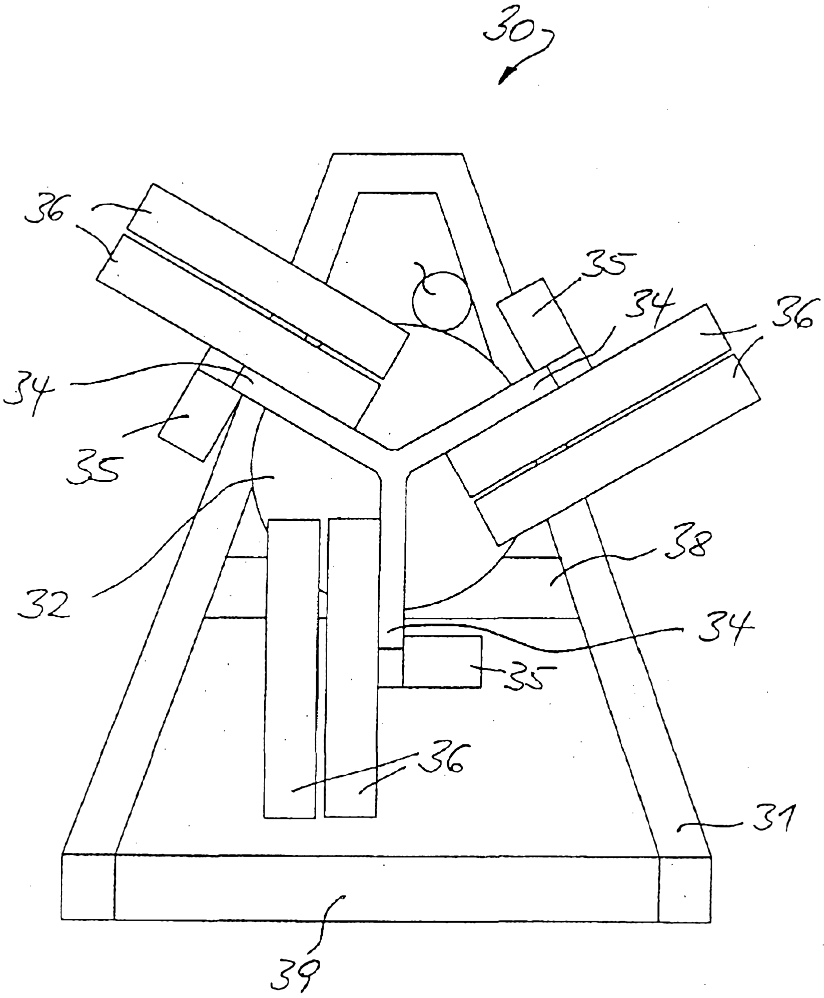

Fig. 5

Fig. 6