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(54) Title: CONNECTING ELEMENT FOR CONNECTING A BLADE TO THE HUB IN AN INDUSTRIAL AXIAL FAN, AND
BLADE SYSTEM COMPRISING SAID CONNECTING ELEMENT

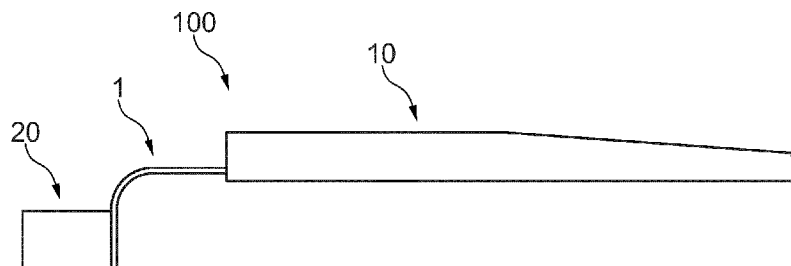


Fig. 5

(57) Abstract: The present invention concerns a connecting element for connecting a blade, or airfoil profile, to the hub of an industrial axial fan, a blade system comprising said connecting element, and an industrial axial fan comprising such blade system. The connecting element (1) for connecting a blade (10) to the hub (20) of an industrial axial fan according to the present invention, is realized in a single L-shaped piece comprising a first part (1a) having a substantially straight develop and a second part (1b) having a substantially straight develop, said first (1a) and second (1b) part being connected by a linking part (1c) presenting a curvature radius, said first (1a) and second (1b) parts lying on substantially perpendicular planes. The connecting element according to the present invention allows to achieve several advantages with respect to the prior art, one of said advantages consisting of its extremely simple shape and manufacturing process, which render the connecting element economically advantageous.



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Connecting element for connecting a blade to the hub in an industrial axial fan, and blade system comprising said connecting element

FIELD OF THE INVENTION

The present invention concerns a connecting element for connecting a blade, or
5 airfoil profile, to the hub of an industrial axial fan, a blade system comprising said connecting element, and an industrial axial fan comprising such blade system.

The axial fans for industrial application typically comprise a hub and a plurality of airfoil profiles.

A blade basically comprises two parts, the airfoil profile having the function to move
10 the air, and the connecting element or attachment having the function to link the airfoil profile to the hub.

Object of the present invention is the connecting element connecting the airfoil to the hub and the blade system comprising a blade, an hub and the connecting element according to the present invention.

15 It is further an object of the present invention an industrial axial fan comprising such blade system.

STATE OF THE ART

In the field of axial fans, many different technical solutions are known for connecting
20 the airfoil profile to the hub of the fan.

In order to briefly discuss the prior art, it is important to reassume the static and dynamic forces acting on the blades of an industrial axial fan during its operation, in particular with respect to the effect of the centrifugal forces.

Then, we will described various solutions actually known in the field and having the
25 purpose to decrease the steady and eventually the unsteady loads on the element connecting the airfoil profile to the hub of the axial fan.

The forces acting on the blades of an axial fan during operation can be divided in steady forces A) and unsteady forces B).

A) The steady forces, as indicated in the attached Figure 4a, are the following:

- 30 - aerodynamic or lift forces (L);
- drag force (D);
- centrifugal force (C);

- blade weight (W).

If the blade axis is inclined of an angle α toward the air suction side with respect to the ideal rotating plane, the centrifugal force generates a bending moment into the axial plane, having direction opposed to the direction of the moment the lift and the weight generate, as shown in the fig. 4b.

Consequently the resulting steady state bending moment transferred to the hub will be reduced, according to the following formula:

$$M = L \cdot x_{ca} + W \cdot x_{cg} - C \cdot y_{cg} \quad (1)$$

Where:

Oxy is a system of coordinates having the origin at the restrained section of the blade supporting element, the x-axis radially directed and the y-axis parallel to the rotational axis

M is the steady state resulting bending moment;

x_{ca} is the radial position of the center of the aerodynamic force

x_{cg} is the radial position of the center of gravity

y_{cg} is the vertical position of the center of gravity

B) The unsteady forces, are those generated by:

- the interaction between the aerodynamic field created around the blade and the structure supporting the fan or the housing comprising it; they are proportional to the steady aerodynamic forces;
- the operation at critical conditions such as blade resonance or structure resonance; their amplitude varies depending on the passive and active damping properties of the blade;
- the interference with the environment like wind or other equipment;
- the vortex wakes created by the blade profile, so that they are self-induced.

Their amplitude cyclically repeats, for that reason they are also commonly called alternated forces.

These forces originate fatigue phenomena, therefore they are more dangerous for the blade life when compared to the steady forces. Furthermore, they are responsible for the vibration of the structure supporting the fan.

Actually, various solutions acting on the blade attachment to reduce the above described forces, are used to improve the final product design reducing the loads and costs of it.

It is also the aim of the present invention to provide an innovative attachment to the blades of industrial axial fans, suitable to reduce the effects of both the steady and the unsteady loads, and the costs of it.

Connecting elements actually known in the field of the industrial axial fan and used on the market to decrease the steady and/or the unsteady loads generated by the forces acting on the blades during operation, are represented in the attached Figures 2a, 2b, 2c, 2d and 2e, and will be herewith briefly described.

A first connecting element comprises the rigid connection shown on Figures 2a and 2b: a stiff connection part or element is used, having a stiffness in the radial direction higher than that of the profile.

The support of the connecting element on the hub is designed so that the airfoil profile axis is inclined in the vertical plane and has a fixed angle α with respect to the ideal rotation plane. This arrangement as the centrifugal force is opposing the lift, allowing to decrease the steady loads according the above mentioned formula (1), but has no effect on the unsteady loads.

Another connecting element known in the art is the hinged connection shown on Figure 2c: a hinge with horizontal axis is acting as a connection between the profile and the hub. In this case the profile is free to rotate perpendicularly to the fan rotation plane, therefore when the fan is in operation it tends to keep a position where the traction force is balanced by the centrifugal force, minimizing the steady loads.

A further connecting element known in the art comprises a flexible connection comprising one single element, as shown on Figure 2d, where one element connecting the profile to the hub has such a high flexibility that it can bend in the vertical plane without being overstressed, reducing both steady and unsteady loads.

Again, a further connecting element comprises a flexible connection comprising two overlapping elements, as shown on Figure 2e, where two elements connecting the profile to the hub interacting each other will bend in a controlled way, in the vertical plane, without being overstressed. Steady and unsteady loads will be reduced.

A further connecting system known in the art comprises a connecting element as it is shown in Figure 2f. The connecting element has a variable stiffness, an adequate extension and the addition of a weight close to the tip of the blade, so that the blade is forced to vibrate according the second mode therefore reducing both steady and unsteady forces.

It must be underlined that during the operation the steady state forces tend to deform the blade in a shape similar to the first mode of a cantilever beam.

At the same time, the centrifugal force tends to counteract to the blade deformation. Therefore longer is the blade connecting element, larger is the center of gravity displacement, greater is the steady state resulting bending moment reduction.

The effect produced by the centrifugal force is linearly depending on the displacement of the center of gravity, which is more than linearly depending on the length of the blade attachment.

The dynamic response of a blade to the alternated loads is depending on its modal properties.

The fan blade can be schematized as follows: a cantilever beam (the attachment), restrained on one end and with a suspended rigid mass (the profile) on the free end. Without affecting the consideration, assuming the attachment has a constant cross section, the blade natural frequencies are inversely proportional to the square of the attachment length, according to the following equation:

$$\omega_i = \frac{\lambda_i}{2\pi L^2} \sqrt{\frac{EJ}{m}} \quad (2)$$

Where:

ω_i is the i -th natural frequency

L is the attachment length

E is the Young modulus

J is the bending inertia moment

m is the equivalent mass per unit length

Considering the same radial extension for the attachment, the invention presents a longer length due to the camber compared to the systems known in the art, that means, for an identical fan blade, its natural frequencies are remarkably lower.

Considering the blade of the axial fan as a mass-damping-stiffness system and assuming it similar to a multi-degrees-of-freedom (MDoF) system, when the system is dynamically excited with a time dependent forces $f(t)$, the equation of motion is the following:

5

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = f(t) \quad (3)$$

Wherein:

M is the blade mass matrix;

10 C is the damping coefficient matrix;

K is the blade stiffness matrix;

$x(t)$ is the system response vector;

$f(t)$ is the forcing function vector.

The system of coupled differential equations (3) can be transformed from the geometrical coordinate system into a system of N uncoupled differential equations in terms of modal coordinates, through the well-known Modal Analysis Method :

15

$$m_i \ddot{q}_i(t) + c_i \dot{q}_i(t) + k_i q_i(t) = p_i(t) \quad (4)$$

20 Where:

m_i is the i -th modal mass

c_i is the i -th modal damping

k_i is the i -th modal stiffness

$p_i(t)$ is the i -th modal load

25 $q_i(t)$ is the i -th modal coordinate

$i = 1, 2, \dots, N$

Equation (4) can be rewritten in terms of the dynamic variables ω_i which is the system frequency and δ_i which is the modal damping ratio, both defined as follows:

30

$$\omega_i = \sqrt{\frac{k_i}{m_i}} \quad (5)$$

5

$$\delta_i = \frac{c_i}{2m_i\omega_i} \quad (6)$$

The Rayleigh formulation of the modal damping ratio is a good approximation of the non-linear damping, typical for the multi-body assembly:

10

$$c_i = a_0 m_i + a_1 k_i \quad (7)$$

Substituting equation (7) in equation (6) the modal damping can be re written in terms of the natural frequency:

$$\delta_i = \frac{a_0}{2} \frac{1}{\omega_i} + \frac{a_1}{2} \omega_i \quad (8)$$

15

Where a_0 and a_1 are constant depending on the mass and stiffness properties of the system.

The function (8) is showed in figure 10.

20

The blade response in terms of geometrical coordinates can be obtained from the superposition of the displacement related to each single modal contribution.

It is evident that reducing each single modal displacement contribution leads to a reduction of the blade overall response and consequently to a reduction of the load effects on the blade.

25

The single modal contribution is strictly depending on the two main modal parameters listed above: the frequency and the modal damping. As shown in figure 10, lowering the blade frequency cause higher damping that means a reduction in the blade response and, once again, in the loads on the blade.

There is therefore a need in the field for having a connecting element which, for the same radial size and under the same loads, allows to obtain higher displacement

and consequently higher counteracting effect than the blade assemblies of the prior art.

SUMMARY OF THE INVENTION

5 It is therefore the aim of the present invention to provide a connecting element for industrial axial fans, suitable to allow that the blade, when it is subject to unsteady loads, is forced to modify its modal properties: frequencies and deformation shapes. Within this aim, it is an object of the present invention to provide a connecting element for connecting the airfoil profile to the hub of an axial industrial fan suitable
10 to minimize the effects of the unsteady loads on the blade system.

More in details, it is also an object of the present invention to provide a connecting element suitable to reduce the response of the blade to alternated loads in general and resonance condition in particular.

Another object of the present invention is to provide a connecting element which
15 allows to minimize the natural frequencies of the system with respect the systems known in the art; for the first modes, the associated modal damping are higher than for the prior art solutions and for the higher modes, the associated damping is lower. In order to achieve this aim and these and other objects that will become more clear from the following detailed description of a preferred embodiment that is merely
20 illustrative and not limitative of the present invention, the present invention provides a connecting element which has a rectangular cross section and an "L" shaped longitudinal section, being the short side of "L" connected to the hub and the long side to the profile, with a typical ratio between the two sides of 0.1.

The natural frequencies of a blade system comprising a connecting element
25 according to the present invention are lower than the ones of the known systems; for the first modes, the associated modal damping are higher than for the prior art solutions and for the higher modes, the associated damping is lower. Due to the distribution of the exciting forces, only the first three modes give significant contribution to the blade response; therefore the response of the blade to the cyclic
30 loads is strongly attenuated. In addition the exciting cyclic loads have a spatial (radial) distribution which amplitude is time-dependent as per the following formula:

$$f(x, t) = g(x) \cdot h(t) \quad (9)$$

Where:

$g(x)$ is a function only of the radial position

$h(t)$ is a periodic function

5

This means that after half of the period, the forcing function has exactly the same amplitude but with opposite sign. The deformed shape of the system has not the same symmetry, because the restraint is not symmetric as better shown in the figures 3a and 3b. As a first main consequence of this particular deforming way, the blade response is more damped. As a second consequence, the natural frequency

10

of the blade is not constant, therefore there is not an actual resonance condition. Therefore, with respect to a blade system of prior art which generally cannot operate in a large range of speed around the critical one due to the intensification of the response, for the blade system of the present invention comprising a connecting

15

element according to the present invention, which system is also part of the present invention, this range of speed is drastically reduced and in many cases there will be no limitation in the operating speed range.

20

BRIEF DESCRIPTION OF THE DRAWINGS

Further characteristics and advantages of the present invention will become clear from the following detailed description of a preferred embodiment that is merely illustrative and not limitative and is shown in the figures that are attached hereto, in which:

25

Figures 1a, 1b, 2a, 2b, 2c, 2d, 2e, 2f show different examples of blade assemblies for axial fans according to the prior art;

Figures 3a and 3b show the two deformed conditions of the blade system comprising the connecting element according to the present invention;

30

Figures 4a and 4b show the forces acting on a blade system comprising a connecting element according to the present invention;

Figure 5 represents a lateral view of a blade connected to an hub by means of a connecting element according to the present invention;

Figure 6 shows a top view of a connecting element according to one embodiment of the present invention;

5 Figure 7 shows a perspective view of the connecting element of Figure 6 after the bending;

Figure 8 shows a connecting element according to the present invention according to a second embodiment, obtained by transversal extrusion or pulltrusion;

10 Figure 9 shows a lateral view of the connecting element of Figure 8, in which can be appreciated the variable transversal section obtained by extrusion or pulltrusion and the thickening in the most critical area;

Figure 10 represents a diagram showing the modal damping as a function of the natural frequency of a blade assembly;

15 Figures 11a and 11b represent different possible arrangements of the connecting element according to the present invention turned up and, respectively, turned down;

Figure 12 shows an example of an installation of an industrial axial fan comprising a blade assembly comprising a connecting element according to the present invention;

20 Figure 13 shows a connecting element according to the present invention bolted to an hub.

Figure 14 shows a connecting element according to the present invention according to a third embodiment, in which the angle between the two parts of the connecting element realizes the blade precone angle;

25 Figures 15 and 16 show a connecting element according to the present invention according to a third embodiment, in which the precone angle is obtained in different but easy ways.

DETAILED DESCRIPTION OF THE INVENTION

30 With reference to the above mentioned Figures, the main task of the present invention is to provide a connecting element for connecting the airfoil profile to the hub of an industrial axial fan.

With reference to the above, the present invention concerns a connecting element **1** consisting of an extremely simple element, see for example Figures 5 to 7, having essentially a rectangular cross-section and a "L" shaped longitudinal-section comprising a first part **1a** having a substantially straight develop and a second part **1b** having a straight develop, said first **1a** and second **1b** part being connected by a linking part **1c** presenting a curvature radius so that said first **1a** and second **1b** parts lie on substantially perpendicular planes.

Said first part **1a** of the L-shaped profile, which is the shorter part, is apt to be connected to the hub **20** while said second part **1b**, which is the longer part, is apt to be connected to the airfoil profile **10**, said link part **1c** connecting said short part **1a** to said long part **1b**.

The blade system **100** comprising the connecting element **1** according to the present invention, is also part of the invention.

The blade system **100** for industrial axial fans is characterized by the fact that the blade, subject to unsteady loads, is forced to modify its modal properties: frequencies and deformation shapes, as described above.

The inventors have carried out functional tests to compare the blade system **100** of the present invention, comprising the connecting element **1** according to the invention, to the prior art systems. The results confirm that with the connecting element **1** of the present invention the natural frequencies of the system are 20% lower than in the prior art, the damping ratios of the first three vibration modes are respectively 24%, 15% and 3% higher than the same damping ratios of a blade system according to the prior art, only the fourth mode has 4% of lower damping.

Considering a blade system typical loading condition, the relative participation factor of the first four modes are respectively 0.43, 0.24, 0.14 and 0.09; therefore the response of the blade to that system of loads is completely described by the superposition of the response of these four modes.

Due to the differences in the damping ratio, the blade system **100** of the present invention, comprising the innovative connecting element **1**, has a maximum response 22% reduced with respect to the response of a blade system of the prior art. Considering that the loads on the blade are proportional to its response, the invention involves a significant reduction in loads acting on the blade.

Additionally, the connecting element **1** according to the present invention has the further, very important characteristic to be non-symmetrical.

The influence of these factors on the behavior of the system is explained here below with reference to Figures 3a and 3b.

- 5 During the operation the steady state forces (weight **W**, and lift force **L**) tend to deform the blade **10** in a shape similar to the first vibration mode of a cantilever beam.

At the same time, the centrifugal force **C** tends to counteract to the blade deformation.

- 10 The effect produced by the centrifugal force **C** is linearly depending on the displacement of the center of gravity, which is more than linearly depending on the length of the blade attachment.

For the same radial size and under the same loads, the blade system of the present invention comprising a connecting element which has a longer length with respect
15 to the connecting elements of the prior art, can provide higher displacement of the blade and, consequently, higher counteracting effect than the blade known in the art.

As it is evident from Figures 5 to 7 the structure and the profile of the connecting element **1** according to the present invention is very simple to be manufactured.

- 20 Still preserving its peculiar features, the connecting element **1** may be realized by means of several different methods, allowing to reach very low production costs when compared with those of the connecting elements currently available on the market.

Further advantages reached by the blade system of the present invention thanks to
25 the connecting element of the invention, are the following:

- the connecting element **1** may be obtained by a simple manufacturing process comprising a first cutting phase and a second drilling phase, starting from a sheet of aluminum, steel or other proper material according to the required shape, and a final bending phase (reference is to Figures from 5 to 7);
- 30 - the connecting element **1** may be obtained by a manufacturing process comprising a first cutting phase and a second drilling phase, starting from a semi finished product obtained by extrusion or pulltrusion (reference is to Figures 8 and 9);

It will be appreciated that such extrusion allows to easily realize different shapes, which can obtain further important advantages: for example a larger thickness may be provided when higher stresses are foreseen, i.e. in the hub-connection zone (reference is to Figure 9);

- 5 - the connecting element **1** may be obtained by a manufacturing process comprising a first cutting phase and a second drilling phase, starting from a pulltruded or molded element made of plastic or fiberglass material;
- the connecting element **1** may be obtained by a manufacturing process comprising a first cutting phase and a second drilling phase, starting from a simple “ L” shape
10 profile.

The L-shaped connecting element according to the present invention may be eventually combined with a prior art system to increase its effects.

- Another advantage obtained by the connecting element of the present invention consists in its unsymmetrical shape: thanks to the L-shaped unsymmetrical profile,
15 the connecting element **1** can be assembled with the linking part **1c** turned either up or down (fig. 5a and 5b): the unsymmetrical shape of the connecting element allows to raise or lower the blade rotation plane according the installation needs (reference is to Figure 12).

- Of course the connecting element can be fixed to the hub **20** with one or more bolts
20 depending on the operation duty (reference is to Figure 13).

CLAIMS

1. Connecting element (1) for connecting a blade (10) to the hub (20) of an industrial axial fan, said connecting element (1) being realized in a single L-shaped piece comprising a first part (1a) having a substantially straight develop and a second part (1b) having a substantially straight develop, said
5 first (1a) and second (1b) part being connected by a linking part (1c) presenting a curvature radius, said first (1a) and second (1b) parts lying on substantially perpendicular planes.
2. Connecting element (1) according to claim 1, characterized in that said first
10 part (1a) and said second part (1b) lie on planes inclined of an angle which realizes directly on the connecting element instead of on the hub the blade precone angle.
3. Connecting element (1) according to claim 1, characterized in that said first part (1a) is shorter than said second part (1b).
- 15 4. Connecting element (1) according to claim 1, characterized in that it has a quadrangular cross-section.
5. Connecting element (1) according to claim 1, characterized in that it has a rectangular cross-section.
6. Connecting element (1) according to one or more of the preceding claims,
20 characterized in that it is made of metallic material.
7. Connecting element (1) according to one or more of the claims, characterized in that it is made of plastic material.
8. Connecting element (1) according to one or more of claims, characterized in that it is made of fiber glass material.
- 25 9. Connecting element (1) according to one or more of the preceding claims, characterized in that it is obtained by a manufacturing process comprising the following steps:
 - providing a sheet of metallic, plastic or fiberglass material;
 - cutting and drilling said metallic sheet;
 - 30 - bending the cut and drilled sheet obtaining the final L-shaped piece.

10. Connecting element (1) according to one or more of the claims, characterized in that it is obtained by a manufacturing process comprising the following steps:

- providing a semi finished product obtained by extrusion or pulltrusion;
- cutting and drilling said semi finished product;
- bending the cut and drilled semi finished product.

11. Blade assembly (100) of an industrial axial fan comprising:

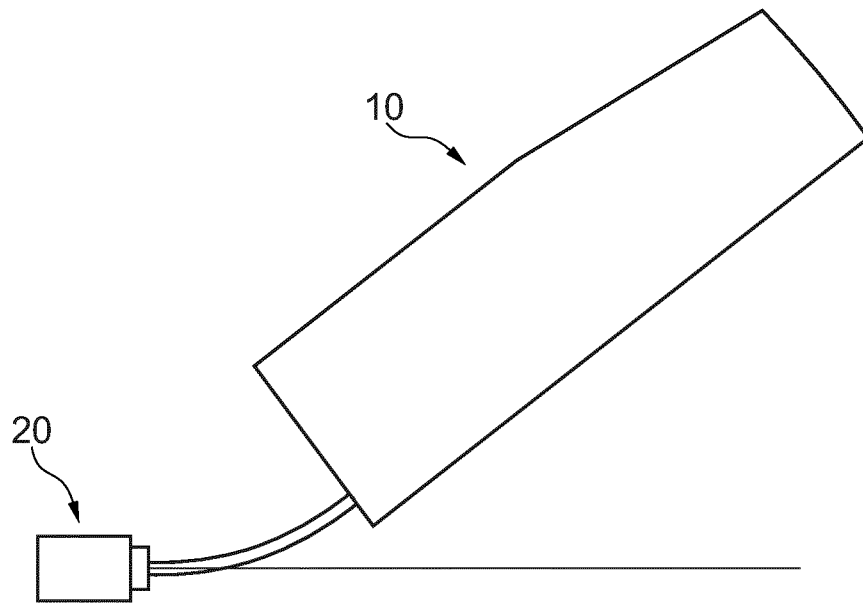
- a blade (10),
- a hub (20),
- a connecting element (1),

characterized in that said connecting element (1) is realized in a single L-shaped piece comprising a first, shorter, part (1a) having a straight develop and a second part (1b) having a substantially straight develop, said first (1a) and second (1b) part being connected by a linking part (1c) presenting a curvature radius, said first (1a) and second (1b) parts lying on perpendicular planes.

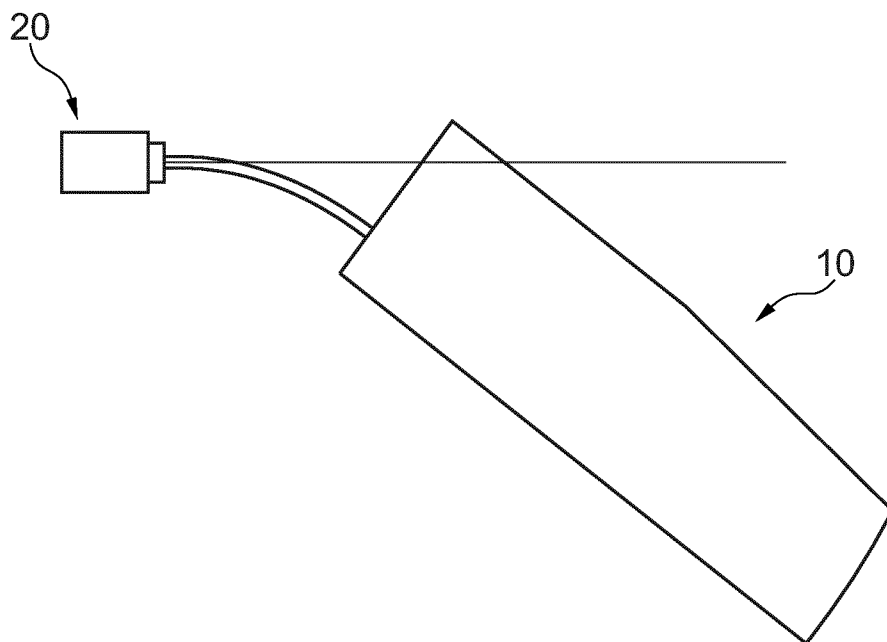
12. Blade assembly (100) according to claim 11, characterized in that said first (1a) and second (1b) part being connected by a linking part (1c) presenting a curvature radius, said first (1a) and second (1b) parts lying on planes inclined of an angle which realizes directly on the connecting element instead of on the hub the blade precone angle.

13. Blade assembly (100) according to claim 11, characterized in that said first part (1a) is shorter than said second part (1b), and in that said first part (1a) of said connecting element (1) is connected to the hub (20) and said second part (1b) of said connecting element (1) is connected to the blade (10).

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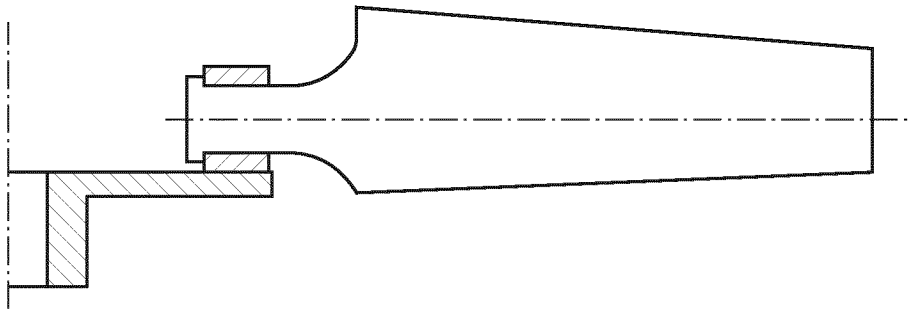


PRIOR-ART
Fig. 1a

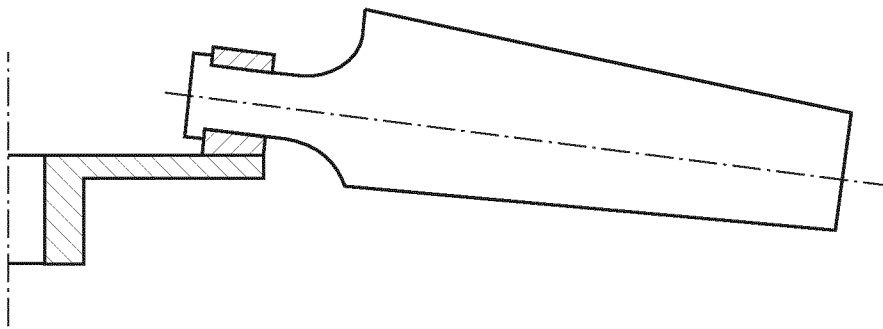


PRIOR-ART
Fig. 1b

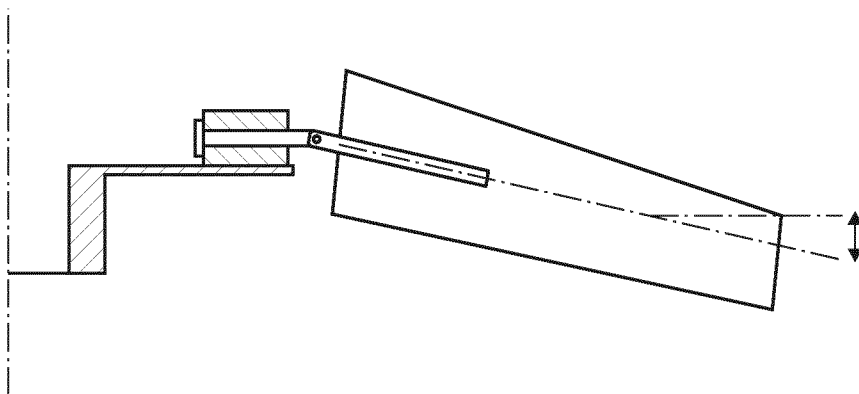
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PRIOR-ART
Fig. 2a

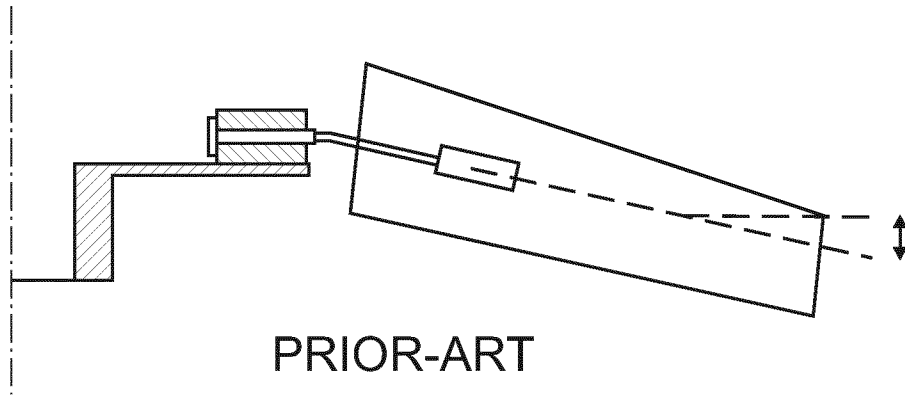


PRIOR-ART
Fig. 2b



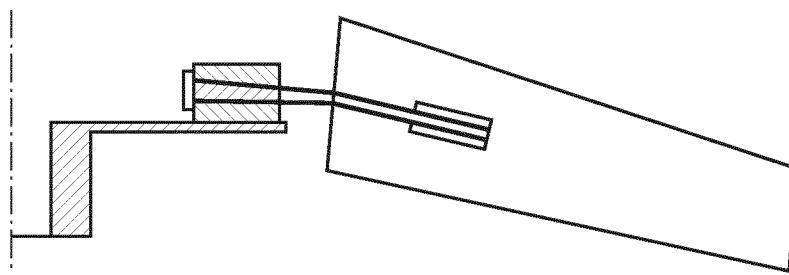
PRIOR-ART
Fig. 2c

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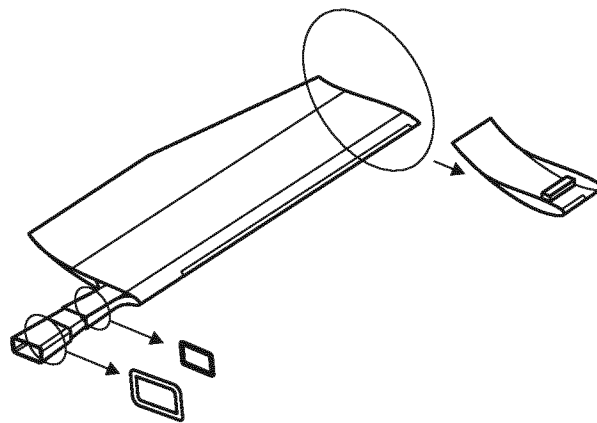
PRIOR-ART

Fig. 2d



PRIOR-ART

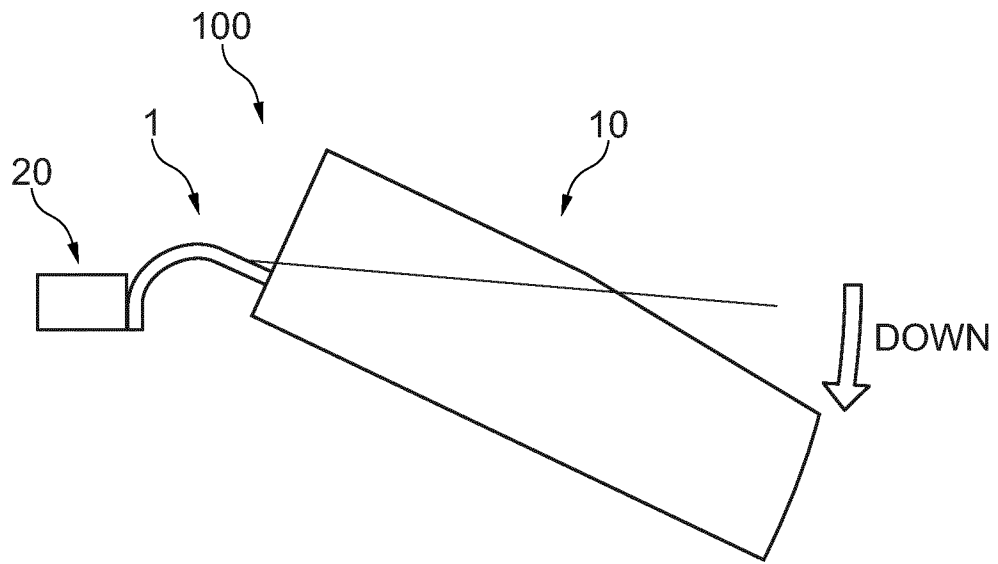
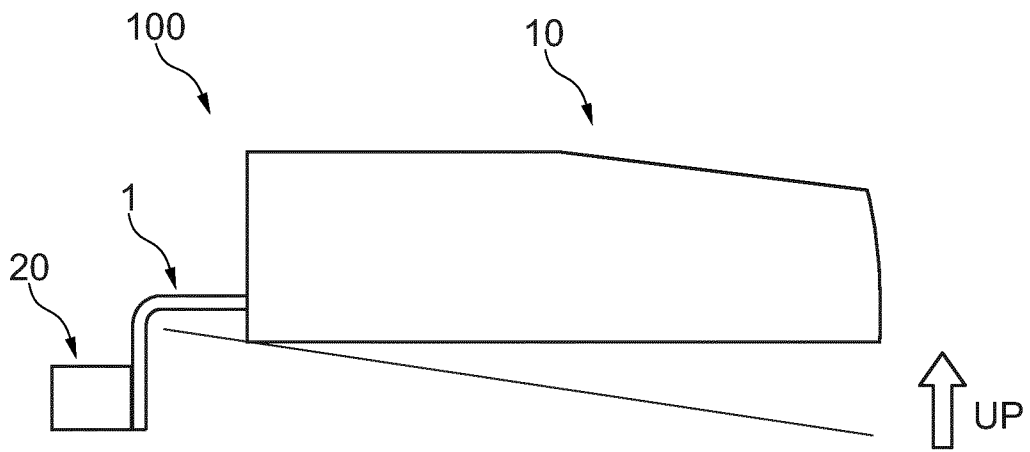
Fig. 2e



PRIOR-ART

Fig. 2f

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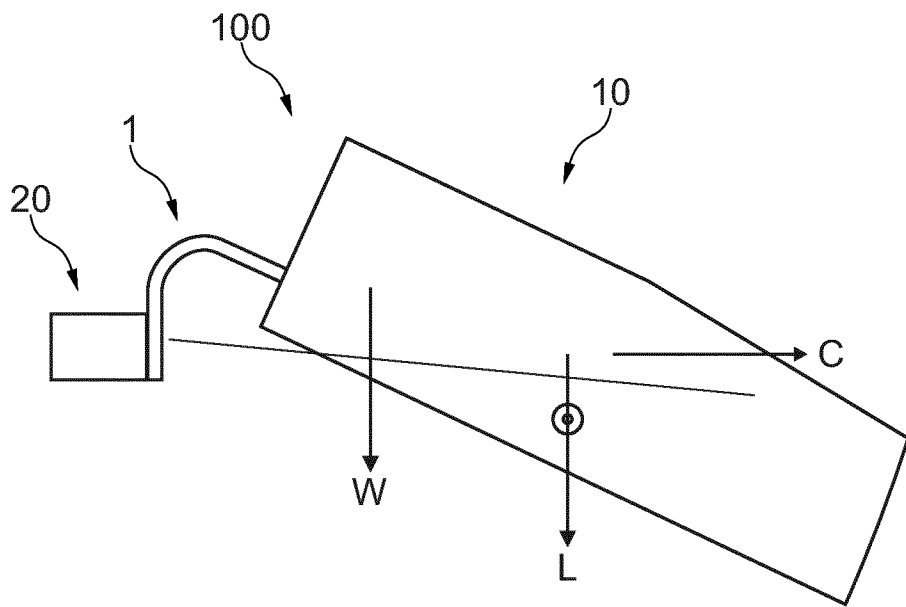


Fig. 4a

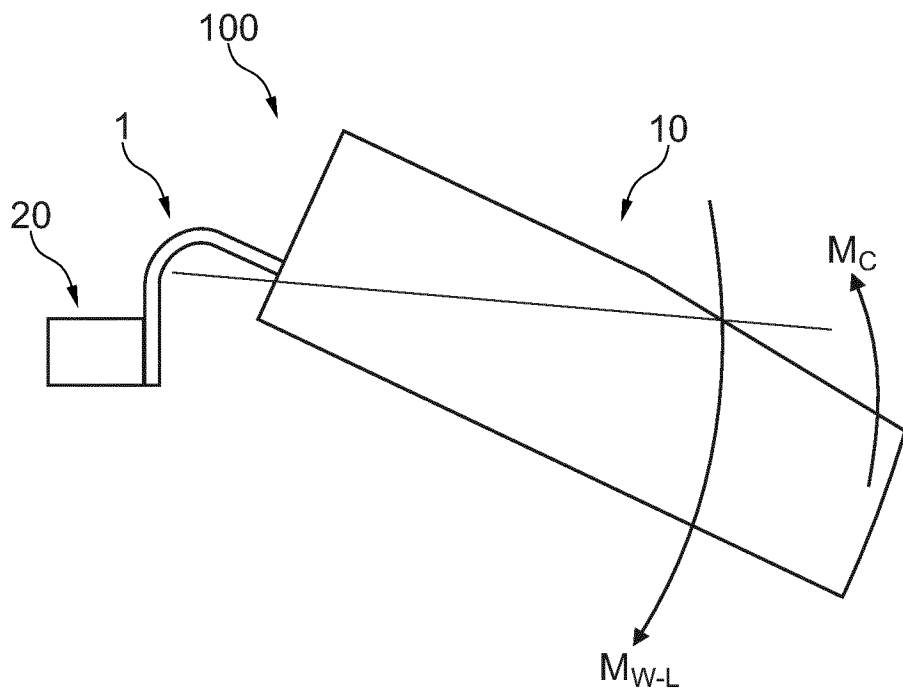


Fig. 4b

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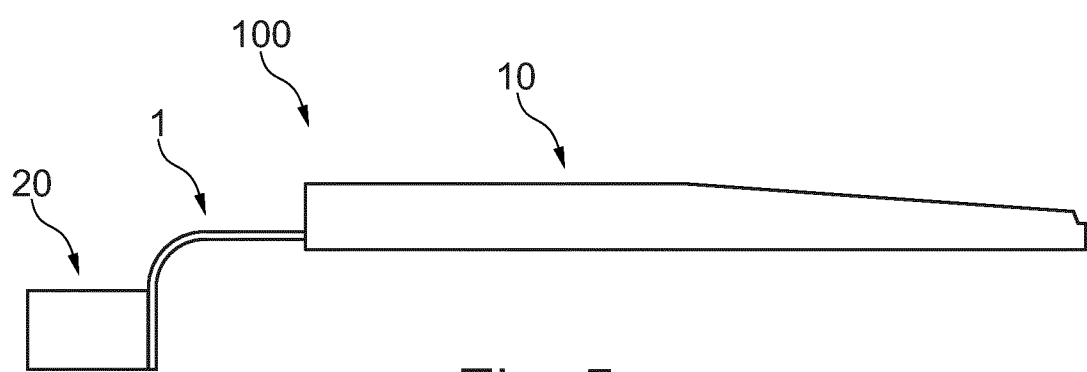


Fig. 5

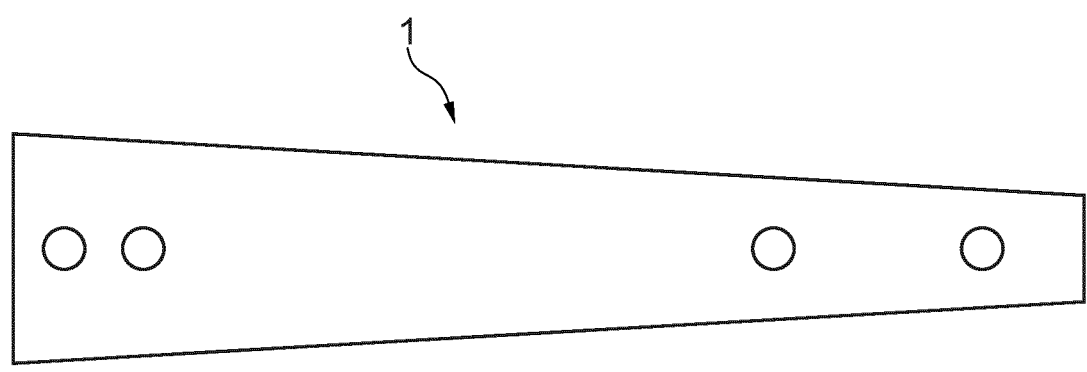


Fig. 6

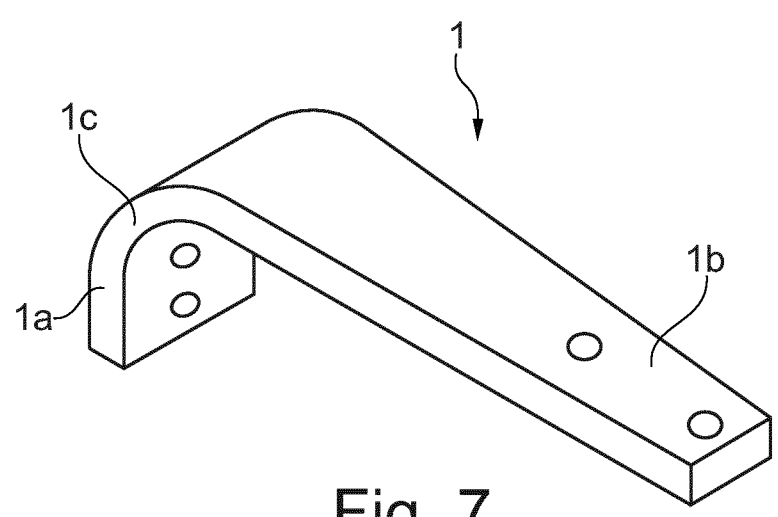


Fig. 7

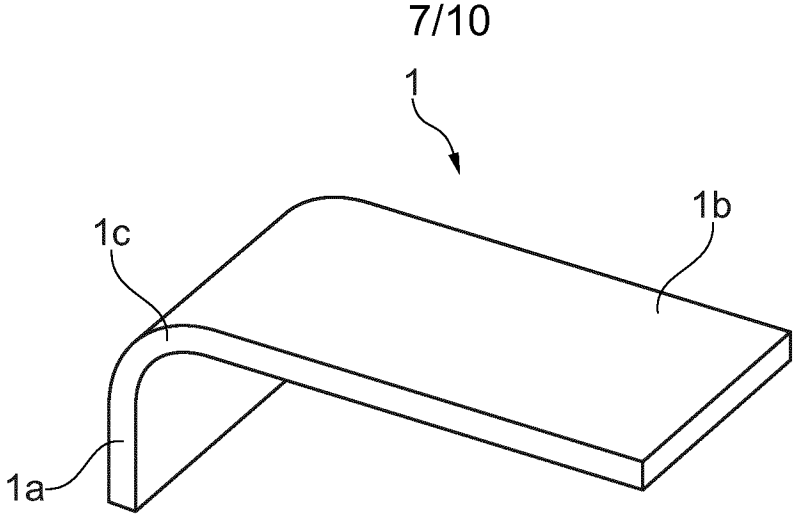


Fig. 8

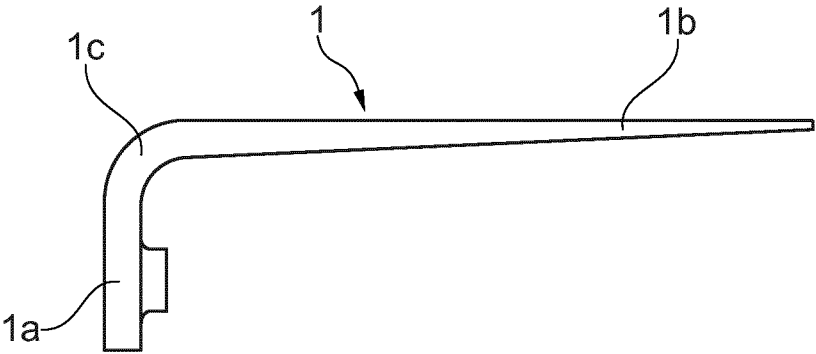


Fig. 9

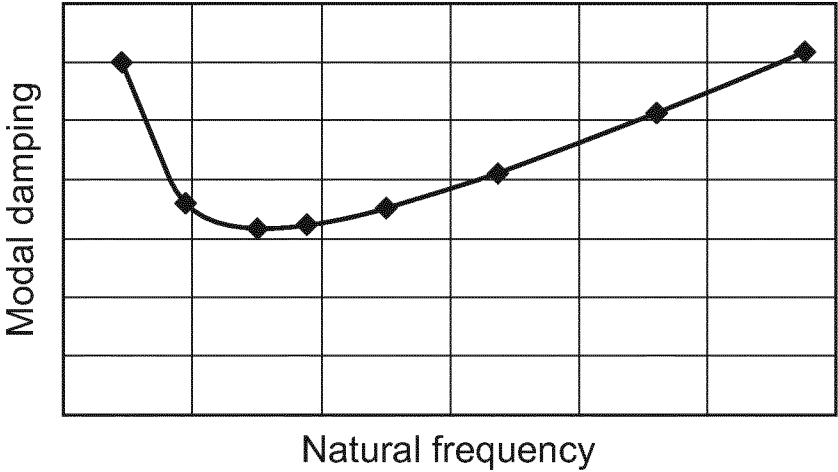


Fig. 10

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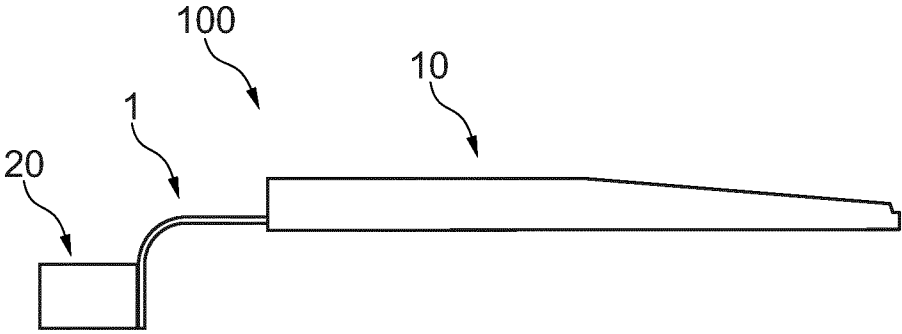


Fig. 11a

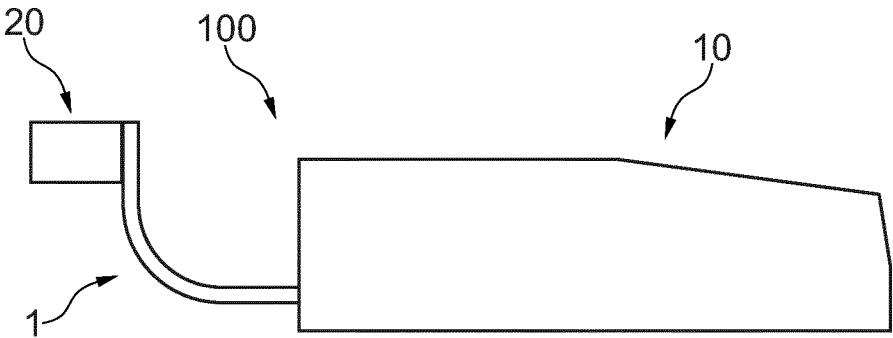


Fig. 11b

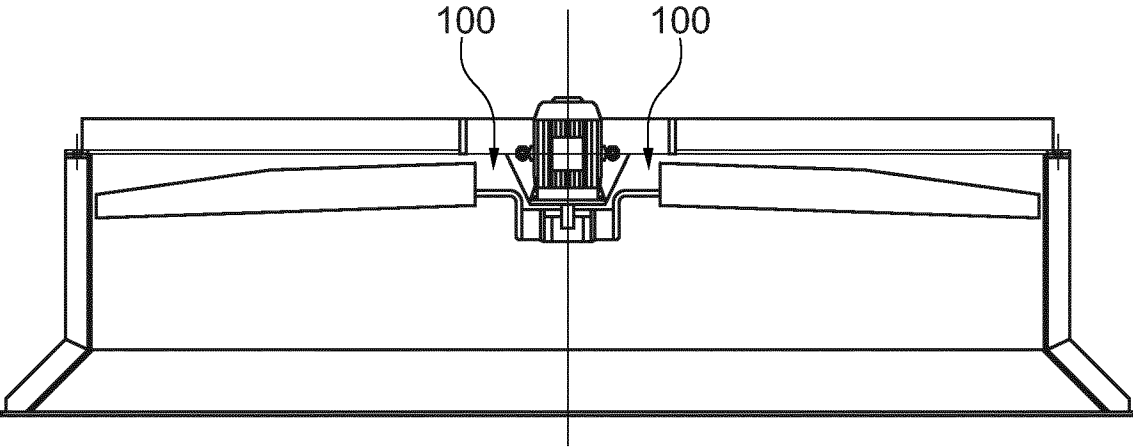


Fig. 12

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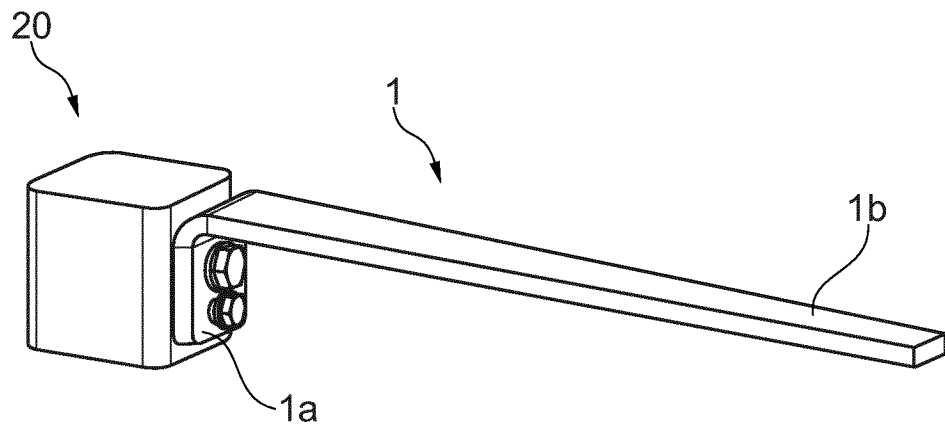


Fig. 13

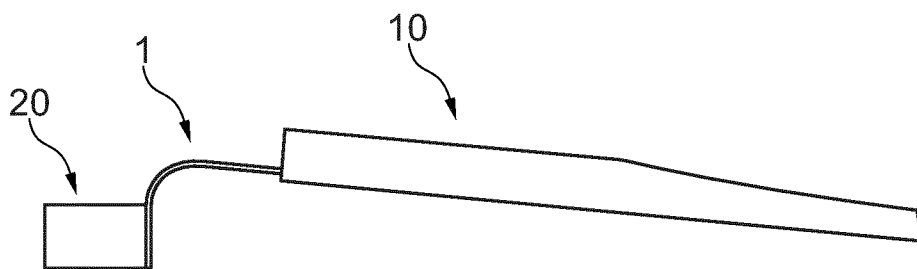


Fig. 14

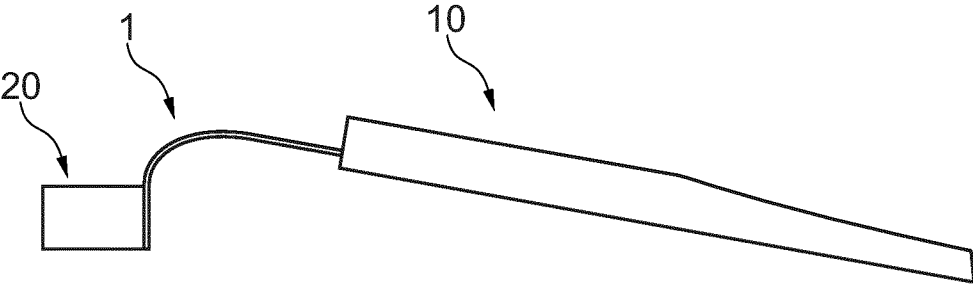


Fig. 15

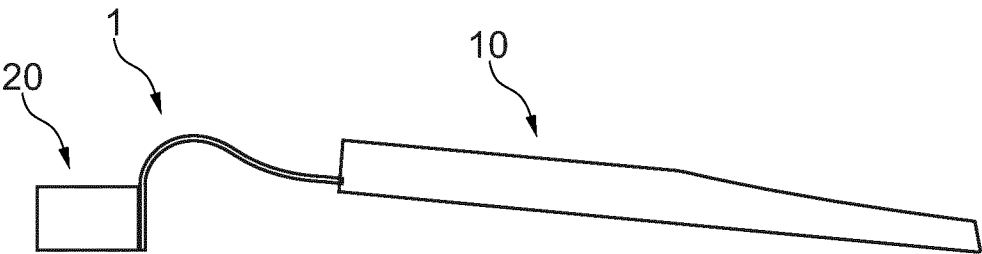


Fig. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/074027

A. CLASSIFICATION OF SUBJECT MATTER

INV. F04D19/00 F04D29/34 F04D29/66
ADD. F04D29/64

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04D

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2008 248700 A (KOBE STEEL LTD) 16 October 2008 (2008-10-16) abstract figures 2, 3 paragraph [0032]	1-13
X	US 6 010 308 A (YOUN FANG-CHAN [TW]) 4 January 2000 (2000-01-04) figure 3 column 2, lines 8-22	1-13
X	JP S54 135709 U (-) 20 September 1979 (1979-09-20) figures 1, 2	1-13
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Date of the actual completion of the international search

24 June 2016

Date of mailing of the international search report

01/07/2016

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de Verbigier, L

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/074027

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 979 949 A1 (WU SAN CHI [TW]) 16 February 2000 (2000-02-16) paragraph [0002] figure 1	1-13
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/074027

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