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## (54) AXIAL FLOW FAN WITH OPTIMISED BLADE TWIST CLOSE TO THE IMPELLER HUB

AXIALLÜFTER MIT OPTIMIERTER SCHAUFELVERDREHUNG IN DER NÄHE ZUR LAUFRADNABE

VENTILATEUR AXIAL AVEC VRILLAGE D’AUBE OPTIMISÉ PRÈS DU MOYEU DE LA ROUE À AUBES

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**WO-A1-2018/229081**
**US-A1- 2004 165 986**



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## Description

**[0001]** The invention relates to an axial flow fan with an improved wing design.

## Background

**[0002]** Axial flow fans are well known in the art and many different designs have been proposed and manufactured in order to improve the performance of the fan, in particular with respect to generation of noise and improved power efficiency. It is an object of the present invention to provide an improved fan design to improve the efficiency of the fan.

## Description of the invention

**[0003]** Disclosed herein is an axial flow fan according to claim 1. It comprises a hub rotatable about an axis; an annular shroud extending concentric with said axis in a radial distance from said hub; a plurality of fan blades connected at a root end to said hub and having a free tip end extending radially towards said shroud, and a fan driver coupled to said hub and arranged for driving the rotation of said hub around the axis.

**[0004]** For R being the radial distance from said axis to the free tip end of the blade and *r* being the radial distance from said axis, the plurality of fan blades each comprises a root area extending from a radial positon of r/R=0.17 to a radial positon of r/R=0.34, the root area having a root angle $\Delta\theta_{root}$ extending between the chord of the blade at any radial position in the root area and the chord at the radial position of r/R=0.34, wherein $\Delta\theta_{root}$ substantially follows a curve defined as:

$$\Delta\theta_{root} = arctan\left(\frac{0.375 \cdot \frac{R}{r} + 0.85}{\pi}\right) - 31{,}9°.$$

**[0005]** WO 2015/090318 also discloses an example of an axial flow fan with a number of the wings designed for reducing the power consumption by gradually angling the wings. The chord angle in WO 2015/090318 is significantly steeper than the chord angle obtained with the above axial flow fan, which has shown to introduce an improved efficiency of 15% in terms of improved energy efficiency.

**[0006]** The document US 2004/165986 A1 discloses in table 4 another example of radial evolution of chord angle. The blades normally have a steeper chord angle $\theta$ at the region near the hub and tends to drive the core of the flow right after the rotor in a so-called forced vortex, which appear to improve the efficiency of the fan. The region directly next to the hub, i.e. between the hub and the radial distance of r/R=0.17, the angle may also be adequately described by the above equation. The deviation between the measured angle value and $\Delta\theta_{root}$ will however normally be larger than the deviation in the root area, where r/R=0.17-0.34.

**[0007]** According to the invention, the angle $\Delta\theta_{root}$ deviates less than 1 ° from the curve defined by the equation within the root area.

**[0008]** The angle $\Delta\theta_{root}$ may also deviate less than 4° from the curve defined by the equation within the root area for r/R values up to r/R=0.47.

**[0009]** In one or more embodiments the plurality of fan blades each comprises a middle area extending from the radial positon of r/R=0.34 to the radial position of r/R=0.72, the middle area having a middle angle $\Delta\theta_{middle}$ extending between the chord of the blade at any radial position in the middle area and the chord at the radial position of r/R=0.72, wherein $\Delta\theta_{middle}$ substantially follows a curve defined as:

$$\Delta\theta_{middle} = arctan\left(\frac{0.7 \cdot \frac{R}{r} - 0.1}{\pi}\right) - 15.6°.$$

**[0010]** By substantially is meant a deviation of up to 5°. In one or more embodiments, the angle $\Delta\theta_{middle}$ deviates less than 4° from the curve defined by the equation within the middle area.

**[0011]** In one or more embodiments, the angle $\Delta\theta_{middle}$ deviates less than 3° from the curve defined by the equation within the middle area.

**[0012]** In one or more embodiments, the angle $\Delta\theta_{middle}$ deviates less than 2° from the curve defined by the equation within the middle area.

**[0013]** In one or more embodiments, the angle $\Delta\theta_{middle}$ deviates less than 1° from the curve defined by the equation within the middle area.

**[0014]** The angle $\Delta\theta_{middle}$ may also deviate less than 4° from the curve defined by the equation within the middle area for r/R values lying outside the middle area. In one or more embodiments, the angle $\Delta\theta_{middle}$ deviates less than 4° from the curve defined by the equation within the middle area for r/R=0.23-1. Thus there is a 'root-middle' area for values between r/R=0.23 and r/R=0.47, where the root area and the middle area overlaps and where the angle $\Delta\theta$ continuously changes from the description given for the root area and that of the middle area.

**[0015]** In one or more embodiments, the plurality of fan blades each comprises a tip area extending from the radial positon of r/R=0.72 to the tip of the free tip end at r/R=1, the tip area having a tip angle $\Delta\theta_{tip}$ extending between the chord of the blade at any radial position in the tip area and the chord at the radial position of r/R=1, wherein $\Delta\theta_{tip}$ substantially follows a curve defined as:

$$\Delta\theta_{tip} = arctan\left(\frac{0.2\cdot\frac{R}{r}+0.6}{\pi}\right)\text{-}14.3°.$$

**[0016]** By substantially is meant a deviation of up to 5°. In one or more embodiments, the angle $\Delta\theta_{tip}$ deviates less than 4° from the curve defined by the equation within the tip area.

**[0017]** In one or more embodiments, the angle $\Delta\theta_{tip}$ deviates less than 3° from the curve defined by the equation within the tip area.

**[0018]** In one or more embodiments, the angle $\Delta\theta_{tip}$ deviates less than 2° from the curve defined by the equation within the tip area.

**[0019]** In one or more embodiments, the angle $\Delta\theta_{tip}$ deviates less than 1° from the curve defined by the equation within the tip area.

**[0020]** The angle $\Delta\theta_{tip}$ may also deviate less than 4° from the curve defined by the equation within the tip area for r/R values lying outside the tip area. In one or more embodiments, the angle $\Delta\theta_{tip}$ deviates less than 4° from the curve defined by the equation within the tip area for r/R=0.51-0.72. Thus, there is a 'middle-tip' area for values between r/R=0.51 and r/R=1, where the middle area and the tip area overlaps and where the angle $\Delta\theta$ continuously changes from the description given for the middle area and that of the tip area.

**[0021]** According to the invention, the angle $\theta$ between a plane of rotation of the blades and the chord of the blade at the radial position of r/R=0.34 is in the range of 20° to 40°, preferably in the range of 25 to 35°, such as substantially 31.9°.

**[0022]** In one or more embodiments, R is in the range of 500 to 900 millimetres, such as 600 to 800 millimetres, or such as 650 to 750 millimetres.

**[0023]** In one or more embodiments, the chord increases in the root area from the hub towards the radial position of r/R=0.34, flattens out until the radial position of r/R=0.40 and decreases towards the tip of the blade at the radial position of r/R=1. In one or more embodiments, the inner radius of the annular shroud is in the range of 600 to 1500 millimetres, such as 700 to 1300 millimetres, or such as 800 to 900 millimetres. The inner radius of the annular shroud is normally smaller than R.

**[0024]** In one or more embodiments, the radius ($R_{hub}$) of the hub is in the range of 50 to 150 millimetres, such as 60 to 120 millimetres, or such as 70 to 80 millimetres.

**[0025]** The fan may further comprise a diffuser arranged concentric with said axis at a downstream position of the annular shroud.

**[0026]** In one or more embodiments, the diffuser has a conical shape with a diffusion angle in the range of 2 to 15° to the axisof rotation of the rotor, preferably in the range of 6 to 10°.

**[0027]** The fan may also further comprise an inlet part provided with a bellmouth arranged concentric with said axis at an upstream position of the annular shroud.

**[0028]** In one or more embodiments, the hub comprises a seating part allowing the blades to be arranged in a plurality of blade pitch angles, and blade locking part for locking the blade pitch angle of the at least one blade into a specific blade pitch angle, wherein said locking part is designed to lock said blade into one specific blade pitch angle only.

**[0029]** In one or more embodiments, there is one locking part for each of the blades.

**[0030]** In one or more embodiments, the blades each comprises a recess cooperating with a corresponding pin of the locking part.

## Brief description of the drawings

**[0031]**

Figure 1 shows a perspective view of a hub part, three blades and three locking parts for an axial flow fan according to an aspect of the present invention.

Figure 2 shows a longitudinal schematic cross-section of an axial flow fan according to an aspect of the present invention.

Figure 3 shows a blade of an axial flow fan according to the invention.

Figure 4 illustrates a cross-section of a blade together with the flow direction, the direction of blade movement and the angle θ between the blade chord and the direction of movement.

Figure 5 shows a blade of an axial flow fan according to the invention, where the blade is connected to a hub.

Figure 6 illustrates a number of cross-sections of the blade in figure 5.

Figure 7 shows three different designs of the locking parts shown in the embodiment of the fan in figure 1.

**Description of preferred embodiments**

**[0032]** An axial flow fan 1 according to an embodiment of the invention is shown in figures 1 and 2, where figure 1 shows a perspective view of an axial flow fan 1 and figure 2 shows a longitudinal schematic cross-section of an axial flow fan 1.

**[0033]** The fan 1 comprises a hub 3 where to a plurality of fan blades 2 are connected at the root end 11 of the blades 2. The free tip end 7 of the blades 2 extend radially towards the shroud 6 as shown in figure 2. The fan 1 in figure 1 has three blades 2, but may as well be equipped with any convenient number of blades 2. It is generally preferred that the rotor 5 of the fan comprises from 3 to 6 blades.

**[0034]** The fan has a fan driver (not shown) coupled to the hub 3 and arranged for driving the rotation of the hub 3 around the axis 4 shown in figure 2. The fan driver may be arranged in the hub 3 or next to the hub 3 and be connected thereto by means of a drive arrangement, e.g. a belt drive (not shown).

**[0035]** The hub 3 and the blades 2 form a rotor 5, which is rotated about an axis 4 (see figure 2) by means of the fan driver, e.g. a motor. The rotor 5 is arranged inside the cylindrical shroud 6 which is concentric arranged about the axis 4 so there is a clearance between the tip 7 of the blades 2 and the shroud 6. The rotation of the rotor 5 drives a flow of air axially through the fan 1 in the direction of the arrow A as shown in figure 2. The flow path through the fan 1 is illustrated by streamlines 8 indicated in figure 2.

**[0036]** The shroud 6 is preceded by an inlet part 9 arranged upstream of the shroud, i.e. in the direction against the driven flow A, where the inlet part 9 also is concentric with the axis 4 and comprises a bellmouth to smoothen the flow at the inlet part 9 in order to avoid separation of the flow.

**[0037]** The passage of the air flow through the rotor 5 causes a pressure increase which is further increased by regained part of the kinetic energy present in of the air flow immediately after the rotor due to the axial velocity component by means of a diffuser 10 arranged downstream of the shroud 6 and concentric with the axis 4. The diffuser 10 has a conical shape with an diffusion angle of 8.5° to the centre line, i.e. to the axis 4 of rotation of the rotor 5. The blades 2 are attached by their root end 11 to the hub 3, preferably in a manner discussed later.

**[0038]** A single blade 2 of the fan 1 is shown in figure 3 where the axis 4 of rotation of the rotor 5 is indicated, the distance R from the axis 4 and to the tip end 7 of the blade 2 and an indication of the radial position of $r/R=0.34$, i.e. where the distance r from the axis 4 is 0.34 times the radial position R of the blade tip end 7.

**[0039]** A cross section of a fan blade 2 is shown in figure 4 with indication of the leading edge 12 of the blade 2 as well as the trailing edge 13 of the blade 2. The chord line 14 is extending between the leading edge 12 and the trailing edge 13, and the length of the chord of the blade 2 is defined by the distance between the leading edge 12 and the trailing edge 13. The blade 2 is moved in the direction indicated as M on figure 4 due to the rotation of the rotor 5 of the fan 1 during operation thereof.

**[0040]** The angle θ between the chord line 14 and the direction of movement M is indicated on figure 4 together with the direction A of the incoming air flow. The direction A is depicted as being perpendicular to the direction M of movement which is generally the case for an axial flow fan 1.

**[0041]** Figure 5 shows a blade 2 according to the invention connected to by the root end 11 to a hub 3. A number of cross sectional cut from the first cross sectional cut A-A starts at the root end 11 to the last cross sectional cut 40-40 at the tip end 7 of the blade 2 are marked in figure 5. The cross sectional cuts are evenly distributed over the length of the blade 2.

**[0042]** Figure 6 shows selected examples of the cross sectional cuts of the blade 2 shown in figure 5. The angle θ between the chord line 14 and the direction of movement M are listed in the cross sectional cuts in figure 6 along with a value of the chord length. Table 1 lists the values for the chord length, the angle θ between the chord line 14 and the direction of movement M, the radial distance r at the different cross sectional cuts of the blade 2 shown in figure 5.

**[0043]** Table 1 also shows the values of angle θ calculated using equations 1-3 given as:

$$\theta_{root} = arctan\left(\frac{0.375\cdot\frac{R}{r}+0.85}{\pi}\right) \quad \text{Eq. 1}$$

$$\theta_{middlle} = arctan\left(\frac{0.7\cdot\frac{R}{r}-0.1}{\pi}\right) \quad \text{Eq. 2}$$

$$\theta_{tip} = arctan\left(\frac{0.2\cdot\frac{R}{r}+0.6}{\pi}\right) \quad \text{Eq. 3}$$

where for R is the radial distance from the axis 4 to the free tip end 7 of the blade 2 and *r* is the radial distance from the axis.

Table 1

| **Cut** | **r/R** | **r** | **θ** | **Chord** | **θ Eq. 1** | ***Dev. Eq. 1*** | **θ Eq. 2** | ***Dev. Eq. 2*** | **Dev. Eq. 3** | ***θ Eq. 3*** |
|---|---|---|---|---|---|---|---|---|---|---|
| [-] | [-] | [m] | [°] | [m] | [°] | *[°]* | [°] | *[°]* | *[°]* | *[°]* |
| A | 0,100 | 0,072 | 52,70 | 0,122 | 55,73 | *-3,03* | 65,58 | *-12, 88* | 39,67 | *13, 03* |
| B | 0,114 | 0,082 | 51,14 | 0,127 | 52,89 | *-1,75* | 62,61 | *-11,47* | 36,93 | *14,21* |
| C | 0,127 | 0,092 | 49,40 | 0,135 | 50,37 | -0,97 | 59,78 | *-10,38* | 34,63 | 14,77 |
| D | 0,141 | 0,102 | 47,75 | 0,138 | 48,12 | *-0,37* | 57,09 | *-9,34* | 32,68 | *15,07* |
| E | 0,155 | 0,112 | 46,04 | 0,138 | 46,12 | *-0,08* | 54,55 | *-8,51* | 31,02 | *15, 02* |
| F | 0,169 | 0,122 | 44,61 | 0,139 | 44,33 | *0,28* | 52,15 | *-7,54* | 29,59 | *15, 02* |
| G | 0,183 | 0,132 | 43,15 | 0,142 | 42,72 | *0,43* | 49,89 | *-6,74* | 28,33 | *14,82* |
| H | 0,197 | 0,142 | 41,76 | 0,146 | 41,27 | *0,49* | 47,75 | *-5,99* | 27,23 | *14,53* |
| I | 0,211 | 0,152 | 40,48 | 0,151 | 39,95 | *0,53* | 45,75 | *-5,27* | 26,26 | *14,22* |
| J | 0,224 | 0,162 | 39,19 | 0,157 | 38,75 | *0,44* | 43,87 | *-4,68* | 25,39 | *13,80* |
| K | 0,238 | 0,172 | 38,11 | 0,163 | 37,65 | *0,46* | 42,10 | *-3,99* | 24,62 | *13,49* |
| L | 0,252 | 0,182 | 37,11 | 0,170 | 36,65 | *0,46* | 40,43 | *-3,32* | 23,92 | *13,19* |
| M | 0,266 | 0,192 | 36,17 | 0,176 | 35,73 | *0,44* | 38,87 | *-2,70* | 23,29 | *12,88* |
| N | 0,280 | 0,202 | 35,21 | 0,183 | 34,88 | *0,33* | 37,40 | *-2,19* | 22,71 | *12,50* |
| O | 0,294 | 0,212 | 34,34 | 0,189 | 34,10 | *0,24* | 36,02 | *-1,68* | 22,19 | *12,15* |
| P | 0,307 | 0,222 | 33,49 | 0,194 | 33,38 | *0,11* | 34,72 | *-1, 23* | 21,70 | *11,79* |
| Q | 0,321 | 0,232 | 32,66 | 0,199 | 32,70 | *-0,04* | 33,49 | *-0,83* | 21,26 | *11,40* |
| R | 0,335 | 0,242 | 31,85 | 0,203 | 32,07 | *-0,22* | 32,33 | *-0,48* | 20,85 | *11,00* |
| S | 0,349 | 0,252 | 31,06 | 0,205 | 31,49 | *-0,43* | 31,24 | *-0,18* | 20,47 | *10,59* |
| T | 0,363 | 0,262 | 30,30 | 0,207 | 30,94 | *-0,64* | 30,21 | *0,09* | 20,12 | *10,18* |
| U | 0,377 | 0,272 | 29,53 | 0,207 | 30,43 | *-0,90* | 29,23 | *0,30* | 19,80 | *9,73* |
| V | 0,391 | 0,282 | 28,81 | 0,206 | 29,95 | *-1,14* | 28,31 | *0,50* | 19,49 | *9,32* |
| W | 0,404 | 0,292 | 27,95 | 0,204 | 29,50 | *-1, 55* | 27,43 | *0,52* | 19,21 | *8,74* |
| X | 0,418 | 0,302 | 27,17 | 0,202 | 29,07 | *-1,90* | 26,60 | *0,57* | 18,94 | *8,23* |
| Y | 0,432 | 0,312 | 26,31 | 0,199 | 28,67 | *-2,36* | 25,82 | *0,49* | 18,69 | *7,62* |
| Z | 0,446 | 0,322 | 25,38 | 0,196 | 28,29 | *-2,91* | 25,07 | *0, 31* | 18,46 | *6,92* |
| 1 | 0,460 | 0,332 | 24,50 | 0,193 | 27,93 | *-3,43* | 24,36 | *0,14* | 18,23 | *6,27* |

(continued)

| Cut | r/R | r | θ | Chord | θ Eq. 1 | *Dev. Eq. 1* | θ Eq. 2 | *Dev. Eq. 2* | Dev. Eq. 3 | *θ Eq. 3* |
|---|---|---|---|---|---|---|---|---|---|---|
| [-] | [-] | [m] | [°] | [m] | [°] | *[°]* | [°] | *[°]* | *[°]* | *[°]* |
| 2 | 0,474 | 0,342 | 23,66 | 0,190 | 27,59 | *-3,93* | 23,68 | *-0,02* | 18,02 | *5,64* |
| 3 | 0,488 | 0,352 | 22,87 | 0,187 | 27,27 | *-4,40* | 23,04 | *-0,17* | 17,83 | *5,04* |
| 4 | 0,501 | 0,362 | 22,12 | 0,185 | 26,96 | *-4,84* | 22,42 | *-0,30* | 17,64 | *4,48* |
| 5 | 0,515 | 0,372 | 21,42 | 0,183 | 26,67 | *-5,25* | 21,83 | *-0,41* | 17,46 | *3,96* |
| 6 | 0,529 | 0,382 | 20,78 | 0,181 | 26,39 | *-5, 61* | 21,27 | *-0,49* | 17,29 | *3,49* |
| 7 | 0,543 | 0,392 | 20,20 | 0,179 | 26,12 | *-5,92* | 20,73 | *-0,53* | 17,13 | *3,07* |
| 8 | 0,557 | 0,402 | 19,66 | 0,176 | 25,87 | *-6, 21* | 20,22 | *-0,56* | 16,98 | *2,68* |
| 9 | 0,571 | 0,412 | 19,17 | 0,174 | 25,63 | *-6,46* | 19,73 | *-0,56* | 16,83 | *2,34* |
| 10 | 0,584 | 0,422 | 18,71 | 0,172 | 25,40 | *-6,69* | 19,26 | *-0,55* | 16,69 | *2,02* |
| 11 | 0,598 | 0,432 | 18,24 | 0,170 | 25,18 | *-6,94* | 18,81 | *-0,57* | 16,56 | *1,68* |
| 12 | 0,612 | 0,442 | 17,85 | 0,167 | 24,96 | *-7,11* | 18,37 | *-0,52* | 16,43 | *1,42* |
| 13 | 0,626 | 0,452 | 17,50 | 0,165 | 24,76 | *-7,26* | 17,96 | *-0,46* | 16,31 | *1,19* |
| 14 | 0,640 | 0,462 | 17,17 | 0,163 | 24,57 | *-7,40* | 17,56 | *-0,39* | 16,20 | *0,97* |
| 15 | 0,654 | 0,472 | 16,87 | 0,160 | 24,38 | *-7,51* | 17,17 | *-0,30* | 16,09 | *0,78* |
| 16 | 0,668 | 0,482 | 16,60 | 0,158 | 24,20 | *-7,60* | 16,80 | *-0,20* | 15,98 | *0,62* |
| 17 | 0,681 | 0,492 | 16,35 | 0,156 | 24,02 | *-7,67* | 16,44 | *-0,09* | 15,88 | *0,47* |
| 18 | 0,695 | 0,502 | 16,11 | 0,154 | 23,86 | *-7,75* | 16,10 | *0,01* | 15,78 | *0,33* |
| 19 | 0,709 | 0,512 | 15,96 | 0,151 | 23,70 | *-7,74* | 15,77 | *0,19* | 15,68 | *0,28* |
| 20 | 0,723 | 0,522 | 15,70 | 0,149 | 23,54 | *-7,84* | 15,45 | *0,25* | 15,59 | *0,11* |
| 21 | 0,737 | 0,532 | 15,57 | 0,147 | 23,39 | *-7,82* | 15,14 | *0,43* | 15,50 | *0,07* |
| 22 | 0,751 | 0,542 | 15,40 | 0,144 | 23,25 | *-7,85* | 14,84 | *0,56* | 15,42 | *-0,02* |
| 23 | 0,765 | 0,552 | 15,24 | 0,142 | 23,11 | *-7,87* | 14,55 | *0,69* | 15,34 | *-0,10* |
| 24 | 0,778 | 0,562 | 15,10 | 0,140 | 22,97 | *-7,87* | 14,27 | *0,83* | 15,26 | *-0,16* |
| 25 | 0,792 | 0,572 | 14,97 | 0,138 | 22,84 | *-7,87* | 14,00 | *0,97* | 15,18 | *-0,21* |
| 26 | 0,806 | 0,582 | 14,86 | 0,135 | 22,72 | *-7,86* | 13,74 | *1,12* | 15,11 | *-0,25* |
| 27 | 0,820 | 0,592 | 14,75 | 0,133 | 22,59 | *-7,84* | 13,49 | *1,26* | 15,04 | *-0,29* |
| 28 | 0,834 | 0,602 | 14,86 | 0,130 | 22,48 | *-7,62* | 13,25 | *1, 61* | 14,97 | *-0,11* |
| 29 | 0,848 | 0,612 | 14,59 | 0,128 | 22,36 | *-7,77* | 13,01 | *1,58* | 14,90 | *-0,31* |
| 30 | 0,861 | 0,622 | 14,54 | 0,126 | 22,25 | *-7,71* | 12,78 | *1,76* | 14,84 | *-0,30* |
| 31 | 0,875 | 0,632 | 14,50 | 0,124 | 22,14 | *-7,64* | 12,56 | *1,94* | 14,77 | *-0,27* |
| 32 | 0,889 | 0,642 | 14,47 | 0,121 | 22,04 | *-7,57* | 12,34 | *2,13* | 14,71 | *-0,24* |
| 33 | 0,903 | 0,652 | 14,45 | 0,119 | 21,94 | *-7,49* | 12,13 | *2,32* | 14,65 | *-0,20* |
| 34 | 0,917 | 0,662 | 14,42 | 0,117 | 21,84 | *-7,42* | 11,92 | *2,50* | 14,60 | *-0,18* |
| 35 | 0,931 | 0,672 | 14,45 | 0,115 | 21,74 | *-7,29* | 11,73 | *2,72* | 14,54 | *-0,09* |
| 36 | 0,945 | 0,682 | 14,50 | 0,113 | 21,65 | *-7,15* | 11,53 | *2,97* | 14,49 | *0,01* |
| 37 | 0,958 | 0,692 | 14,50 | 0,110 | 21,56 | *-7,06* | 11,35 | *3,15* | 14,44 | *0,06* |
| 38 | 0,972 | 0,702 | 14,59 | 0,108 | 21,47 | *-6,88* | 11,16 | *3,43* | 14,38 | *0,21* |

(continued)

| Cut | r/R | r | θ | Chord | θ Eq. 1 | *Dev. Eq. 1* | θ Eq. 2 | *Dev. Eq. 2* | Dev. Eq. 3 | *θ Eq. 3* |
|---|---|---|---|---|---|---|---|---|---|---|
| [-] | [-] | [m] | [°] | [m] | [°] | *[°]* | [°] | *[°]* | *[°]* | *[°]* |
| 39 | 0,986 | 0,712 | 14,64 | 0,106 | 21,39 | *-6,75* | 10,99 | *3,65* | 14,33 | 0,*31* |
| 40 | 1,000 | 0,722 | 14,75 | 0,105 | 21,30 | *-6,55* | 10,81 | *3,94* | 14,29 | *0,46* |

**[0044]** The first column of the table is the cross-sectional cut as seen in figure 5, the next four columns provide the parameters of the blade 2 as found by standard design tools, and the last six columns are the chord angles θ found by means of Eq. 1, Eq. 2 and Eq. 3, and the respective deviations between the calculated angles using Eq. 1, Eq. 2 and Eq. 3 and the measured angle.

**[0045]** Table 1 shows that the deviation between the measured chord angle θ and the one calculated with the use of Eq. 1 is less than 1° at relative radial positions between r/R=0.13 and r/R=0.38. Close to the blade root, the deviation increases however still maintaining a value of less than 3.5° using Eq. 1.

**[0046]** Table 1 also shows that the deviation between the measured chord angle θ and the one calculated with the use of Eq. 2 is less than 1° at relative radial positions between r/R=0.32 and r/R=0.79 and less than 4° at relative radial position between r/R=0.24 and r/R=1 when using Eq. 2.

**[0047]** Table 1 further shows that the deviation between the measured chord angle θ and the one calculated with the use of Eq. 3 is less than 1° at relative radial positions from r/R=0.65 to r/R=1 and less than 4° at relative radial positions above r/R=0.51 when using Eq. 3.

**[0048]** Extensive testing of the blades of fans designed according to the design principles has revealed that a change of pitch angle of the blade to adjust a fan designed for one nominal set of operational conditions to a different set of operational conditions, mainly a different flow rate through the fan and a different rotational speed *n* of the fan to a large extent preserve the advantages of the fan design, i.e. an improved overall efficiency of the fan as compared to traditionally designed fans, for which reason an axial fan having blades following the design principles generally have shown to exhibit the advantages, even though the blades are turned to another pitch and the fan is operated with other operational conditions than the original nominal set of operational conditions. These advantages have been apparent at pitch angles deviating at least about 10° from the designed pitch angle and are increasing for pitch angles deviating in the range of 5° from the designed pitch angle of the blade 2.

**[0049]** The assembly in figure 1 also show a seating part 16 of the hub 3, three blades 2 and three locking parts 18 for an axial flow fan according to an aspect of the present invention. The blades 2 are at the root end 11 equipped with a projection 15 that allows the individual blade 2 to be seated in a blade seating opening 17 of the seating part 16 at any pitch angle of the blade 2 as desired, the projections 15 being rotatable in the U-shaped seating openings 17. The blade root protections 15 being equipped with a recess (not visible) designed for cooperating with a pin 20 having a rectangular cross-section, the pin 20 being extending from the body of a locking part 18 which is suited to the inserted into the blade seating opening 17 when the blade root projection 15 is in place so as to lock the pitch angle of the blade 2 to a specific blade pitch angle defined by the locking part 18.

**[0050]** In figure 7 is shown three different locking parts 18a, 18b, 18c where the pin 20a, 20b, 20c are arranged at different positions to define different pitch angles of the blade 2. The locking parts 18a, 18b, 18c are provided with side tracks 19 to accommodate the edges of the blade seating opening 17 of the seating part 16 of the hub 3.

**[0051]** By providing a fan 1 with such system of a seating part 16, blades 2 provided with a recess in the blade root projection 15 and locking parts 18a, 18b, 18c defining one specific pitch angle of the blade 2, any possible erroneous re-assembly of the hub 3 after repair of the fan 1 resulting in erroneous blade pitch may be avoided.

### List of reference numerals

**[0052]**

| | |
|---|---|
| 1 | Axial flow fan |
| 2 | Blade |
| 3 | Hub |
| 4 | Axis of rotation of the rotor |
| 5 | Rotor |
| 6 | Shroud |
| 7 | Blade tip |
| 8 | Streamlines of air flow through fan |

| | |
|---|---|
| 9 | Inlet part |
| 10 | Diffuser |
| 11 | Root end of blade |
| 12 | Leading edge of blade |
| 13 | Trailing edge of blade |
| 14 | Chord line |
| 15 | Blade root projection |
| 16 | Seating part of hub |
| 17 | Blade seating opening |
| 18, 18a, 18b, 18c | Locking part |
| 19 | Side tracks |
| 20, 20a, 20b, 20c | Pin |
| A | Direction of incoming air flow before the rotor |
| M | Direction of movement of the blade |
| r | Distance from axis of rotation to a radial position of the rotor |
| R | Distance from axis of rotation to tip end of blade |
| $R_{hub}$ | Radius of the hub |
| $\theta$ | Angle between the blade chord and the direction of movement |
| $\Delta\theta$ | Angle between the chord of the blade and the blade chord at a predetermined radial position, e.g. of r/R = 0.34 |
| $\Delta\theta_{root}$ | Angle between the chord of the blade and the blade chord at a predetermined radial position at r/R = 0.34 in the root area between r/R=0.17-0.34 |
| $\Delta\theta_{middle}$ | Angle between the chord of the blade and the blade chord at a predetermined radial position at r/R = 0.72 in the middle area between r/R=0.34-0.72 |
| $\Delta\theta_{tip}$ | Angle between the chord of the blade and the blade chord at a predetermined radial position at r/R = 0.72 in the tip area between r/R=0.72-1. |

## Claims

**1.** An axial flow fan (1) comprising:

- a hub (3) rotatable about an axis (4);
- an annular shroud (6) extending concentric with said axis (4) in a radial distance from said hub (3);
- a plurality of fan blades (2) connected at a root end (11) to said hub (3) and having a free tip end (7) extending radially towards said shroud (6), and
- a fan driver coupled to said hub and arranged for driving the rotation of said hub around the axis,

wherein for R being the radial distance from said axis (4) to the free tip end (7) of the blade and r being the radial distance from said axis (4), the angle $\theta$ between a plane of rotation of the blades and the chord of each blade at the radial position of r/R = 0.34 is in the range of 20° to 40°,
the axial flow fan being **characterised in that** the plurality of fan blades (2) each comprises a root area extending from a radial positon of r/R=0.17 to a radial positon of r/R=0.34, the root area having a root angle $\Delta\theta_{root}$ extending between the chord of the blade at any radial position in the root area and the chord at the radial position of r/R=0.34, wherein $\Delta\theta_{root}$ follows a curve defined as:

$$\Delta\theta_{root} = arctan\left(\frac{0.375\cdot\frac{R}{r}+0.85}{\pi}\right)\text{-}31{,}9°,$$

and wherein the angle $\Delta\theta_{root}$ deviates less than 1° from the curve defined by the equation within the root area.

**2.** An axial flow fan according to claim 1, wherein the plurality of fan blades each comprises a middle area extending from the radial positon of r/R=0.34 to the radial position of r/R=0.72, the middle area having a middle angle $\Delta\theta_{middle}$ extending between the chord of the blade at any radial position in the middle area and the chord at the radial position of r/R=0.72, wherein $\Delta\theta_{middle}$ follows a curve defined as:

$$\Delta\theta_{middle} = arctan\left(\frac{0.7\cdot\frac{R}{r}-0.1}{\pi}\right)\text{-}15.6°.$$

**3.** An axial flow fan according to claim 1 or 2, wherein the plurality of fan blades each comprises a tip area extending from the radial positon of r/R=0.72 to the tip of the free tip end at r/R=1, the tip area having a tip angle $\Delta\theta_{tip}$ extending between the chord of the blade at any radial position in the tip area and the chord at the radial position of r/R=1, wherein $\Delta\theta_{tip}$ follows a curve defined as:

$$\Delta\theta_{tip} = arctan\left(\frac{0.2\cdot\frac{R}{r}+0.6}{\pi}\right)\text{-}14.3°.$$

**4.** An axial flow fan according to any of the preceding claims, wherein the angle $\theta$ between a plane of rotation of the blades and the chord of the blade at the radial position of r/R=0.34 is in the range of 25 to 35°.

**5.** An axial flow fan according to any preceding claim, wherein:

- the angle $\Delta\theta_{middle}$ deviates less than 4°, preferably less than 3°, more preferably less than 2°, even more preferably less than 1° from the curve defined by the equation within the middle area; and/or
- the angle $\Delta\theta_{tip}$ deviates less than 4°, preferably less than 3°, more preferably less than 2°, even more preferably less than 1° from the curve defined by the equation within the tip area.

**6.** An axial flow fan according to any preceding claim, wherein R is in the range of 500 to 900 millimetres.

**7.** An axial flow fan according to any preceding claim, wherein the chord increases in the root area from the hub towards the radial position of r/R=0.34, flattens out until the radial position of r/R=0.40 and decreases towards the tip of the blade at the radial position of r/R=1.

**8.** An axial flow fan according to any preceding claim, wherein the inner radius of the annular shroud is in the range of 600 to 1500 millimetres.

**9.** An axial flow fan according to any preceding claim, wherein the radius $(R_{hub})$ of the hub is in the range of 50 to 150 millimetres.

**10.** An axial flow fan according to any preceding claim comprising a diffuser (10) arranged concentric with said axis (4) at a downstream position of the annular shroud (6).

**11.** An axial flow fan according to claim 10, wherein the diffuser (10) has a conical shape with a diffusion angle in the range of 2 to 15° to the axis (4) of rotation of the rotor, preferably in the range of 6 to 10°.

**12.** An axial flow fan according to any preceding claim comprising an inlet part (9) provided with a bellmouth arranged concentric with said axis (4) at an upstream position of the annular shroud (6).

**13.** An axial flow fan according to any preceding claim, wherein the hub (3) comprises

- a seating part (16) allowing the blades (2) to be arranged in a plurality of blade pitch angles, and
- a blade locking part (18) for locking the blade pitch angle of the at least one blade (2) into a specific blade pitch angle,

wherein said locking part (18, 18a, 18b, 18c) is designed to lock said blade (2) into one specific blade pitch angle only.

**14.** An axial flow fan according to claim 13, comprising one locking part (18, 18a, 18b, 18c) for each of the blades (2).

**15.** An axial flow fan according to claim 13 or 14, wherein the blades (2) each comprises a recess cooperating with a corresponding pin (20, 20a, 20b, 20c) of the locking part (18, 18a, 18b, 18c).

## Patentansprüche

1. Axiallüfter (1), umfassend:

- eine Nabe (3), die um eine Achse (4) drehbar ist;
- eine ringförmige Ummantelung (6), die sich konzentrisch zu der Achse (4) in einem radialen Abstand von der Nabe (3) erstreckt;
- eine Vielzahl von Lüfterschaufeln (2), die an einem Wurzelende (11) mit der Nabe (3) verbunden ist und ein freies Spitzenende (7) hat, das sich radial in Richtung der Ummantelung (6) erstreckt, und
- einen Lüfterantrieb, der mit der Nabe gekoppelt und so angeordnet ist, dass er die Drehung der Nabe um die Achse antreibt,

wobei, wenn R der radiale Abstand von der Achse (4) zum freien Spitzenende (7) der Schaufel und *r* der radiale Abstand von der Achse (4) ist, der Winkel $\theta$ zwischen einer Rotationsebene der Schaufeln und der Sehne jeder Schaufel an der radialen Position von r/R = 0,34 im Bereich von 20° bis 40° liegt, wobei der Axiallüfter **dadurch gekennzeichnet ist, dass** die Vielzahl von Lüfterschaufeln (2) jeweils einen Wurzelbereich umfasst, der sich von einer radialen Position von r/R = 0,17 zu einer radialen Position von r/R = 0,34 erstreckt, wobei der Wurzelbereich einen Wurzelwinkel $\Delta\theta_{Wurzel}$ hat, der sich zwischen der Sehne der Schaufel an einer beliebigen radialen Position im Wurzelbereich und der Sehne an der radialen Position von r/R = 0,34 erstreckt, wobei $\Delta\theta_{Wurzel}$ einer Kurve folgt, die definiert ist als:

$$\Delta\theta_{\mathrm{Wurzel}} = arctan\left(\frac{0.375\cdot\frac{R}{r}+0.85}{\pi}\right)\text{-31,9°},$$

und wobei der Winkel $\Delta\theta_{Wurzel}$ weniger als 1° von der durch die Gleichung definierten Kurve innerhalb des Wurzelbereichs abweicht.

2. Axiallüfter nach Anspruch 1, wobei die Vielzahl von Lüfterschaufeln jeweils einen mittleren Bereich umfasst, der sich von der radialen Position von r/R=0,34 bis zur radialen Position von r/R=0,72 erstreckt, wobei der mittlere Bereich einen mittleren Winkel $\Delta\theta_{Mitte}$ hat, der sich zwischen der Sehne der Schaufel an einer beliebigen radialen Position im mittleren Bereich und der Sehne an der radialen Position von r/R=0,72 erstreckt, wobei $\Delta\theta_{Mitte}$ einer Kurve folgt, die definiert ist als:

$$\Delta\theta_{\mathrm{Mitte}} = arctan\left(\frac{0.7\cdot\frac{R}{r}-0.1}{\pi}\right)\text{-15.6°}.$$

3. Axiallüfter nach Anspruch 1 oder 2, wobei die Vielzahl von Lüfterschaufeln jeweils einen Spitzenbereich umfasst, der sich von der radialen Position von r/R=0,72 bis zur Spitze des freien Spitzenendes bei r/R=1 erstreckt, wobei der Spitzenbereich einen Spitzenwinkel $\Delta\theta_{Spitze}$ hat, der sich zwischen der Sehne der Schaufel an einer beliebigen radialen Position im Spitzenbereich und der Sehne an der radialen Position von r/R=1 erstreckt, wobei $\Delta\theta_{Spitze}$ einer Kurve folgt, die definiert ist als:

$$\Delta\theta_{\mathrm{Spitze}} = arctan\left(\frac{0.2\cdot\frac{R}{r}+0.6}{\pi}\right)\text{-14.3°}.$$

4. Axiallüfter nach einem der vorhergehenden Ansprüche, wobei der Winkel $\theta$ zwischen einer Rotationsebene der Schaufeln und der Sehen der Schaufel an der radialen Position von r/R=0,34 im Bereich von 25 bis 35° liegt.

5. Axiallüfter nach einem der vorhergehenden Ansprüche, wobei:

der Winkel $\Delta\theta_{Mitte}$ weniger als 4°, bevorzugt weniger als 3°, noch bevorzugter weniger als 2°, sogar noch bevorzugter weniger als 1° von der durch die Gleichung definierten Kurve im mittleren Bereich abweicht; und/oder der Winkel $\Delta\theta_{Spitze}$ weniger als 4°, bevorzugt weniger als 3°, noch bevorzugter weniger als 2°, sogar noch bevorzugter weniger als 1° von der durch die Gleichung definierten Kurve innerhalb des Spitzenbereichs abweicht.

6. Axiallüfter nach einem der vorhergehenden Ansprüche, wobei R im Bereich von 500 bis 900 Millimetern liegt.

7. Axiallüfter nach einem der vorhergehenden Ansprüche, wobei die Sehne im Wurzelbereich von der Nabe aus in Richtung der radialen Position von r/R=0,34 zunimmt, bis zur radialen Position von r/R=0,40 abflacht und in Richtung der Spitze der Schaufel bei der radialen Position von r/R=1 abnimmt.

8. Axiallüfter nach einem der vorhergehenden Ansprüche, wobei der Innenradius der ringförmigen Ummantelung im Bereich von 600 bis 1500 mm liegt.

9. Axiallüfter nach einem der vorhergehenden Ansprüche, wobei der Radius ($R_{Nabe}$) der Nabe im Bereich von 50 bis 150 Millimetern liegt.

10. Axiallüfter nach einem der vorhergehenden Ansprüche, umfassend einen Diffusor (10), der konzentrisch zu der Achse (4) an einer stromabwärts gelegenen Position der ringförmigen Ummantelung (6) angeordnet ist.

11. Axiallüfter nach Anspruch 10, wobei der Diffusor (10) eine konische Form mit einem Diffusionswinkel im Bereich von 2 bis 15° zur Achse (4) der Rotation des Rotors, vorzugsweise im Bereich von 6 bis 10°, hat.

12. Axiallüfter nach einem der vorhergehenden Ansprüche, umfassend einen Einlassteil (9), der mit einer Glocke versehen ist, die konzentrisch zur Achse (4) an einer stromaufwärts gelegenen Position der ringförmigen Ummantelung (6) angeordnet ist.

13. Axiallüfter nach einem der vorhergehenden Ansprüche, wobei die Nabe (3) umfasst

- ein Aufnahmeteil (16), das es erlaubt, die Schaufeln (2) in einer Vielzahl von Schaufelanstellwinkeln anzuordnen, und
- ein Schaufelverriegelungsteil (18) zum Verriegeln des Schaufelanstellwinkels der mindestens einen Schaufel (2) in einem bestimmten Schaufelanstellwinkel,

wobei das Verriegelungsteil (18, 18a, 18b, 18c) so ausgelegt ist, dass es die Schaufel (2) nur in einem bestimmten Schaufelanstellwinkel verriegelt.

14. Axiallüfter nach Anspruch 13, umfassend ein Verriegelungsteil (18, 18a, 18b, 18c) für jede der Schaufeln (2).

15. Axiallüfter nach Anspruch 13 oder 14, wobei die Schaufeln (2) jeweils eine Ausnehmung umfassen, die mit einem entsprechenden Stift (20, 20a, 20b, 20c) des Verriegelungsteils (18, 18a, 18b, 18c) zusammenwirkt.

## Revendications

1. Ventilateur à flux axial (1) comprenant :

- un moyeu (3) pouvant tourner autour d'un axe (4) ;
- un carénage annulaire (6) s'étendant concentriquement audit axe (4) sur une distance radiale à partir dudit moyeu (3) ;
- une pluralité de pales (2) de ventilateur reliées au niveau d'une extrémité de pied (11) audit moyeu (3) et ayant une extrémité de bout libre (7) s'étendant radialement vers ledit carénage (6), et
- un dispositif d'entraînement de ventilateur accouplé audit moyeu et disposé pour entraîner la rotation dudit moyeu autour de l'axe, dans lequel pour *R* étant la distance radiale dudit axe (4) à l'extrémité de bout libre (7) de la pale et *r* étant la distance radiale à partir dudit axe (4), l'angle $\theta$ entre un plan de rotation des pales et la corde du profil de chaque pale à la position radiale de r/R = 0,34 est dans la plage de 20° à 40°,

le ventilateur à flux axial étant **caractérisé en ce que** la pluralité de pales (2) de ventilateur comprennent chacune une zone de pied s'étendant d'une position radiale de r/R = 0,17 à une position radiale de r/R = 0,34, la zone de pied ayant un angle de pied $\Delta\theta_{pied}$ s'étendant entre la corde du profil de la pale en toute position radiale dans la zone de pied et la corde du profil à la position radiale de r/R = 0,34, $\Delta\theta_{pied}$ suivant une courbe définie comme :

$$\Delta\theta_{\text{pied}} = arctan\left(\frac{0{,}375\cdot\frac{R}{r}+0{,}85}{\pi}\right)\text{-}31{,}9°,$$

et l'angle $\Delta\theta_{pied}$ déviant de moins de 1° de la courbe définie par l'équation à l'intérieur de la zone de pied.

**2.** Ventilateur à flux axial selon la revendication 1, dans lequel la pluralité de pales de ventilateur comprennent chacune une zone centrale s'étendant de la position radiale de r/R = 0,34 à la position radiale de r/R=0,72, la zone centrale ayant un angle de centre $\Delta\theta_{centre}$ s'étendant entre la corde du profil de la pale en toute position radiale dans la zone centrale et la corde du profil à la position radiale de r/R = 0,72, $\Delta\theta_{centre}$ suivant une courbe définie comme :

$$\Delta\theta_{\text{centre}} = arctan\left(\frac{0{,}7\cdot\frac{R}{r}-0{,}1}{\pi}\right)\text{-}15{,}6°.$$

**3.** Ventilateur à flux axial selon la revendication 1 ou 2, dans lequel la pluralité de pales de ventilateur comprennent chacune une zone de bout s'étendant de la position radiale de r/R = 0,72 au bout de l'extrémité de bout libre à r/R = 1, la zone de bout ayant un angle de bout $\Delta\theta_{bout}$ s'étendant entre la corde du profil de la pale en toute position radiale dans la zone de bout et la corde du profil à la position radiale de r/R = 1, $\Delta\theta_{bout}$ suivant une courbe définie comme :

$$\Delta\theta_{\text{bout}} = arctan\left(\frac{0{,}2\cdot\frac{R}{r}+0{,}6}{\pi}\right)\text{-}14{,}3°.$$

**4.** Ventilateur à flux axial selon l'une quelconque des revendications précédentes, dans lequel l'angle $\theta$ entre un plan de rotation des pales et la corde du profil de la pale à la position radiale de r/R = 0,34 est dans la plage de 25 à 35°.

**5.** Ventilateur à flux axial selon l'une quelconque des revendications précédentes, dans lequel :

- l'angle $\Delta\theta_{centre}$ dévie de moins de 4°, de préférence de moins de 3°, plus préférablement de moins de 2°, encore plus préférablement de moins de 1° de la courbe définie par l'équation à l'intérieur de la zone centrale ; et/ou
- l'angle $\Delta\theta_{bout}$ dévie de moins de 4°, de préférence de moins de 3°, plus préférablement de moins de 2°, encore plus préférablement de moins de 1° de la courbe définie par l'équation à l'intérieur de la zone de bout.

**6.** Ventilateur à flux axial selon l'une quelconque des revendications précédentes, dans lequel R est dans la plage de 500 à 900 millimètres.

**7.** Ventilateur à flux axial selon l'une quelconque des revendications précédentes, dans lequel la corde du profil augmente dans la zone de pied à partir du moyeu vers la position radiale de r/R = 0,34, s'aplatit jusqu'à la position radiale de r/R = 0,40 et diminue vers le bout de la pale à la position radiale de r/R = 1.

**8.** Ventilateur à flux axial selon l'une quelconque des revendications précédentes, dans lequel le rayon interne du carénage annulaire est dans la plage de 600 à 1 500 millimètres.

**9.** Ventilateur à flux axial selon l'une quelconque des revendications précédentes, dans lequel le rayon ($R_{moyeu}$) du moyeu est dans la plage de 50 à 150 millimètres.

**10.** Ventilateur à flux axial selon l'une quelconque des revendications précédentes, comprenant un diffuseur (10) disposé concentriquement audit axe (4) en une position en aval du carénage annulaire (6).

**11.** Ventilateur à flux axial selon la revendication 10, dans lequel le diffuseur (10) a une forme conique avec un angle de diffusion dans la plage de 2 à 15°, de préférence dans la plage de 6 à 10°, par rapport à l'axe (4) de rotation du rotor.

**12.** Ventilateur à flux axial selon l'une quelconque des revendications précédentes, comprenant une partie d'entrée (9) dotée d'un évasement disposé concentriquement audit axe (4) en une position en amont du carénage annulaire (6).

**13.** Ventilateur à flux axial selon l'une quelconque des revendications précédentes, dans lequel le moyeu (3) comprend

- une partie d'appui (16) permettant aux pales (2) d'être disposées en une pluralité d'angles de pas de pale, et
- une partie de blocage (18) de pale destinée à bloquer l'angle de pas de pale de ladite au moins une pale (2) en un angle spécifique de pas de pale,

dans lequel ladite partie de blocage (18, 18a, 18b, 18c) est conçue pour bloquer ladite pale (2) en un seul angle spécifique de pas de pale.

**14.** Ventilateur à flux axial selon la revendication 13, comprenant une partie de blocage (18, 18a, 18b, 18c) pour chacune des pales (2).

**15.** Ventilateur à flux axial selon la revendication 13 ou 14, dans lequel les pales (2) comprennent chacune un retrait coopérant avec une broche correspondante (20, 20a, 20b, 20c) de la partie de blocage (18, 18a, 18b, 18c).

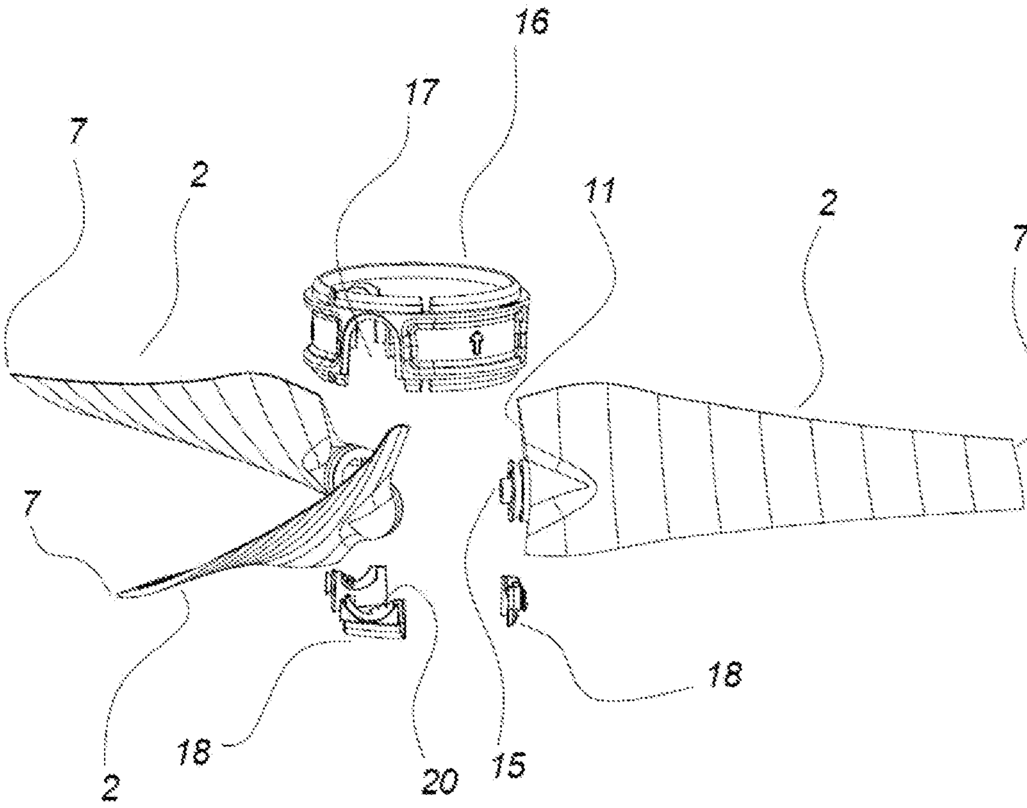


**Fig. 1**

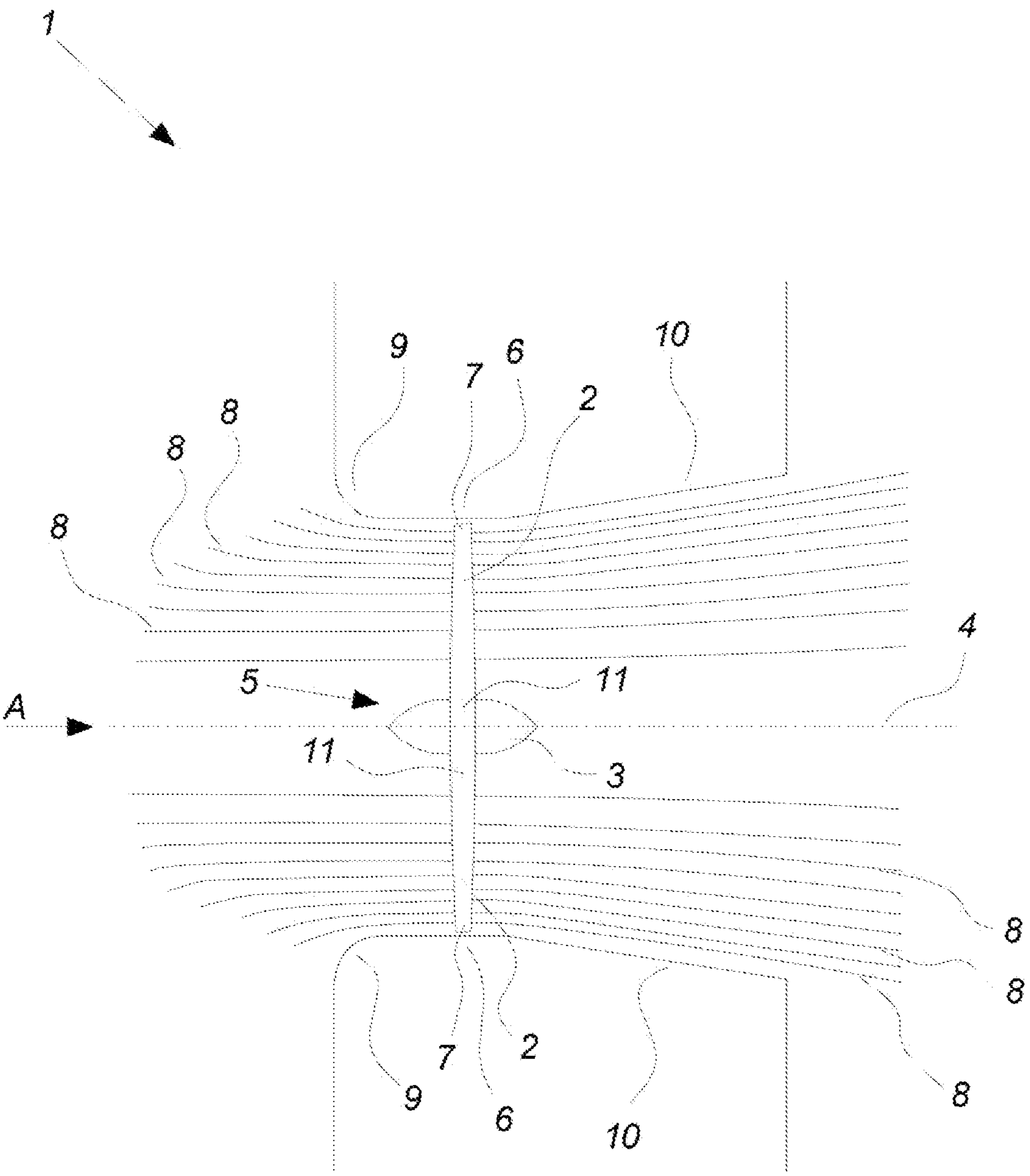


Fig. 2

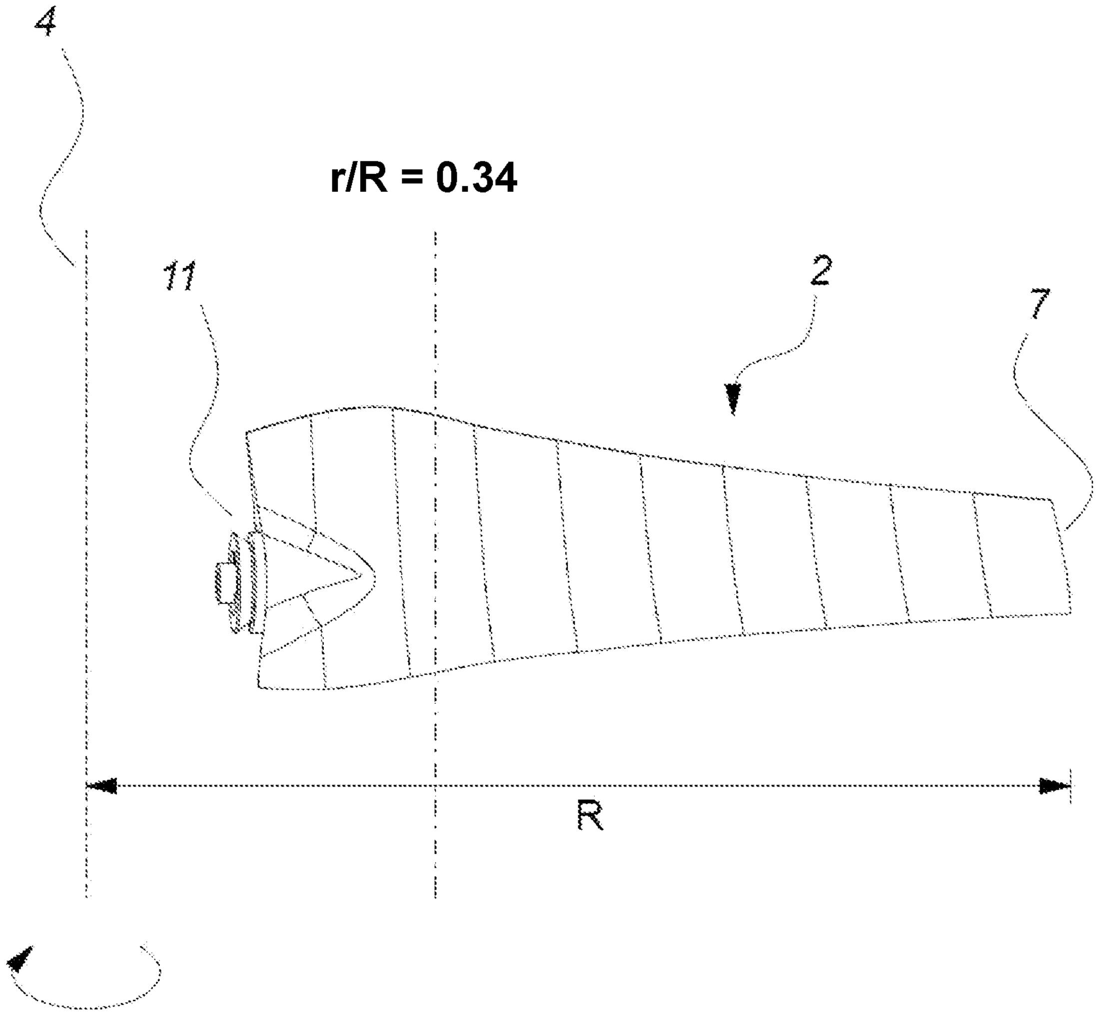


Fig. 3

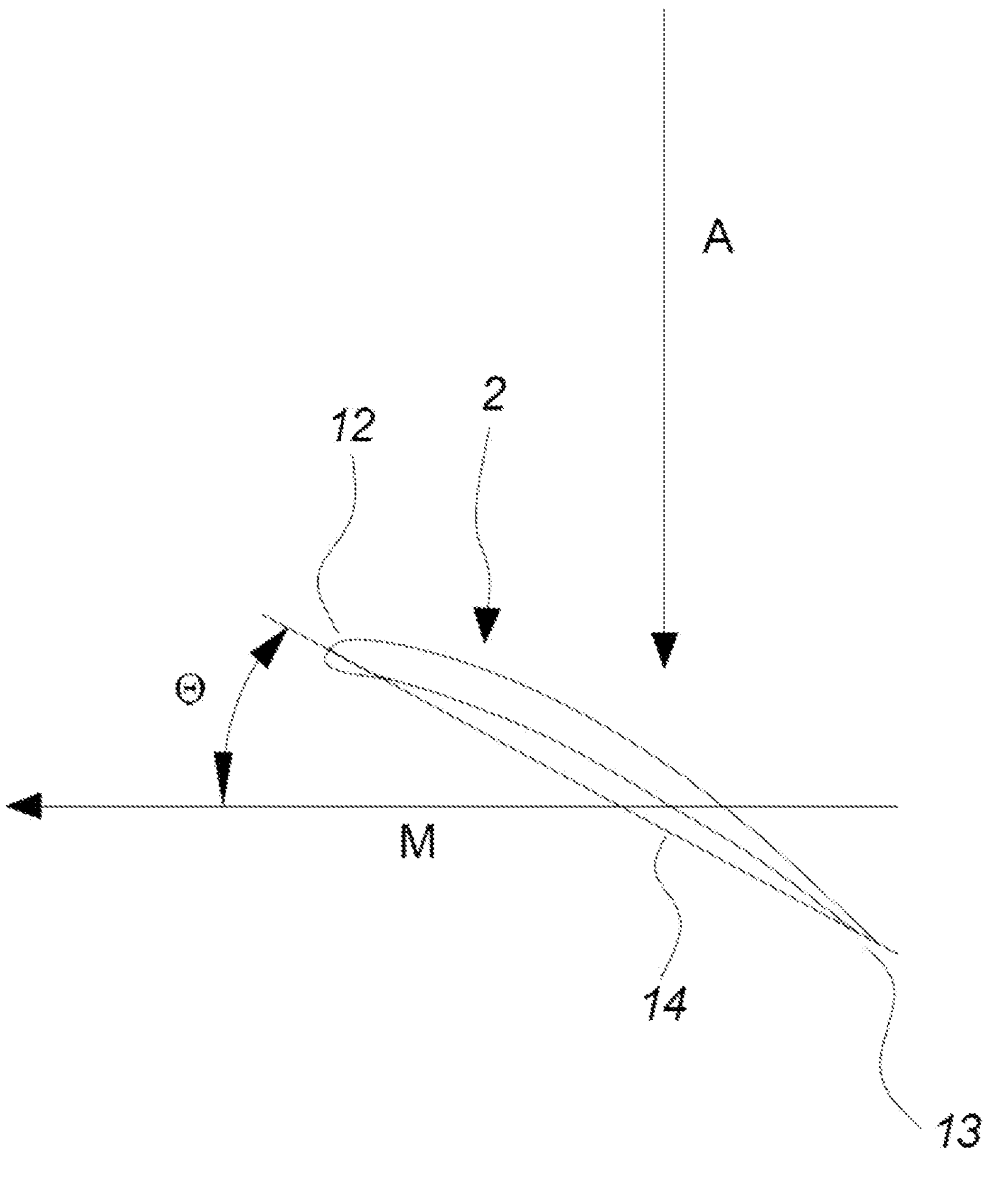


Fig. 4

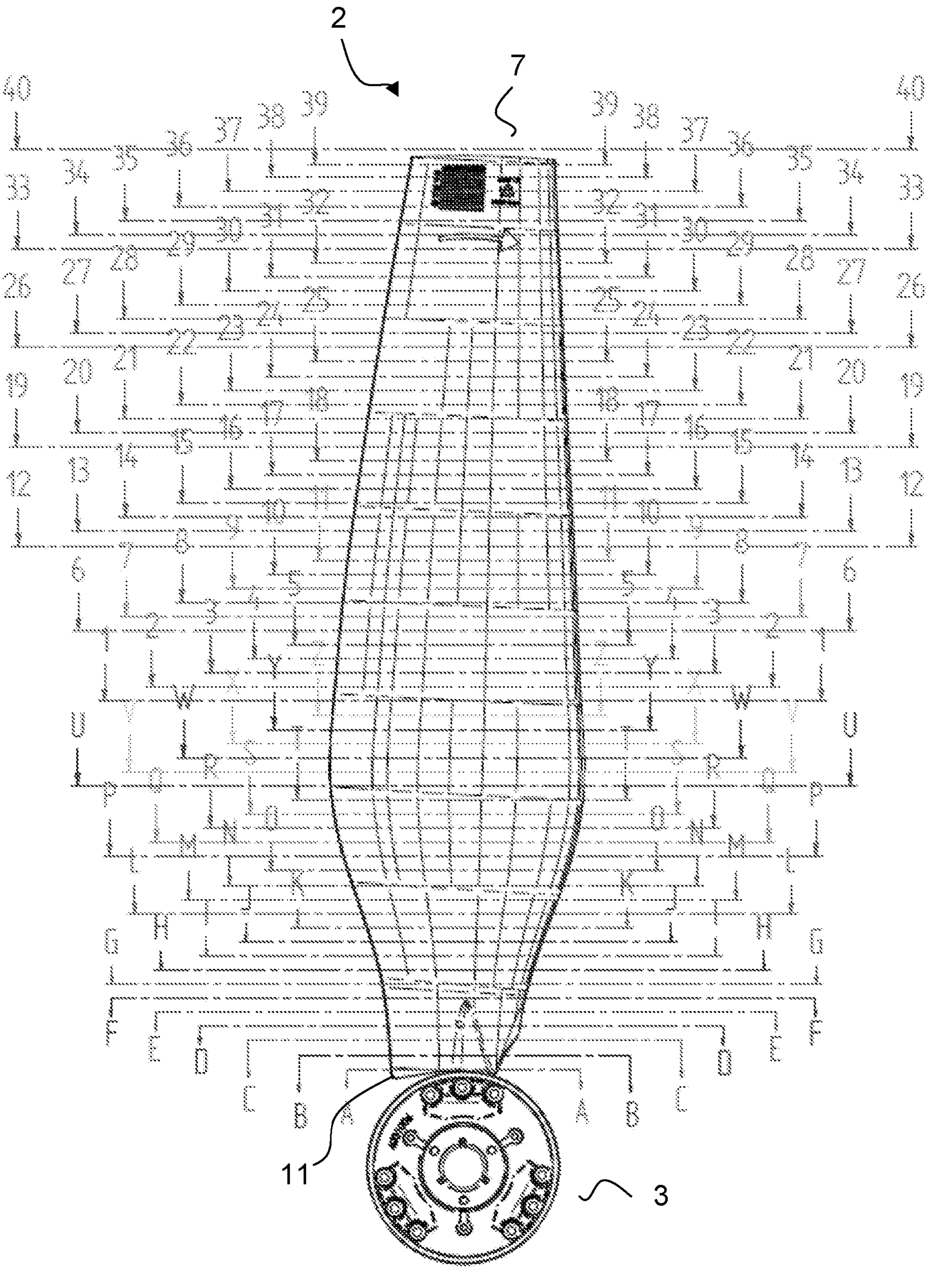


Fig. 5

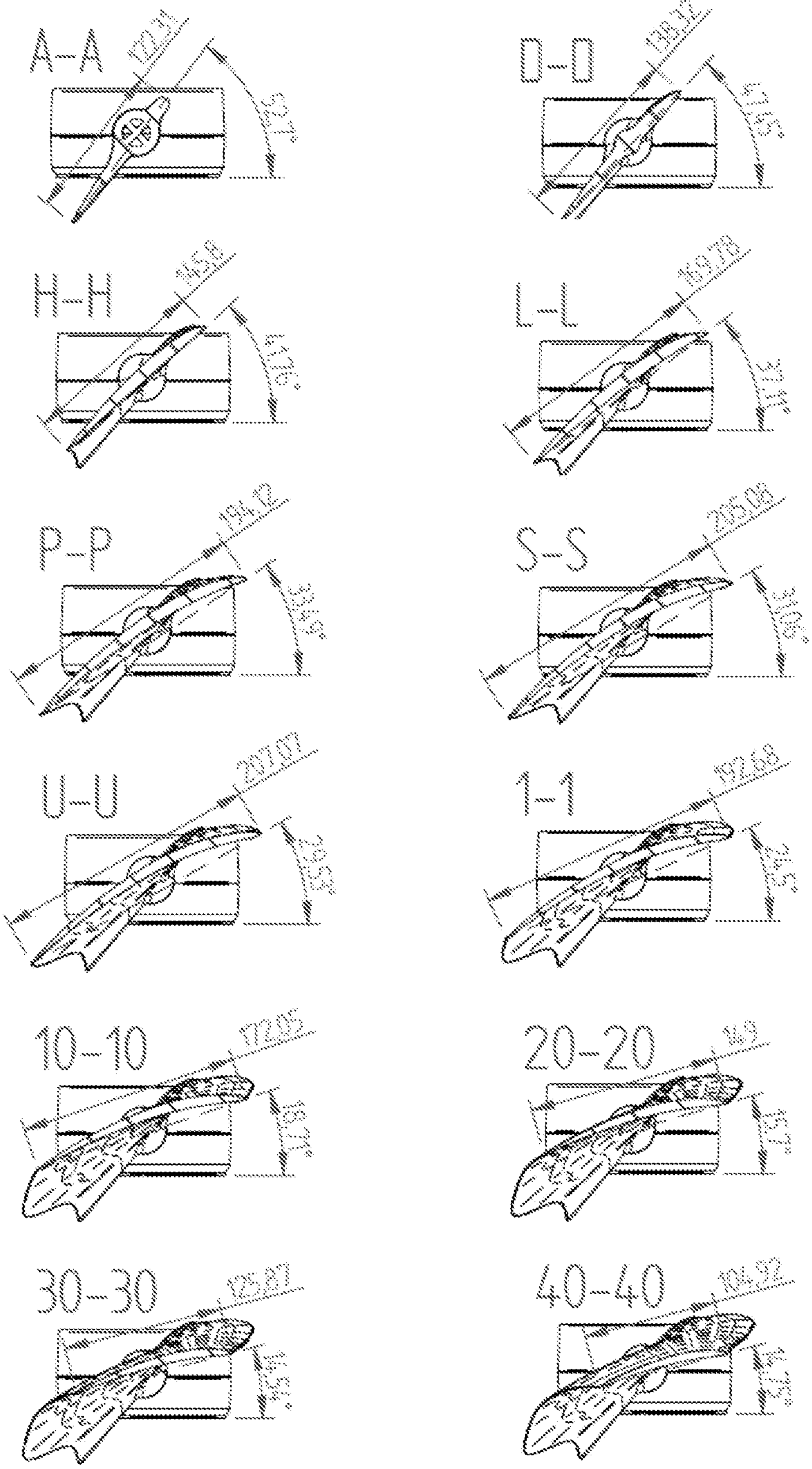


Fig. 6

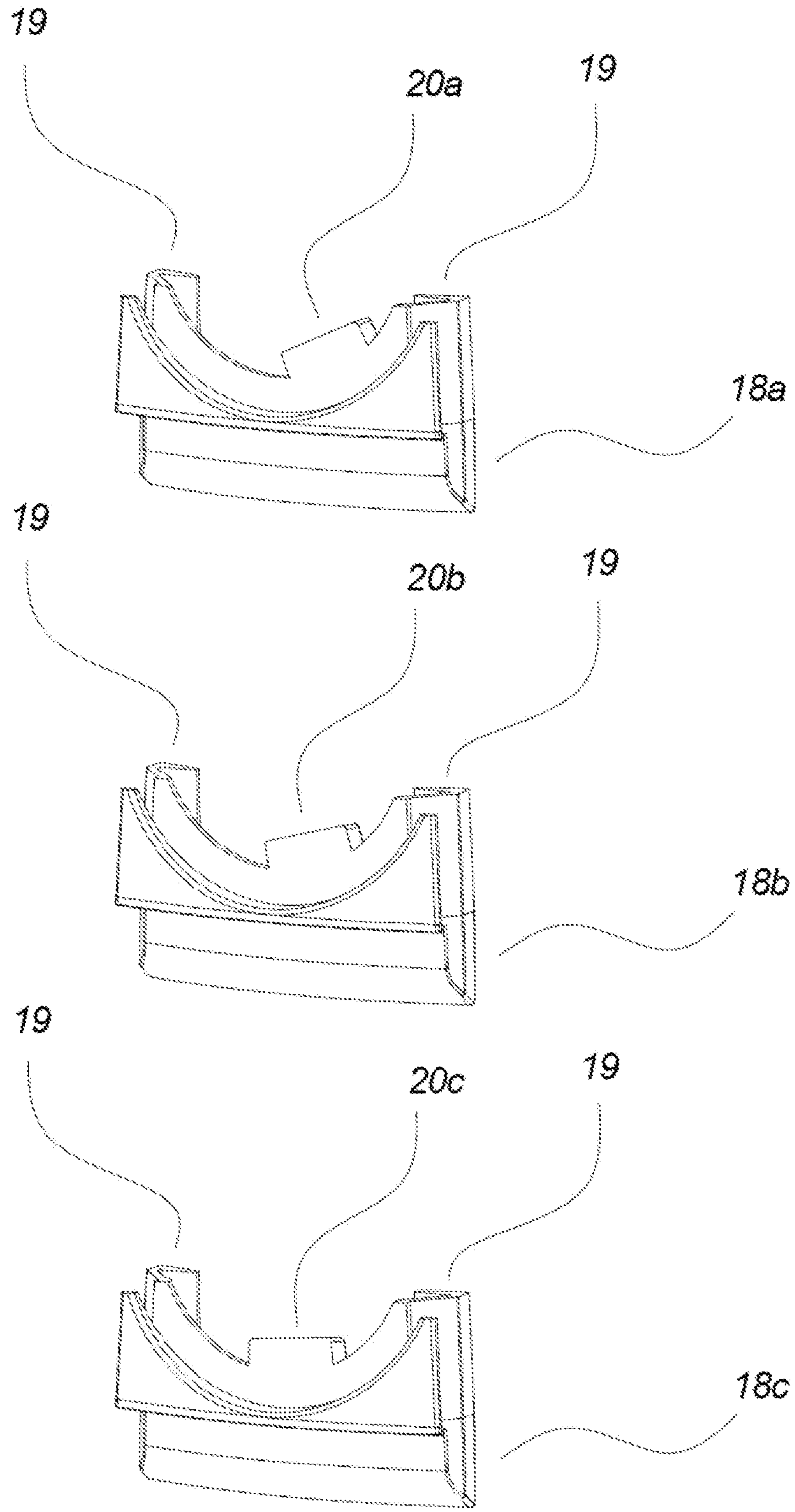


Fig. 7

## REFERENCES CITED IN THE DESCRIPTION

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