(19) DANMARK

(10) DK/EP 2574711 T4

Patent- og Varemærkestyrelsen

(12) Oversættelse af ændret europæisk patentskrift

(51) Int.Cl.: *F 03 D 13/20 (2016.01)* *E 02 D 27/42 (2006.01)* *E 04 H 12/08 (2006.01)*

(45) Oversættelsen bekendtgjort den: **2023-09-25**

(80) Dato for Den Europæiske Patentmyndigheds bekendtgørelse om opretholdelse af patentet i ændret form: **2023-07-12**

(86) Europæisk ansøgning nr.: **12006627.9**

(86) Europæisk indleveringsdag: **2004-08-25**

(87) Den europæiske ansøgnings publiceringsdag: **2013-04-03**

(30) Prioritet: **2003-08-25 DE 10339438**

(62) Stamansøgningsnr: **04764463.8**

(84) Designerede stater: **AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PL PT RO SE SI SK TR**

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(54) Benævnelse: **TÅRN TIL ET VINDENERGIANLÆG**

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Calculations of force transfer

TOWER FOR A WIND ENERGY FACILITY

Description

Modern wind turbines are mainly built with pipe-form towers, and in particular steel pipe-form towers, since this type of construction, called shell construction, is the simplest most economical tower construction. With large wind turbines having more than 70 m rotor diameter and more than 80 m tower height, as well as an output power of more than 1,5 megawatts, the tower diameter required in the lower tower region is a decisive technical barrier. Diameters of more than 4,3 m can only be transported with difficulty, since often the passage height underneath bridges does not permit any larger dimensions. The overall length and weight of the towers furthermore require the tower to be divided into several sections which are each screwed to one another by way of a ring flange connection. Apart from the transportation logistics, the large ring flange connections represent a considerable cost factor in the case of towers for very large wind turbines (3-5 MW).

As a result of the transport difficulties concrete towers are therefore increasingly being used which are either made at the installation site of the wind turbine or are made from small individual parts which are adhesively bonded and tensioned to one another. Both types of tower, however, are considerably more expensive to manufacture than steel pipe-form towers. For this reason, steel pipe/concrete hybrid towers are also being constructed where the upper tower part is designed as wide as possible as a steel pipe-form tower, and only the lower tower part, having too large a diameter for transport, is made from concrete. With this type of construction, however, the transition from steel tower to concrete tower has proved technically complex and costly.

Furthermore, there are lattice towers, widely known as electricity pylons, which are already used for large wind turbines having heights up to 114 m with 2 megawatts output. Aside from the advantage of problem-free transport, these towers have the decisive disadvantage, however, that they have a clearly larger horizontal extension than a comparable steel pipe or concrete tower, which often causes problems with the distance required between the rotor blade tip and tower (blade

clearance). If the rotor blade bends severely in the event of a storm, the danger exists of contacting the tower, which is very dangerous for the entire structure.

On the other hand, the larger horizontal extension of the lattice tower enables an overall more effective use of materials. This advantage, which is generally known of framework structures, allows a lower overall mass and thus a lower purchase price. This economic advantage is, however, as a rule cancelled out by the costs of the maintenance of the lattice towers which is to be carried out over the 20-year service life. By way of example, the screw connections in highly dynamically-loaded towers of wind turbines have to be checked periodically - a time-consuming activity which is dangerous at the great height of the lattice towers and which can only be carried out by extremely skilled specialists working at heights which place great strain on the body.

It is known from DE-PS 736 454 and DE 198 02 210 A1 that the tower can have an upper and a lower tower portion, wherein the lower tower portion is configured as a lattice tower, and the upper tower portion has a pipe form.

However, problems arise here regarding the transition from a shell structure (pipe tower) to a framework structure (lattice tower), since this is technically very demanding. Therefore, in existing lattice towers for wind turbines, as a rule, a relatively short pipe-form component, the so-called “top,” is inserted directly beneath the nacelle to enable the transition to the nacelle, which is provided with a ring flange. The transition is generally formed there in that the - as a rule, four - corner posts of the lattice tower are screwed directly onto the outside of the top by means of junction-plate connections. This concept is therefore possible because the tower is subjected to only relatively low bending stresses directly beneath the nacelle. Thus, in this case, essentially only the horizontally-acting rotor thrust has to be transferred (acting as a lateral force for the tower). Such a construction is economically not possible further down where the tower is mainly stressed by the bending moment acting from the rotor thrust via the lever arm over the tower length. Towers for a wind turbine according to the prior art are also known from the documents FR2597161 and BE451404. The object of the invention is therefore to provide a tower structure for large wind turbines which overcomes the drawbacks in the prior part - particularly with regard to

transportation, economic viability, maintenance, and blade clearance. This is achieved by a tower for a wind turbine having the features of Claim 1.

The tower according to the invention consists, as is known from the prior art, of an upper pipe-form tower portion, as well as a lower tower portion, which is designed as a lattice tower with at least three corner posts. Both tower portions are connected to one another in a transition region, wherein the dimensions of the upper tower portion in the transition region are clearly smaller than the dimensions of the lower tower portion in the transition region.

According to the invention, it is provided that the upper tower portion form at least one sixth of the overall tower. This has the advantage that a convenient standard design can be used in the upper region of the tower.

Furthermore, the torsional loads which occur in the upper tower portion are, as a result of the smaller cross-section, clearly higher than in the lower tower portion. Since a pipe-form tower has a high torsional rigidity, the torsional forces which occur can thus be better absorbed than, for example, by a lattice tower.

As already explained above, the transition from the lower tower portion to the upper tower portion represents a problem. The reason for this is that the force flow has to be passed on from the pipe cross-section of the upper tower portion to the three - or, for example, even four - corner posts of the lower tower portion. The simplest solution would, for example, be a plate to which the upper tower portion and lower tower portion are fastened. Such a plate would, however, have the drawback that the plate would have to have very large dimensions in order to be able to withstand the loads which occur, so that considerable further costs would be incurred.

According to the invention, it is indeed also provided that the cross-section of the lower tower portion beneath the transition region be greater than the cross-section of the upper tower portion, wherein, however, the transition region is designed so that the cross-section of the lower tower portion is adapted in force-optimized fashion to the cross-section of the upper tower portion. The invention thus offers the advantage that a transition region is provided which is designed so that the force flow is optimally guided from the upper tower portion to the lower tower portion so that the entire transition region need not be oversized.

The synergy of the features of the invention mentioned above results in a tower of optimum design. The tower according to the invention has in its upper region a standard tower. In the lower tower portion, which, as a result of its dimensions, for example, can no longer be designed as a pipe-form tower, since it can then no longer be transported, the tower according to the invention has a lattice tower structure. The provision of the lattice tower portion furthermore has a great advantage in the case of offshore wind turbines where it offers a lower surface area exposed to the force of waves than a pipe-form tower. The advantageously adapted transition region leads to a lattice tower portion whose corner posts and strut formations have lower wall thicknesses, so that the mass of the tower and the associated costs for the tower, which represents a considerable cost factor in relation to the wind turbine as a whole, are advantageously reduced.

Each corner post can have an inclination relative to the vertical axis of the tower which is selected so that, with an imaginary extension of the corner posts, their longitudinal axes cross over in a virtual intersection point. It is advantageous to configure the tower of the present invention so that the virtual intersection point of the corner posts lies in a region above the transition region, which can extend up or down from the nacelle over a third of the tower length, since the corner posts are thus stressed essentially only by normal forces and not by bending.

Lattice towers generally have strut formations between the corner posts for additionally taking up the forces which occur. Arranging the intersection point in the upper region of the wind turbine means that the force flow takes place predominantly through the corner posts, and the force flow which is guided over the strut formations is kept substantially lower. In this way, the loads arising in the strut formations are advantageously minimized, whereby the strut formations can be made with smaller dimensions, and thus the wall thicknesses of the strut formations can be selected to be smaller, whereby the welded seam volume at the leg connections is advantageously reduced (cost savings).

According to an advantageous configuration of the present invention, the transition region is designed so that the cross-section of the lower tower portion tapers up to the cross-section of the upper tower portion, and in fact particularly advantageously over a length corresponding to at least below half the pipe tower diameter.

According to a further advantageous configuration of the invention, the transition region is formed by a transition component which is designed such that the horizontal extent is considerably greater in the lower region than the extent in the upper region. The considerable bends in the outer contour of the tower which thus arise actually contradict the common construction rules, since, particularly in the case of the shell-type of construction, any kind of bend leads to tension peaks which weaken the supporting structure. It is, however, possible with the measures mentioned in the dependent claims to lessen or completely overcome these unacceptable disadvantages of the two bend spots in order to be able to fully exploit the advantages of the hybrid construction method according to the invention.

In the prior art, in the case of a shell construction, such bends are known only in the case of very small wind turbines where optimizing the stress has still played no part. Instead, the manufacturing technology is at the forefront, which thus enabled two commercially available pipe diameters be connected to one another in a simple manner. With such small machines (power output below 300 kW), even available short pipe-form towers were set partially on lower parts of pipes having a larger diameter with the aid of pronounced conical transition components.

With modern wind turbines with power outputs greater than one megawatt, in the prior art, only pipe towers with slight bends (maximum 5 - 8°) are economical, wherein the bend is located, fundamentally, relatively close beneath the nacelle. This method of construction, known for example from the EP 0821161 and termed “double conical pipe tower,” enables mainly a large fastening flange at the connecting location to the nacelle and, furthermore, serves to adapt the inherent frequency of the component to the requirements.

According to a further advantageous configuration of the invention, it is of particular advantage to design the transition between the upper and lower tower portions (directly, where applicable) beneath the horizontal plane which is defined by the rotor blade tip in the case of a perpendicularly downwardly-aligned rotor blade. This measure enables all the disadvantages mentioned in the prior art to be avoided in a simple manner.

In the upper tower portion, the configuration as a pipe tower adequately meets the needs for a narrow construction with unequalled economy, but also the ease of maintenance with weather-protected climbing and work area is a decisive advantage for the great heights. As soon as the pipe-form tower meets its transport limits, the lattice tower is inserted in the lower tower portion underneath the plane of the blade tip. With its considerably greater horizontal extent, this can enable considerable material savings and thus a greater commercial viability. The maintenance problem is less critical in the lower tower part, since cherry-pickers are available in the prior art which enable easy and in particular safe and comfortable access in the lower tower region for the maintenance personnel.

A further drawback of the lattice towers, to the effect that, when iced up in winter, it would be necessary to take into consideration considerable additional masses due to ice accretion due to the large surface area of the structure, is severely reduced, since, now, the additional mass still only acts upon the statically and dynamically far less critical lower tower part.

For the said reasons, it is advantageous to design the transition region at a distance from the rotor axis which can amount to 1,0 to 1,6 times, and more particularly 1,0 to 1,3 times, the rotor radius.

In order to enable the transportability of the transition component, it is particularly advantageous to design the upper region of the transition component so that, when assembling the wind turbine at the installation site, it can be connected to the upper tower portion - preferably by means of a releasable connection.

It is likewise particularly advantageous to design the lower region of the transition component so that the transition component can be connected to each corner post of the lattice tower by means of a preferably releasable connection.

It can furthermore be advantageous to also screw some struts to the lower region of the transition component in addition to the corner posts.

The flange connection with the pipe tower is to be regarded as particularly critical, as experience with steel pipe /concrete hybrid towers has shown.

A particularly advantageous embodiment of the invention therefore provides that the releasable connection between the upper region of the transition component and the upper tower portion have a two-row screw flange, in the form of a connecting location preferably inside the transition component, and a matching T-flange which is arranged on the upper tower portion.

Providing this connecting location with a large-dimensioned, two-row flange furthermore offers the advantage that the flange also serves at the same time as a buckle resistance for the force deflection which occurs in the bend spot of the outer contour. The increase in tension caused by the risk of buckling is thus for the most part effectively avoided.

The lower region of the transition component is advantageously configured so that it has connecting locations for junction-plate connections to the corner posts of the lattice tower.

Since the lower lattice tower is loaded by a considerable extra mass through the upper pipe tower, it is of a quite considerable advantage to design the corner posts of the lattice masts as hollow profiles in order to prevent any bending outwards due to the weight load of the pipe tower.

The transition component is furthermore designed, particularly advantageously, so that the permissible transport height is observed by the structural height of the transition component. The maximum transport height possible as a result of the restricted passage height underneath bridges amounts in Germany as a rule to 4,3 m, although 5,5 m-high goods can also be transported on selected roads.

If, in the case of very large wind turbines (e.g., 3 – 5 MW output), as a result of the dimensions, transporting the transition component in one piece is not possible, then a configuration of the present invention where the transition component is designed in at least two pieces connected to one another - preferably releasably - at the connecting location proves particularly advantageous. The connection can be provided, for example, advantageously by screw flanges or junction-plate connections, although welding the sub-components at the construction site can be a very economical solution if the connecting locations are in less stressed zones.

The transition component can be divided here particularly advantageously into at least two sub-components by a vertical parting plane. A division into a number of identical sub-components corresponding to the number of corner posts of the lattice tower is to be regarded as particularly economical for technical production reasons.

Another advantageous configuration of the invention provides for dividing the transition component in at least one horizontal parting plane.

Obviously, in the case of particularly large wind turbines, both division possibilities can also be combined with one another.

In order to utilize the maximum permissible transport height as fully as possible, an advantageous configuration of the invention provides for designing the transition component or sub-component of the transition component in such a way that it can be transported as a low-loader with the aid of adaptor components, which are mounted on the existing or specially provided connecting locations.

Depending upon the size and weight of the transition component or the sub-components of the transition component, the transport of several directly or indirectly (by adaptor components) interconnected transition components or sub-components is also possible in a low-loader. This offers by way of example the possibility of screwing the sub-components of a two-part transition component, which is of too high a structural height, to one another at the (half) ring flanges and then transporting said sub-components horizontally as a low-loader while observing the permissible transport height.

According to an embodiment according to the invention, the transition component can be configured particularly efficiently if it has a wall and is designed in the form of a shell construction.

It is of particular advantage if the basic shape of the transition component corresponds essentially to a pipe with pronounced conicity whose average inclination of the wall to the center axis is greater than the inclination of the wall of the lower region of the pipe tower and/or than the inclination of the upper region of the corner posts of the lattice tower.

The average inclination is here defined as the angle between the vertical (or also the center line) and an imaginary line from the maximum horizontal extent in the upper region of the transition component to the maximum horizontal extent in the lower region.

In order to produce the pronounced expansion according to the invention of the horizontal extension of the tower in the transition component in a particularly advantageous manner with respect to the force flow, the average inclination of the wall of the transition component to the center axis should be at least 15°, and preferably more than 25°.

In the case of the conical pipe as the basic body of the transition component, any pipe cross-section is possible, i.e., triangular, square, polygonal (e.g., 16-cornered), or even round cross-section. The invention furthermore comprises expressly conical pipes whose cross-sectional form changes over the length.

A particularly advantageous configuration provides that the cross-section of the transition component merge continuously from an essentially round cross-section in the upper region into a substantially polygonal, and preferably triangular or square, cross-section, in the lower region. Essentially round can also include here polygonal, e.g., 16-cornered.

If the connection with the pipe tower is via a ring flange, then the transition from, by way of example, a 16-cornered transition component to the round tower can be compensated for by this ring flange.

If at least the lower part of the pipe tower is also designed as a polygon, then the attachment can also be undertaken without problem by a junction-plate connection. In the event of a different inclination of the lateral faces of the transition component to the wall of the pipe tower, then, in this case, a bending resistance is possibly still to be provided.

In order to save upon material and weight, it is particularly advantageous to provide the wall of the transition component with at least one aperture. Through skilfully designed apertures, it is possible in particular to improve the force flow

compared to versions without apertures. This particularly applies in the case of arch-form apertures, which extend from corner post to corner post.

A further optimization of the force flow is achieved by bead-like or door-frame-like stiffening portions at the edges of the arch-form apertures.

In order to increase the rigidity of the transition component, it is advantageous if, in the lower region of the transition component, horizontal supports are formed between the corner posts of the lattice tower, said horizontal supports connecting the adjacent corner posts and/or the (diagonally) opposite corner posts to one another.

These horizontal supports can be connected integrally to the transition component, or can also be fastened particularly advantageously by the junction-plate connection between the transition component and the corner posts.

Likewise, in order to increase the rigidity of the transition component, a further advantageous configuration of the invention provides that, with a design having at least four corner posts, ribs be formed which strengthen the connecting lines of the (diagonally) opposite corner posts.

In a particularly advantageous embodiment, the transition component is designed as a casting.

The freedom of design for the castings enables shaping, so that the smooth rounded transitions prevent tension peaks in the bending points of the welded steel structure variant.

A particularly force-flow enhancing design is achieved if the wall of the transition component, seen in vertical section, is convexly curved, since a particularly smooth transition from the flange in the upper region to the corner posts in the lower region can be achieved.

In particular, the inclination of the connecting locations in the lower region of the transition component is particularly advantageously to be formed so that it corresponds to the inclination of the upper region of the corner posts of the lattice tower.

The cast structure is particularly advantageous even in the case of multi-part transition components having vertical parting planes, since, then, for example, 4 identical cast parts are combined into one transition component (piecemeal effect). Preferred casting materials for the casting variant are, for example, steel casting or spheroidal graphite casting - for example, GGG40.3.

If the tower according to the invention is built with a small number of components, the design of the transition component as a welded structure is particularly advantageous, since the high molding costs for the cast structure are avoided.

Since, frequently, with conventional towers, the transition to the concrete foundation is likewise designed with T-flanges, an advantageous further development of the invention proposes providing, by means of the hybrid concept according to the invention, a modular tower system, wherein an existing pipe tower (e.g., a 80 m tower for a 1,5 to 2 MW machine) can be placed by means of the transition component according to the invention on different, e.g., 30, 50, and 70 m high, sub-components in a lattice tower construction in order to achieve overall tower heights of 110, 130, and 150 m depending upon the location. In this way, previously uneconomical inland locations can also be considered for commercially viable wind energy use.

According to a further advantageous embodiment of the invention, the lower tower portion formed as a lattice tower has several sections arranged one above the other, wherein each section comprises the corner posts and at least one strut formation running diagonally between the corner posts.

According to a further advantageous configuration of the invention, it is provided that the inclination of the diagonally-running strut formations be formed the same in all the sections so that, as a result of the identical inclination of the strut formations, the connecting points between the legs and the strut formations are formed the same. This configuration has the advantage that identical junctions can be used in order to connect the corner posts and the strut formations. The construction of the tower can be optimized advantageously in this way. Up until now, the corner posts and the struts were adapted to one another during assembly and then expensively welded.

Compared with welded junctions, cast junctions can be made clearly more compact, and thus more economically. Welded junctions for stability reasons must

normally be designed so that the welded seams do not intersect. This often requires an extension of the junctions in the region of the pipe transitions, which is not required with a cast design. Standard pipe profiles, e.g., from a pipeline structure, can preferably be used both as corner posts and also as diagonal struts between the junctions to further improve the commercial viability. The attachment can be produced for example by screw flanges or welded connections.

The use of identical junctions has the advantage that the junctions can be manufactured in advance, and, when assembling the tower, the corner posts and strut formations need only be inserted into the junctions and welded or screwed. This represents a considerably easier work practice when constructing the lattice tower. Furthermore, considerable costs savings can be achieved when manufacturing the identical junctions through serial mass production.

Particularly in the case of offshore systems which have a lattice tower, additional pipes have to be provided for laying the cables to the network terminal. These offer in the case of offshore systems an additional exposure surface for waves, whereby additional loads act upon the lattice tower. According to an advantageous embodiment of the invention, it is therefore provided that the cables for connecting the wind turbine to the electrical grid be laid in the corner posts of the lattice tower portion, whereby a reduction in the wave loads is achieved. According to a further advantageous embodiment of the invention, cable conduits are previously laid inside the corner posts, within which the cables run. These are advantageously designed as plastic pipes and enable the cable to be easily drawn through once the tower has been erected and anchored on the seabed.

Further features, aspects, and advantages of the invention are in part disclosed by the following description and in part are anticipated by the description or are apparent in practical use of the invention. Two embodiments of the invention are described sufficiently in detail. It is evident that other embodiments can be used and changes can be made without departing from the scope of the invention. The following detailed description is therefore not to be regarded in a limited sense, but, in particular, details of the two designs can also be interchanged in any way.

The invention will now be explained in detail with reference to the following illustrations.

In the drawings:

Fig. 1 shows a wind turbine of the prior art;

Fig. 2 shows an overall view of the tower configuration according to the invention;

Fig. 3 shows a detail view of an embodiment of a transition component according to the invention;

Fig. 4 shows a detail view of a further embodiment of a transition component according to the invention;

Fig. 5 shows the development of the wall of the transition component of Figure 4.

Fig. 1 shows a wind turbine of the prior art in which two tower variants, a pipe tower (10A) and a lattice tower (10B), are projected one above the other as the supporting tower (10). The tower (10) supports a nacelle (30) which is attached to be rotatable about the vertical tower axis and on which a rotor (20) having at least one rotor blade (22) with a blade tip (23) is mounted for rotation about a substantially horizontal axis. A design is shown here as a three-blade rotor, wherein the horizontal plane of the rotor blade tip (23) in the lower position is marked with a dotted line (25).

In addition to the rotor-bearing arrangement, the nacelle (30) contains, in the usual way, a generator, and optionally a gear unit, a wind-tracking system, various electrical components, and further auxiliary systems. These elements are not shown, for reasons of overall clarity.

For transportation reasons, the pipe tower (10A) has several flange connections 12A. These flange connections are designed in the prior art as unilateral ring flanges - as a rule, facing inwards. Only the lowermost flange as a transition to the foundation base (18A) is designed in the prior art as a T-flange (two-row inward- and outward-facing flange).

With the design variant as a lattice tower (10B), the transition to the ring-shaped flange of the nacelle is normally formed by a relatively short transition component

(14B) called a top. The lattice tower rests on foundations (18B) which are as a rule designed individually for each corner post (11B).

Through the tower variants of the pipe tower (10A) and lattice tower (10B) projected one above the other, it can be clearly seen in the plane of the rotor blade tips (25) that the distance of the blade tip from the tower (blade clearance) is very much shorter in the case of the lattice tower (10B) and thus more critical than in the case of the pipe tower (10A).

Fig. 2 shows the overall view of a wind turbine having a tower design according to the invention. As in Fig. 1, (20) marks the rotor and (30) marks the nacelle. The tower (40) consists, in the lower portion (41), of a lattice tower (42) which in the illustrated design is fitted with four corner posts (43) and a plurality of diagonal struts (44), and, in the upper portion (46), consists of a substantially tubular pipe tower (47).

The connection of the lattice tower (42) and of the pipe tower (47) occurs in a transition region which is designed so that the cross-section of the lattice tower is adapted with optimized force flow to the pipe tower. Adaptation with optimized force flow means here a structural design which either, through a continuous geometrical change, produces a smooth geometric transition between the different cross-sectional forms of the upper and lower tower portions and thus avoids tension spikes in the transition region, and/or diverts existing tension spikes in the transition region into the connecting structure through suitable ribs and/or struts. The requirement for the correct force-flow transition is a vertical length of the transition region in the erected state from at least the length of the radius of the lower pipe tower diameter and/or the use of supporting elements (shells, ribs, struts) which substantially connect the corner posts of the lower lattice mast to the wall of the upper pipe tower.

In the illustrated exemplary embodiment, the transition region is designed so that a transition component (50) is arranged directly beneath the horizontal plane (25) of the rotor blade tip (23), with the horizontal extent of the transition component in the lower region (70) being considerably greater (by more than 50 %) than in the upper region (60).

The upper tower portion (46) has in the lower region a (slight) inclination of the pipe wall to the vertical, which is marked α. The inclination of the upper region of

the corner posts (43) of the lattice tower (42) in the lower tower portion (41) is marked analogously with β.

For an optimized lattice tower portion, the corner posts (43) have an inclination which is selected so that the corner posts (43), with an imaginary extension of the corner posts (43) (shown in Fig. 2 by a dotted line), meet in a virtual intersection point VS. The position of the virtual intersection point is arranged in the illustrated exemplary embodiment in a region which, seen from the nacelle, extends downwards by a third of the tower length. Depending upon the combination of the lateral force and the bending moment in the dimensioning load case, the optimum virtual intersection point can also lie above the nacelle.

The average inclination of the transition component (50), which is defined as the angle between the vertical and an imaginary line from the maximum horizontal extent in the upper region (60) to the maximum horizontal extent in the lower region (70), is marked with γ.

In the illustrated, particularly advantageous, embodiment of the invention, γ is considerably greater than both the inclination (β) of the lower tower portion (41) and also the inclination (α) of the upper tower portion.

It would, however, also be conceivable that the individual corner posts be curved and thus have different inclinations, whereby, also here, an average inclination of the corner posts can be defined analogously in relation to the transition component.

Fig. 3 shows a detail illustration of a possible variant of the design of the tower according to the invention with a transition component as a multi-part cast structure. The side view is shown on the right of the line of symmetry, and the illustration in the (vertical) section is shown on the left. The lower tower portion is formed by the illustrated lattice tower portion (42), which consists essentially of four corner posts (43) and diagonal struts (44). The upper tower portion is formed by the pipe tower portion (47) illustrated in cut-out with its wall (48).

A design of the transition component (50) according to the invention is formed as a cast structure in a shell construction with a wall (52) and arch-form apertures (53). The transition component is connected in the upper region (60) to the pipe tower

(47) via a flange connection (61) and is connected in the lower region (70) to the corner posts (43) of the lattice tower (42) via four junction-plate connections (71).

In the upper region (60) of the transition component (50), the wall (52) merges smoothly into a ring-shaped, two-row screw flange (64). The wall (48) of the pipe tower (47) is welded to a T-flange (62) which is screwed to the flange (64) of the transition component (50) via an inner screw circle (66) and an outer screw circle (68). The inner screw fitting (66) is designed as a push-through screw fitting, which is standard in steel construction, and the outer screw fitting (68) is formed in the illustrated example as a blind hole screw fitting, because, in this way, a wall thickness of the wall (52) is spread out particularly favorably for the force flow. Obviously, the wall (52) of the transition component (50) can also be drawn slightly further outwards, so that the outer screw fitting (68) can be designed as a push-through screw fitting, but the transition component (50) is then slightly heavier and thus more expensive.

In the lower region (70), the wall (52) merges into four connecting locations (72) to the corner posts (43). The connection is made by a junction-plate connection (71) via an outer plate (76) and an inner plate (78) which are screwed by a plurality of screws to the connecting location (72) and the corner post (43). Since the inclination of the connecting location (72) and the inclination of the upper region of the corner post (41) are the same, flat sheet-metal plates can be used as the connecting plates (76, 78).

With a view to reducing the number of parts, a further embodiment of the invention provides a direct screw connection between the corner posts (43) and the connecting locations (72) of the transition component (50). In this embodiment, however, the force flow from the corner post (43) into the wall (52) of the transition component (50) is slightly more unfavorable.

In order to strengthen the lower region (70) of the transition component (50), horizontal supports (45) are attached between the four corner posts (43). These supports can selectively connect the adjacent corner posts (43) or also the opposing corner posts (43) to one another, and thus the diagonals of the lattice tower (42). Where applicable, both possibilities can also be used together in order to enable a particularly rigid and thus advantageous construction.

Attaching the diagonal struts (44) and the horizontal support (45) to the junction-plate connection (71) is not shown for reasons of simplification. Such connections are, however, sufficiently well-known in the prior art, e.g., when connecting multi-part corner posts.

With an outer diameter of the T-flange (62) of the pipe tower (47) of 4,3 m, the illustrated transition component (50) has a transportation height of likewise about 4,3 m, given a lower transport width of about 7 m. Since these dimensions can only be transported within limits, a preferred embodiment of the invention provides a multi-part design of the transition component (50). For this, the transition component (50) is divided by a vertical parting plane into a left sub-component (57) and a right sub-component (58). The sub-components (57, 58) are screwed to one another with screwed flanges (56). Alternatively to the screwed flange (56), a further advantageous development of the invention provides junction-plate connections for connecting the sub-components (57, 58) of the transition component (50).

Through this separation the transport dimensions are reduced, when transporting the two sub-components (57, 58) horizontally, to a transport height of about 3,5 m at a width of 4,3 m, whereby problem-free transport is possible within Germany.

A particularly advantageous design of the invention also proposes dividing the transition component up into four pieces symmetrically relative to the center line, so that either even smaller transport dimensions can be achieved, or even larger transition components remain easily transportable. With considerably larger transition components, it is proposed according to the invention to divide the transition component additionally in a horizontal plane.

The illustrated design of the transition component as a casting structure has the advantage that the wall (52) can be designed with a variable wall thickness without any problem, whereby a very efficient use of materials is possible. The regions subject to high stress, such as for example the convexly-curved transition to the ring flange (64) or the connecting location (72), designed as a junction-plate connection (71), to the corner post (43) of the lattice tower (42), can be designed with greater wall thicknesses than regions subjected to lower stress. Similarly, the edging of the arch-form aperture (54) can be provided with a reinforcement designed for example

as a bead. Furthermore, the casting structure enables a sliding transition, with optimized force flow, from the round cross-section in the upper region (60) of the transition component (50) to the cross-section, which is quadrilateral in the illustrated case, in the lower region (70) of the transition component (50).

Particularly with offshore use of the tower concept according to the invention, it is advantageous to use the space present in the transition region expediently for housing, for example, electrical operating means (inverters, switching systems, transformers), a spare parts store (where applicable, with small workshop), or emergency accommodation for maintenance personnel or also a visitors room. For this, the supporting structure which is present can be completed by additional walls to form a closed room which, naturally, is equipped with the required entrances and (emergency) exits, possible windows, and air-conditioning systems. When installing the electrical operating means in the transition component, a particularly advantageous embodiment of the invention proposes installing and testing these operating means in the factory and transporting and installing the transition component with the installations as a so-called power module.

Fig. 4 shows the detail illustration of a further design variant according to the invention of a transition component as a welded structure. Fig. 4 shows, in the lower part, a plan view from above of the transition component (50) as well as, in the upper part, a vertical section through the transition component along the sectional line A-B.

Since the basic construction is very similar to the design shown in Fig. 3 and explained in detail, reference is made essentially only to the differences.

The wall (52) of the transition component (50) is formed by a sheet-metal panel of constant thickness which is rolled in the upper region and is angled in the lower region (70) to adapt to the geometry of the corner posts (43).

The average inclination (γ) of the transition component (50), which is defined as the angle between the vertical and an imaginary line from the maximum horizontal extent in the upper region (60) to the maximum horizontal extent in the lower region (70), is considerably greater than the inclination of the corner posts (43) of the lattice tower (42), and naturally also larger than that of the pipe tower, since this is formed to be cylindrical in the illustrated exemplary embodiment.

The use of a cylindrical pipe tower enables more cost-effective manufacture and is therefore only possible because the lattice tower has a very rigid design, and thus the overall construction can also then be designed to be sufficiently rigid if a rigidity-increasing expansion of the pipe tower is omitted. The use of a cylindrical pipe tower offers itself in particular when the azimuth bearing (rotatable arrangement of the nacelle on the tower) is selected to be particularly large, since a sufficiently rigid design of the pipe tower can then be achieved without expansion.

As regards a simple design of the welded construction, the connecting location (72) in the lower region (70) of the transition component (50) has an inclination which is different from the inclination of the corner posts (43). The connection therefore occurs via sufficiently strongly-dimensioned, curved junction plates (76) which have to take up the deflection of the force flow. The curved plates can be made from thick, and, if necessary, welded, steel plate, but a further development according to the invention also proposes designing the plates as cast components.

Since the force deflection deforms the junction-plate connections inwards (towards the tower axis), strongly-dimensioned horizontal supports (45) are provided diagonally between each two opposing corner posts (43). (For reasons of simplification, only one such support (45) is shown in dotted lines in the lower part of Fig. 4). Through this method of construction, the deflection of the force flow can be reliably managed, and a very economical but slightly heavier structure is produced than in the case of the cast structure.

As with the cast structure, an advantageous further development of the invention proposes a strengthening of the arch-form apertures (53) which is designed particularly advantageously in the form of a welded sheet-metal strip (55) (as in the case of a door frame). The advantages of the design as a welded structure are the more favorable manufacturing costs with a low number of parts and the simpler testing process with the building authorities.

Fig. 5 shows the development of the wall of the transition component according to the invention as shown in Fig. 4. The structurally very favorable shaping can be produced very easily by the sheet-metal panels, which are flame-cut out of steel plate in one piece or, preferably, in the illustrated case of the lattice tower,

with four corner posts in 4 pieces (indicated by dotted lines). The or each metal panel is rolled conically for this purpose, and additional angled edging is advantageous in the transition region to the corner posts in order to ensure better transition to the corner posts. If there are no sufficiently large rolling machines available, then the substantially round form can also be produced at the transition to the upper flange through a number of small, angled edges.

PATENTKRAV

1. Tårn (40) til en stor vindmølle, der har en tårnhøjde på mere end 80 m og en udgangseffekt på over 1,5 MW og omfatter en nacelle (30), som er anbragt på tårnet (40), hvor nacellen, ud over rotorlejearrangementet, indeholder en generator, eventuelt en gearkasse, et vindsporingssystem, forskellige elektriske komponenter og yderligere hjælpesystemer, og vindmøllen også omfatter en rotor (20), der er monteret på nacellen til rotation omkring en i det væsentlige horisontal akse, har en rotordiameter på mere end 70 m og har mindst ét rotorblad (22), idet tårnet har en øvre, rørformet udformet tårndel (46), der i et overgangsområde er forbundet med en nedre tårndel (41), der er udformet i form af et gittertårn (42), hvor gittertårnet (42) har mindst tre hjørnestolper (43), en flerhed af diagonale afstivninger og en flerhed af afsnit, der er anbragt oven over hinanden, hvor hvert afsnit omfatter hjørnestolperne (43) og mindst én afstivningsformation (44), der løber diagonalt mellem hjørnestolperne, hvor den øvre tårndel (46) udgør mindst én sjettedel af hele tårnet, idet den nedre tårndels (41) tværsnit under overgangsområdet er større end den øvre tårndels (46) tværsnit, og hvor overgangsområdet er udformet således, at den nedre tårndels tværsnit på en kraftoptimeret måde er tilpasset til den øvre tårndels tværsnit, hvor den kraftoptimerede tilpasning, enten ved hjælp af en kontinuerlig geometrisk variation, giver en jævn geometrisk overgang mellem de øvre og de nedre tårndeles forskellige tværsnitsformer og således undgår spændingsspidser i overgangsområdet og/eller afleder forekommende spændingsspidser i overgangsområdet ved hjælp af egnede ribber og/eller afstivninger ind i tilslutningskonstruktionen, hvor overgangsområdets vertikale udstrækning udgør mindst halvdelen af det øvre tårnafsnits diameter i overgangsområdet eller direkte nabostillet dertil, hvor overgangsområdet er anbragt under det horisontale plan (25), der, i den monterede tilstand, defineres af bladspidsen (23) i tilfælde af et vertikalt nedadvendt rotorblad (22), hvor overgangsområdet dannes af en overgangskomponent (50), der har et nedre område (70), som kan forbindes med den nedre tårndel (41), og et øvre område (60), som kan forbindes med den øvre tårndel (46).

2. Tårn (40) til en vindmølle ifølge krav 1, **kendetegnet ved, at** overgangskomponentens nedre område (70) er udformet således, at den største

horisontale udstrækning deraf er mindst 30 %, fortrinsvis mere end 50 %, større end en horisontal udstrækning af det øvre område (60).

3. Tårn (40) til en vindmølle ifølge et af de foregående krav, **kendetegnet ved, at** overgangskomponentens (50) øvre område (60) er udformet således, at overgangskomponenten (50) kan forbindes med den øvre tårndel (46) ved hjælp af en udløselig forbindelse (61).

4. Tårn (40) til en vindmølle ifølge et af de foregående krav, **kendetegnet ved, at** overgangskomponenten (50) har en væg (52) og er konfigureret i form af en skalkonstruktion.

5. Tårn (40) til en vindmølle ifølge det foregående krav, **kendetegnet ved, at** overgangskomponentens (50) grundform i det væsentlige svarer til et stærkt konisk rør, hvor væggens (52) gennemsnitlige hældning (γ) i det koniske rør i forhold til midteraksen er større end væggens (48) hældning (α) i det nedre område af rørtårnet (47) og/eller end hældningen (β) af det øvre område af gittertårnets (42) hjørnestolper (43).

6. Tårn til en vindmølle ifølge det foregående krav, **kendetegnet ved, at** forbindelseslokaliteternes (72) hældning i det nedre område (70) af overgangskomponenten (50) svarer til hældningen af det øvre område af gittertårnets (42) hjørnestolper (43).

7. Tårn (40) til en vindmølle ifølge krav 1, **kendetegnet ved, at** de diagonalt forløbende afstivningsformationers hældning er identisk for alle afsnittene.

8. Tårn (40) til en vindmølle ifølge det foregående krav, **kendetegnet ved, at** tårnet, til forbindelse af hjørnestolperne (43) og afstivningsformationerne (44), har identiske knudepunkter især i form af støbte knudepunkter.

9. Tårn (40) til en vindmølle ifølge et af de foregående krav, **kendetegnet ved, at** der i rummet, der forekommer i overgangsområdet, er anbragt elektriske drivmidler, et reserveleje, nødlogi til vedligeholdelsespersonale eller et besøgsværelse.

10. Tårn (40) til en vindmølle ifølge det foregående krav, **kendetegnet ved, at** der er anbragt elektriske drivmidler i overgangskomponenten (50), og overgangskomponenten (50) er dannet som et transporterbart og monterbart effektmodul med drivmidlerne monteret og testet på fabrikken.

11. Tårn (40) til en vindmølle ifølge krav 1, **kendetegnet ved, at** kabler til forbindelse af vindmøllen med elnettet er lagt i hjørnestolperne (43), der er udformet i form af hulprofiler, og/eller **ved at** kabelkanaler, inden i hvilke kablerne løber, er lagt inden i hjørnestolperne (43).

12. Tårn (40) til en vindmølle ifølge et af de foregående krav, **kendetegnet ved, at** det er et tårn til en offshore-vindmølle.

13. Modulært tårnsystem til et tårn til en vindmølle ifølge et af de foregående krav, hvilket tårnsystem består af den øvre, i det væsentlige rørformede tårndel og den nedre tårndel, hvor den nedre tårndel (41) er udformet i form af forskellige nedre tårndele, der er udformet som et gittertårn, **kendetegnet ved, at** den samlede tårnhøjde kan varieres ved hjælp af forskellige bygningshøjder for gittertårnet.

14. Vindmølle med et tårn ifølge et af kravene 1 til 12.

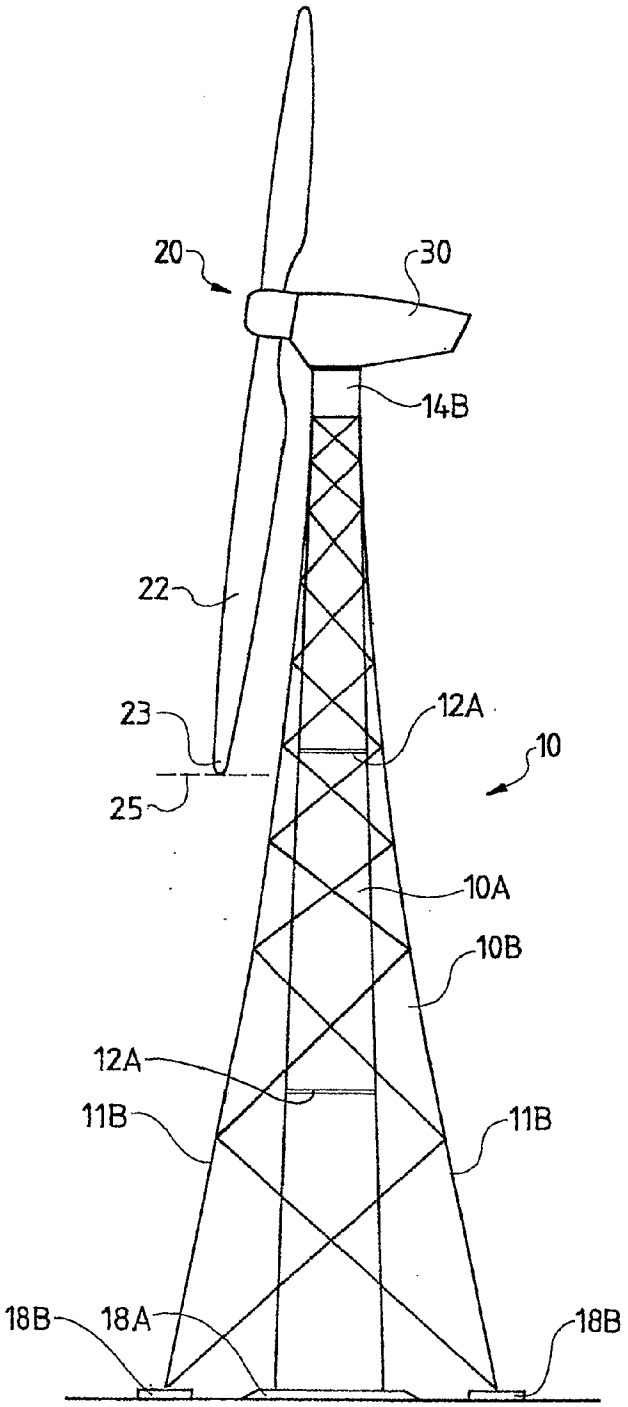


Fig. 1

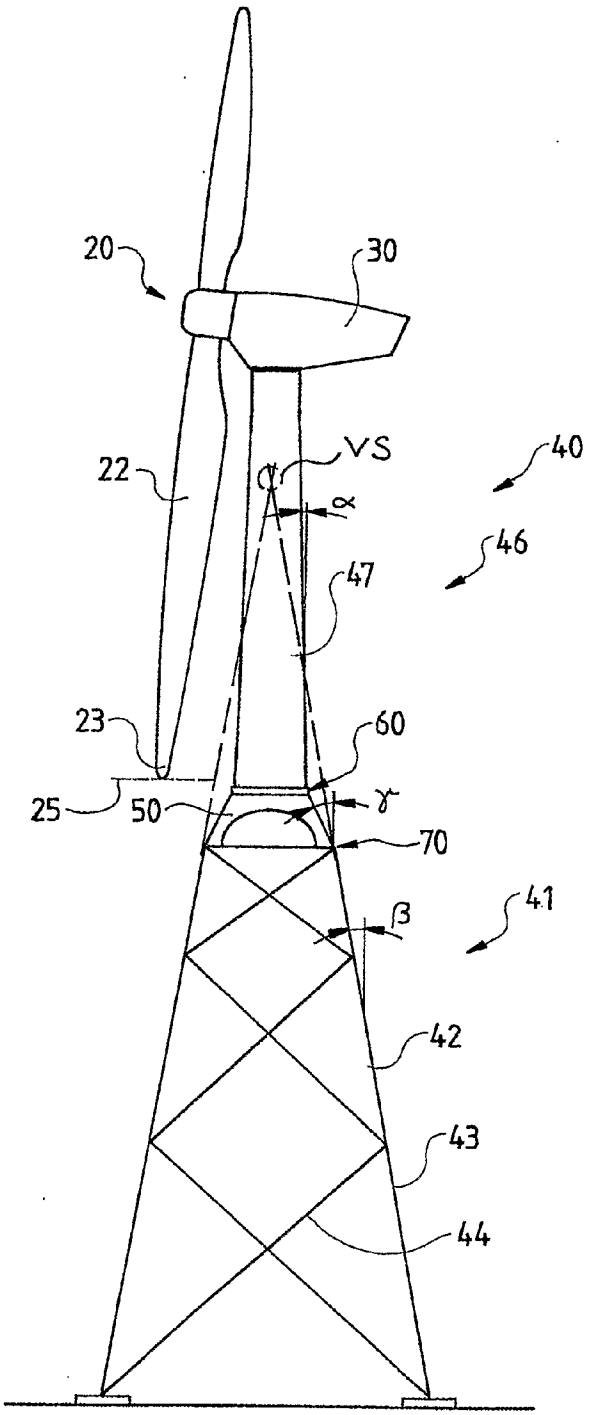


Fig. 2

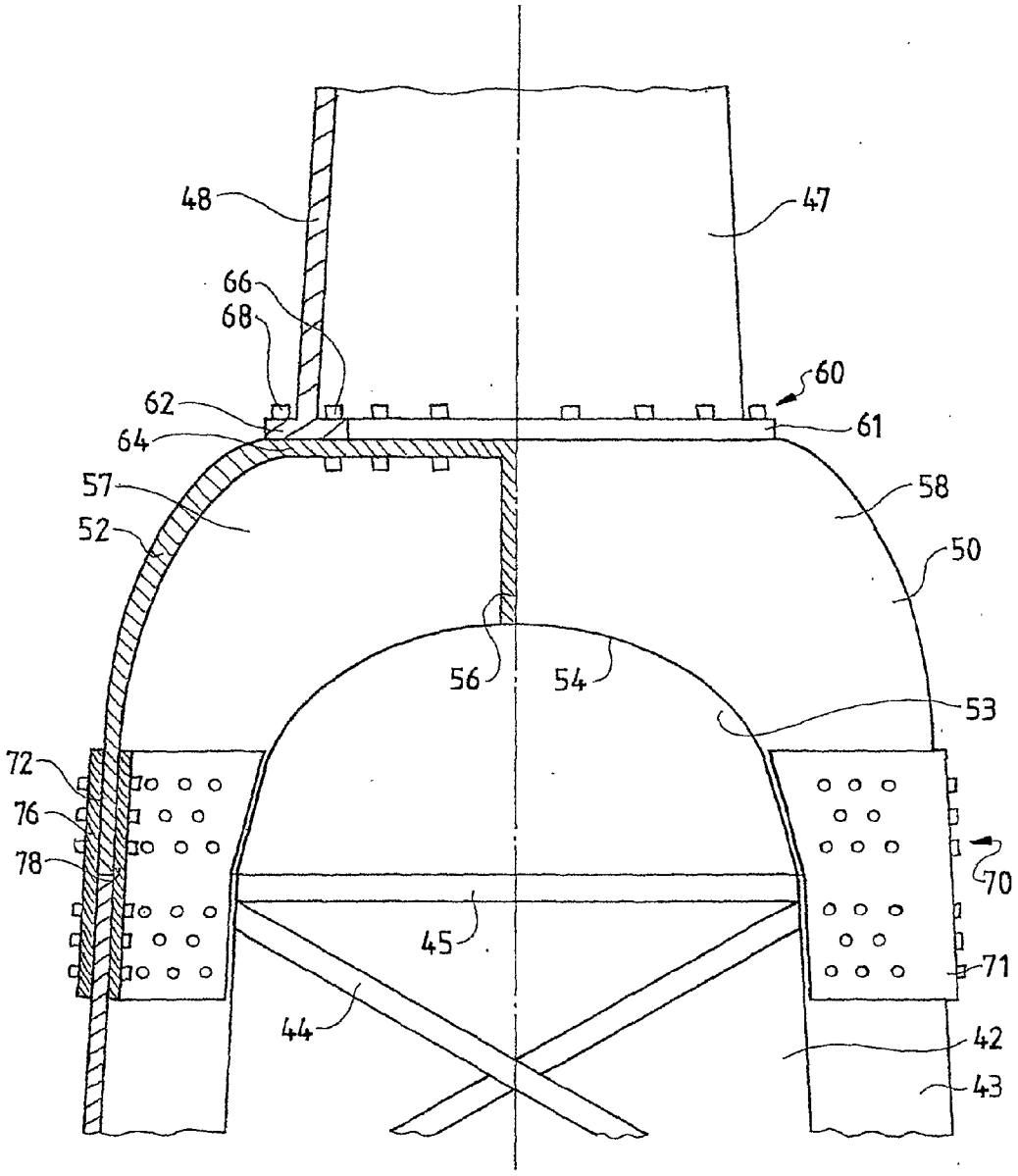
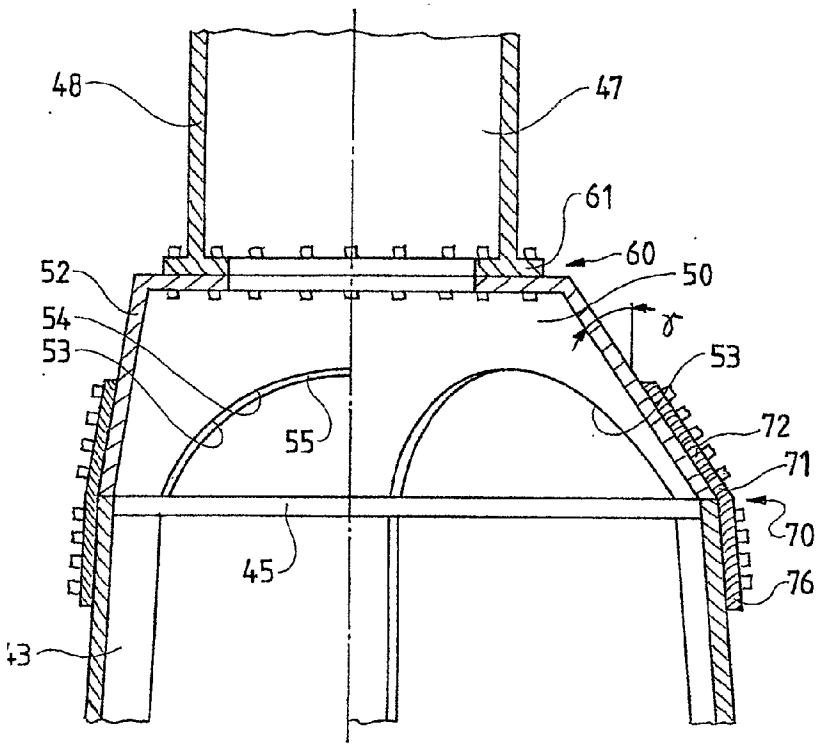


Fig. 3



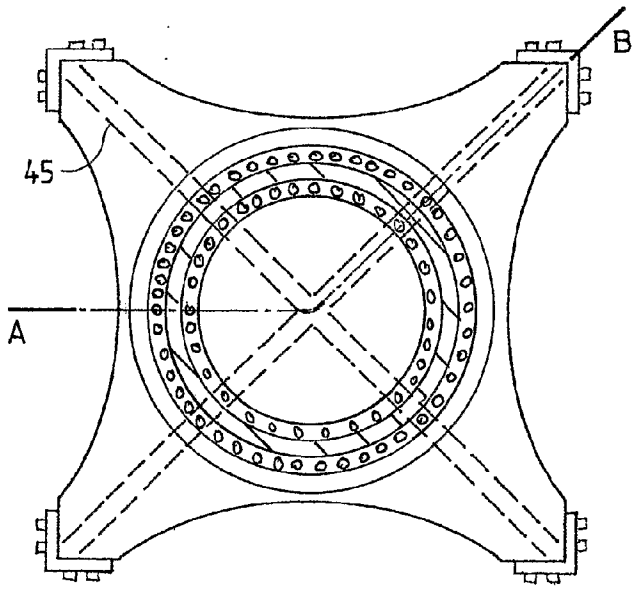


Fig. 4

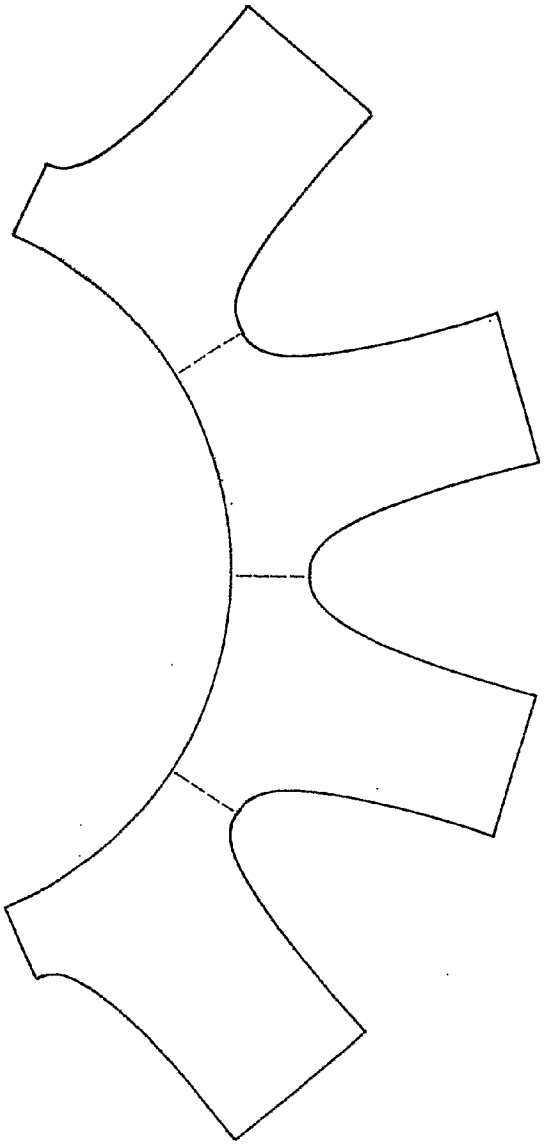


Fig. 5