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(54) ROTOR FOR A HOVER-CAPABLE AIRCRAFT AND METHOD FOR CONTAINMENT OF VIBRATIONS TRANSMITTED TO THE MAST OF A ROTOR OF A HOVER-CAPABLE AIRCRAFT

ROTOR FÜR EIN SCHWEBEFÄHIGES FLUGZEUG UND VERFAHREN ZUR REDUZIERUNG VON VIBRATIONEN AUF DEN MAST EINES SOLCHEN ROTORS

ROTOR POUR UN AÉRONEF CAPABLE DE VOLER EN VOL STATIONNAIRE ET SON PROCÉDÉ POUR RÉDUIRE LES VIBRATIONS TRANSMIS AU MÂT ROTOR D’UN TEL AÉRONEF

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(56) References cited:
WO-A1-2017/145073
US-A- 4 596 513
US-A- 5 647 726
US-A1- 2010 296 930
US-A1- 2010 296 931
US-A1- 2011 268 573

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Description

[0001] The present invention relates to a rotor for a hover-capable aircraft, in particular to a rotor for a helicopter.

[0002] The present invention also relates to a method for the containment of vibrations transmitted to the mast of a rotor of a hover-capable aircraft.

[0003] Helicopters are known to basically comprise a fuselage, a main rotor positioned on the top of the fuselage and rotatable about its own axis, and a tail rotor located at the end of the fuselage.

[0004] In greater detail, the rotor, in turn, basically comprises a hub rotatable about the aforementioned axis and equipped with a plurality of blades radially fastened to and projecting from the aforesaid hub in a cantilevered fashion, and a mast that can be connected to a drive member and operatively connected to the hub to drive it in rotation.

[0005] In use, operation of the rotor causes the creation of high and low frequency vibrations. More specifically, low-frequency vibrations are generated by the wash separating from the blades and from the centre of the hub. This separation takes place at the centre of the hub and affects all the vertical and horizontal aerodynamic surfaces of the tail and the tail rotor.

[0006] In use, rotation of the blades at high angular speeds causes, the generation of further high-frequency vibrations, which are transmitted to the mast and, in consequence, to the fuselage, deteriorating comfort for the occupants inside the fuselage.

[0007] More specifically, the vibratory loads act on both the hub and the mast, both axially and orthogonally to the mast's axis of rotation.

[0008] Within the industry, it is known that the vibratory loads acting of the rotor have pulse rates of $N^*\Omega$ and relative multiples thereof in the reference system integral with the fuselage, where Ω is the rotation speed of the mast and N represents the number of blades of the rotor.

[0009] In other words, the hub and the mast transfer pulses of the vibratory aerodynamic load acting in the plane of the blades onto the aforesaid pulses.

[0010] From the foregoing, there is a clearly felt need within the industry for limiting transmission from the mast to the fuselage of vibrations with the aforementioned pulse rate of $N^*\Omega$ and relative multiples thereof.

[0011] For this purpose, there are known passive and active damping devices.

[0012] Passive damping devices basically comprise masses elastically suspended from the mast or the hub. The vibration of these suspended masses enables at least partially dissipating vibration on the mast and the hub.

[0013] Passive damping devices are normally tuned to a predetermined frequency value for which it desired to contain transmission to the mast.

[0014] Contrarily, active damping devices are fundamentally actuators that exert a sinusoidal damping force on the hub or on the mast, which counters the force generated by the vibrations.

[0015] An example of a passive damping device is illustrated in patent application PCTIB2008001594.

[0016] This patent application describes a damping device capable of curbing the generation and transmission of these vibrations to the mast of the rotor in a simple and inexpensive manner, without interfering with the aerodynamics and functioning of the rotor and/or the flow conveyor.

[0017] More specifically, the aforementioned damping device basically comprises:

- a mass housed inside the flow conveyor; and
- a rod, which is coaxially supported by the mast at its first axial end and is connected to the mass at its second axial end opposite to the first end.

[0018] More specifically, the axial stiffness of the rod is sufficiently high to constrain the mass in a substantially fixed position along the axis of the rotor.

[0019] Contrarily, the flexural stiffness of the rod is such as to allow vibration of the mass in a plane orthogonal to the axis of the rotor and with a frequency corresponding to $N^*\Omega$ pulses and, therefore, such as to oppose the transmission of flexural vibrations generated by rotation of the hub and the blades to the mast.

[0020] If follows that the above-described damping device is only able to effectively counter the transmission of flexural vibrations to the mast in a plane substantially orthogonal to the axis of the rotor, the frequency of these vibrations being in the neighbourhood of a precise value determined by the flexural stiffness of the rod and the weight of the mass.

[0021] There is a clearly felt need within the industry to also efficiently counter the transmission of axial vibrations to the mast, i.e. those parallel to the axis of the mast. There is similarly felt need to have particularly compact and space-saving damping devices, in order to interfere with the layout of the rotor and mast as little as possible.

[0022] Finally, the damping devices are normally tuned to a nominal pulse rate of $N^*\Omega$ before being installed inside the helicopter's rotor.

[0023] The effective value of the $N^*\Omega$ pulses registered during effective operation of the rotor can be slightly different from this nominal value.

[0024] The need is therefore felt to be able to further adjust the tuning frequency of the damping devices to the actual pulse rate of the vibrations transmitted to the mast, once the damping device has been installed on the helicopter.

[0025] US-A-2010/296930, US-A-2011/268573, US-A-5647726, US-A-4596513 and US-A-2010/296931 disclose a rotor for a hover-capable aircraft according to the preamble of claim 1 and a method for the containment of vibrations transmitted to a mast of a rotor of an aircraft according to the preamble of claim 10.

[0026] The object of the present invention is to produce a rotor for an aircraft capable of hovering that enables satisfying at least one of the above-specified needs in a simple and inexpensive manner.

[0027] The aforesaid object is achieved by the present invention, in so far as it relates to a rotor for a hover-capable aircraft according to claim 1.

[0028] The present invention also relates to a method for the containment of vibrations transmitted to a mast of a rotor of an aircraft according to claim 10.

[0029] For a better understanding of the present invention, a preferred embodiment is described hereinafter, purely by way of a non-limitative example and with reference to the accompanying drawings, in which:

- Figure 1 is a side view of a helicopter comprising a rotor according to the present invention;
- Figure 2 shows a perspective view, on a highly enlarged scale, of a damping device housed in the rotor in Figure 1;
- Figure 3 shows an axial section of the rotor in Figure 2, with parts removed for clarity;
- Figure 4 is a top view of the damping device in Figures 2 and 3; and
- Figure 5 shows a perspective view, on a highly enlarged scale, of a detail of the damping device in Figures 2 to 4. Referring to Figure 1, reference numeral 1 indicates a hover-capable aircraft, in particular a helicopter basically comprising a fuselage 2, a main rotor 3 positioned on the top of the fuselage 2 and rotating about an axis A, and a tail rotor 4 located at one end of the fuselage 2 and rotating about its own axis, transversal to axis A.

[0030] In greater detail, the rotor 3 comprises (Figure 2) a hollow hub 5, with axis A, carrying a plurality of cantilever-mounted blades 9, which extend radially to axis A.

[0031] The rotor 3 also comprises a mast 6, rotatable about axis A, angularly integral with the hub 5, and coupled, in a manner not shown, with a drive member, for example a turbine, carried by the helicopter 1. In particular, the mast 6 is hollow.

[0032] More specifically (Figure 3), the mast 6 is partly housed inside the hub 5 and is angularly integral with the hub 5 by means of a splined profile and a pair of wedges radially interposed between the mast 6 and the hub 5. In particular, the splined profile is axially interposed between the aforesaid wedges.

[0033] The main rotor 3 also comprises a flow conveyor 10 designed to guide the airflow generated by the rotation of the rotor 3 according to a predetermined path shaped so as to limit the vibrations generated by separation of the aforesaid flow from the tips of the blades 9 located on the opposite end to the hub 5.

[0034] In greater detail, the flow conveyor 10 is annular, extends around axis A and is located on the opposite side of the hub 5 with respect to the fuselage 2.

[0035] The flow conveyor 10 has a "hat-like" shape and is delimited by a pair of surfaces 11 and 12 axially facing each other; more specifically, surface 11 axially delimits the flow conveyor 10 on the opposite side to the hub 5, while surface 12 axially delimits the flow conveyor 10 on the side closest to the hub 5.

[0036] Surface 11 is continuous and extends, proceeding in a radial direction starting from axis A, at an axially decreasing distance from the hub 5.

[0037] Surface 12 has a first circular peripheral edge 13 and a second peripheral edge (not shown in Figure 3), opposite to edge 13 and arranged radially outermost to peripheral edge 13. Furthermore, the second peripheral edge of surface 12 axially faces a peripheral edge of surface 11.

[0038] Surfaces 11 and 12 are shaped in such a way that that their axial distance decreases when proceeding in a radial direction starting from axis A.

[0039] More specifically, surface 12, when proceeding from edge 13 towards the second edge, first moves away from the hub 5 and then moves closer to the hub 5.

[0040] Surfaces 11 and 12 are connected to each other by a truncated cone-shaped tubular body 14, symmetrical with respect to axis A and having a lateral surface 8 extending between surfaces 11 and 12.

[0041] The rotor 3 further comprises a vibration-damping device 15. In particular, the device 15 is of the passive type and enables containing transmission to the mast 6 of both flexural vibrations in a plane orthogonal to axis A and axial vibrations along axis A, as shall become clear hereinafter in this description.

[0042] The device 15 basically comprises:

- a mass 17 operatively connected to the hub 5 and the mast 6 so as to counter the transmission of vibrations generated by the rotation of the blades 9; and
- an elastically deformable rod 16.

[0043] The rod 16 is supported by the mast 6 and connected to the mass 17, extending at least partly inside the mast 6, and stretching parallel to axis A.

[0044] More specifically, the flexural stiffness of the rod 16 in a plane orthogonal to axis A and the size of the mass 17 are such that the mass 17 vibrates, in use, with a predetermined frequency value, which is associated with the characteristic pulsation of the vibrations generated by rotation of the rotor 3 in the reference system integral with the fuselage 2. This value corresponds to a pulse rate of $N^*\Omega$, where Ω is the rotation speed of the mast and N represents the number of blades of the rotor 3.

[0045] In other words, the rod 16 and the mass 17 form a first flexural tuned mass damper, tuned to the frequency of the vibrations generated by the rotor 3 and exerting a force on the mast 6 such as to counter the transmission of the aforementioned vibrations to the mast 6 and, therefore, to the helicopter 1.

[0046] It is important to stress that the rod 16 is configured so as to have high axial stiffness, such that it can be considered as not causing any axial movement of the mass 17.

[0047] The rotor 3 also comprises a cup-shaped body 20, with axis A, and angularly integral with the mast 6 and the rod 16 so as to connect the mast 6 and the rod 16 to each other.

[0048] More specifically, the cup-shaped body 20 has a tubular form, extending symmetrically about axis A and is radially external to the rod 16.

[0049] The cup-shaped body 20 comprises a main portion 22 encircled by the mast 6 and stretching parallel to axis A, and an annular head surface 21 lying on plane orthogonal to axis A.

[0050] The main portion 22 defines, on the end opposite to the head surface 21, a seat 23 engaged by an axial end 18 of the rod 16.

[0051] The rod 16 passes through the head surface 21, which is axially fastened, by means of a plurality of screws, onto a threaded ring nut 29 coupled to the mast 6.

[0052] The head surface 21 defines an axial end of the cup-shaped body 20 facing towards the flow conveyor 10, while the seat 23 is located at an axial end of the cup-shaped body 20 arranged at the opposite end to the head surface 21.

[0053] A threaded tie rod orthogonal to axis A also passes through the seat 23 and end 18.

[0054] Preferably, the cup-shaped body 20 is made of light alloy.

[0055] The rod 16 comprises a threaded end 19, opposite to end 18, and on which a nut 25 is screwed.

[0056] Finally, the rod 16 comprises an intermediate section between the ends 18 and 19, tapered from end 18 towards end 19, and passing through the head surface 21.

[0057] End 18 of the rod 16 is housed inside the mast 6.

[0058] Moreover, the rod 16 is completely housed inside the cylinder defined by the prolongation of the mast 6 towards the flow conveyor 10.

[0059] The mass 17 is housed inside the flow conveyor 10. In particular, the mass 17 is housed inside a bay 24 radially delimited by surface 8, axially open towards the hub 5, and axially closed on the opposite side to the hub 5 by the portion of surface 11 bounded by surface 8.

[0060] Advantageously, the device 15 comprises a plurality of springs 30 (Figures 2 to 5) operatively connected to the mass 17 and having a desired stiffness along axis A, so as to contain the transmission of axial vibrations to the mast 6.

[0061] In other words, the masses 17 and the springs 30 form a second tuned mass damper that oscillates along axis A, reducing the axial vibrations of the mast 6.

[0062] Preferably, the tuning frequency of the second mass damper, formed by the mass 17 and the springs 30, is equal to that of the first mass damper, formed by the rod 16 and the mass 17, and corresponds to a pulse rate of $N^*\Omega$.

[0063] More specifically, the springs 30 are interposed between the rod 16 and the mass 17.

[0064] With particular reference to Figure 5, each spring 30 is shaped in a serpentine.

[0065] In turn, each spring 30 comprises:

- a plurality of sections 31 with a mainly radial extension; and
- a plurality of sections 32 with a mainly axial extension, which are interposed between two mutually consecutive sections 31.

In the case shown, sections 31 are flat and sections 32 are curved so as to join two mutually consecutive sections 31.

[0066] In addition, the radial space occupied by sections 31 is greater than the axial space occupied by sections 32.

[0067] Furthermore, each spring 30 is constrained to the mass 17 and the rod 16 at its radially free ends 33 of respective sections 31 defining opposite axial ends of the spring 30.

[0068] The shaping and method of constraining the springs 30 are such that they can be considered elastically deformable along axis A and having substantially infinite stiffness in the plane orthogonal to axis A, so that the springs 30 effectively do not cause any vibration of the mass 17 in the plane orthogonal to axis A.

[0069] Referring to Figures 2 and 4, the mass 17 is shaped like a hollow cylinder, internally housing axial end 19 of the rod 16 and the springs 30.

[0070] More specifically, the mass 17 houses a first and a second set 34 and 35 of springs 30.

[0071] Each set 34 and 35 is formed by a plurality of springs 30, five in the case shown, angularly equi-spaced around axis A.

[0072] In particular, the number of springs 30 of each set 34 and 35 corresponds to the number of blades 9 of the rotor 3.

[0073] The sets 34 and 35 are axially superimposed on one another so that the springs 30 of set 34 are arranged in correspondence to the respective springs 30 of set 35.

[0074] The rod 16 also comprises a hub 40 located at end 19 and to which the springs 30 are connected.

[0075] The hub 40 connects the rod 16 and the mass 17 via the springs 30 in an elastically deformable manner in the direction parallel to axis A.

[0076] With particular reference to Figure 3, the hub 40 comprises:

- a pair of elements 41 axially opposite to each other and to which the radially inner ends of the springs 30 of the sets 34 and 35, respectively, are fixed; and
- an element 42, which is axially interposed between elements 41.

In particular, the mass 17 is made of tungsten.
In the case shown, the hub 40 is pentagonal.

[0077] The mass 17 comprises a main body 26 defining the seat 25 and a plurality of plates 27 (not visible in Figure 2) connected in a releasable manner to the main body 26 to enable adjusting the axial vibration frequency of the mass 17 parallel to axis A, and therefore the tuning frequency of the device 15 to the N*Ω pulse rate.

[0078] The plates 27 are formed by rings coaxial to axis A, stacked on top of each other and lying on respective planes orthogonal to axis A.

[0079] Similarly, the rod 16 comprises a plurality of plates 45 (not visible in Figure 2), connected in a releasable manner to the hub 40 and close to end 19, in order to selectively alter the flexural vibration frequency of the mass 17 in a plane orthogonal to axis A and therefore the tuning frequency of the device 15.

[0080] In use, the mast 6 drives the hub 5, the blades 9 and the device 15 in rotation about axis A.

[0081] The rotation of the hub 5 and the blades 9 generates aerodynamic loads on the blades 9 and consequent vibrations, which are transmitted to the mast 6.

[0082] Furthermore, rotation of the device 15 causes:

- flexural oscillation of the mass 17 in the plane orthogonal to axis A, by virtue of the fact that the rod 16 has flexural elastic pliability, while being substantially rigid in the axial direction; and
- axial oscillation of the mass 17 parallel to axis A, by virtue of the fact that the springs 30 have a desired axial stiffness, while being substantially rigid in the plane orthogonal to axis A.

In other words, the device 15 behaves substantially like an assembly comprising:

- the first tuned mass damper formed by the rod 16 and the mass 17, and able of contain the transmission of flexural vibrations in the plane orthogonal to axis A to the mast 6; and
- the second tuned mass damper formed by the springs 30 and the mass 17, and able of contain the transmission of axial vibrations to the mast 6.

[0083] Due to the design configuration of the rod 16, the mass 17 and the springs 30, the flexural and axial vibration frequencies of the mass 17 are such as to be tuned to the fundamental frequency of the vibrations induced by the rotation of the rotor 3, namely N*Ω.

[0084] Therefore, thanks to the flexural and elastic oscillations of the mass 17, the device 15 counters the transmission of the aforementioned axial and flexural vibrations to the mast 6 and, from the latter, to the fuselage 2.

[0085] The device 15 can be easily inserted inside a pre-existing rotor 3, comprising hub 5, mast 6 and blades 9, in order to upgrade the rotor 3.

[0086] To this end, it is sufficient to fix the cup-shaped body 20 to the mast 6, fix the rod 16 to the cup-shaped body 20 and, lastly, fix the mass 17 and the springs 30 to the rod 16.

[0087] Finally, the tuning frequency of the device 15 can be finely adjusted, once the device 15 has been installed aboard the helicopter 1, inside the rotor 3.

[0088] In particular, plates 27 are first added to the mass 17 to tune the device 15 to the desired axial vibration frequency of the mast 6 that it is wished to contain, equal to N*Ω.

Then, plates 45 are added to the hub 40 so as to tune the device 15 to the desired flexural vibration frequency of the mast 6 that it is wished to contain, equal to N*Ω.

[0089] It is important to stress that plates 45 adjust the flexural vibration frequency of the system formed by the rod 16 and the mass 17, but do not substantially alter the axial vibration frequency of the system formed by the springs 30 and the mass 17.

[0090] From examination of the rotor 3 and the method according to the present invention, the advantages that can be achieved therewith are evident.

[0091] In particular, the device 15 comprises the springs 30, which have a desired stiffness along axis A and are connected to the mass 17.

[0092] In this way, the mass 17 can elastically oscillate parallel to axis A, thereby containing the transmission of axial vibrations parallel to axis A to the mast 6.

[0093] Moreover, the mass 17 is also free to oscillate in the plane orthogonal to axis A and elastically connected to the rod 16 having a desired value of axial stiffness.

[0094] Thus, the device 15 uses the same mass 17 as a "moveable element" to contain the transmission of both flexural vibrations and axial vibrations to the mast 6.

[0095] In other words, the same mass 17 is both part of the first tuned mass damper together with the rod 16 and part of the second tuned mass damper together with the springs 30.

[0096] Furthermore, the device 15 uses the same rod 16 to connect both the flexural tuned mass damper, formed by the mass 17 and the rod 16, and the axial tuned mass damper, formed by the mass 17 and the springs 30, to the mast 6.

[0097] It follows that the device 15 is particularly compact and takes up little space, making integration in the rotor 3 possible without unduly altering the design of latter.

[0098] The applicant has also noted that thanks to their serpentine configuration, the springs 30 have a constant stiffness and therefore a substantially linear elastic behaviour.

[0099] In addition, as the device 15 is housed inside the bay 24, it is not subjected to aerodynamic forces that might prevent the device 15 tuning to the aforementioned frequency value characteristic of the vibrations generated by rotation of the rotor 3.

[0100] Finally, the device 15 is easily incorporated in the rotor 3, as it is housed in the bay 24 and is therefore not intrusive with respect to the other components of the rotor 3.

[0101] The method of upgrading according to the invention is particularly advantageous, as it does not require modifying a pre-existing rotor 3 to create new housings for the device 15. In fact, to this end, it is sufficient to fix the cup-shaped body 20 to the mast 6, fix the rod 16 to the cup-shaped body 20, and fix the springs 30 to the rod 16 and the mass 17 to the springs 30.

[0102] Finally, the tuning frequency of the device 15 can be easily adjusted once the device 15 has been installed in the rotor 3, so as to take into account the effective value of the rotation speed Ω of the mast 6.

[0103] To this end, it is sufficient to first add some plates 27 to the mass 17 to tune the device 15 to the desired axial vibration frequency of the mast 6, and then add some plates 45 to the hub 40 to tune the device 15 to desired flexural vibration frequency of the mast 6 that it is wished to contain.

[0104] Finally, it is obvious that modifications and variants can be made regarding the rotor 3 and the method described and illustrated herein without departing from the scope of protection defined by the claims.

[0105] In an embodiment which does not fall in the scope of the invention, the rotor 3 could comprise one or more flat spring (s) instead of the springs 30, fixed to the rod 16 and elastically deformable parallel to axis A.
The helicopter 1 could also be a convertiplane.

Claims

1. A rotor (3) for a hover-capable aircraft (1), comprising:

- a hub (5) rotatable about a first axis (A) and, in turn, comprising a plurality of blades (9);
- a mast (6) connectable to a drive member of said aircraft (1) and operatively connected to said hub (5) to drive the hub (5) in rotation about said axis (A); and

damping means (15) to dampen the transmission of vibrations to said mast (6), which comprise a mass (17) designed to oscillate, in use, in a plane transversal to said axis (A) so as to contain, in use, the flexural vibrations of said mast (6) generated by rotation of the blades (9);
said damping means (15) further comprising elastic means (30) possessing a desired stiffness along said axis (A) and operatively connected to said mass (17) to contain, in use, the vibration of said mast (6) along said axis (A);
said damping means (15) further comprising a first elastic element (16) supported by said mast (6) and designed to flexurally oscillate in a plane transversal to said axis (A); said first elastic element (16) extending along said axis (A); said elastic means (30) also being interposed between said mass (17) and said first elastic element (16);
characterized in that said elastic means (30) comprise at least a second elastic element (30) with a serpentine-like shape, having a plurality of first sections (31) extending mainly radially with respect to said axis (A) alternating with a plurality of second sections (32) extending mainly parallel to said axis (A).

2. The rotor according to claim 1, **characterized in that** the radial extension of each said first section (31) is greater than the axial extension of each said second section (32).

3. The rotor according to either of claims 1 or 2, **characterized in that** said elastic means (30) comprise a first plurality (34) of said second elastic elements (30) angularly equi-spaced with respect to said axis (A).

4. The rotor according to claim 3, **characterized in that** said elastic means (30) comprise a second plurality (35) of said second elastic elements (30), which are angularly equi-spaced with respect to said axis (A); each said second elastic element (30) of said first plurality (34) being axially superimposed on a respective said second elastic element (30) of said second plurality (35).

5. The rotor according to any of the foregoing claims, **characterized in that** said second elastic element (30) comprises a pair of second axial end sections (33) at its free ends, opposite to each other and with one fixed to said mass (17) and the other fixed to said first elastic element (16).

6. The rotor according to any one of claims 3 to 5, **characterized in that** it comprises a further hub (40) angularly integral with said first elastic element (16), fitted on an axial end of said elastic element (16) and on which said second elastic elements (30) are fixed.

7. The rotor according to any of the preceding claims, **characterized in that** said mass (17) is hollow and **in that** said elastic means (30) are housed inside said mass (17).

8. The rotor according to any of the foregoing claims, **characterized in that** said mass (17) and said elastic means (30) form a first tuned mass damper having a first natural frequency, and **in that** said mass (17) and said first elastic element (16) form a second tuned mass damper having a second natural frequency equal to said first natural frequency.

9. A hover-capable aircraft (1), **characterized in that** it comprises a rotor (3) according to any of the preceding claims.

10. A method for the containment of vibrations transmitted to a mast (6) of a rotor (3) of an aircraft (1);
said rotor (3) comprising:

- a hub (5) rotatable about an axis (A) and, in turn, comprising a plurality of blades (9);
- said mast (6), which is connectable to a drive member of said aircraft (1) and operatively connected to said hub (5) to drive the hub (5) in rotation about said axis (A);

said method comprising the step of:

i) connecting a first mass (17) to said mast (6) in a manner free to oscillate in a plane transversal to said axis (A) so as to contain the flexural vibrations of said mast (6);

said method further comprises the steps of:

ii) connecting elastic means (30) having a desired stiffness along said axis (A) to said mass (17), so as to contain the vibration of said mast (6) along said axis (A);
iii) connecting a first elastic element (16) designed to oscillate in a plane transversal to said axis (A) and supported by said mast (6) to said mass (17); and
iv) connecting said first mass (17) to said first elastic element (16);

characterized in that said elastic means (30) comprise at least a second elastic element (30) with a serpentine-like shape, having a plurality of first sections (31) extending mainly radially with respect to said axis (A) alternating with a plurality of second sections (32) extending mainly parallel to said axis (A).

11. The method according to claim 10, **characterized in that** it comprises the steps of:

v) selectively adding further second masses (27) to said first mass (17) to tune the vibration frequency of said first mass (17) parallel to said axis (A) to a desired value; and
vi) selectively adding further third masses (45) to said first elastic element (16) to tune the vibration frequency of said first mass (17) transversely to said axis (A) to said desired value.

12. The method according to claim 11, **characterized in that** said step v) is performed before said step vi).

Patentansprüche

1. Rotor (3) für ein schwebefähiges Luftfahrzeug (1), der Folgendes umfasst:

- eine Nabe (5), die um eine erste Achse (A) drehbar ist, und wiederum mehrere Rotorblätter (9) umfasst;
- einen Mast (6), der mit einem Antriebselement des Luftfahrzeugs (1) verbunden werden kann und funktionstechnisch mit der Nabe (5) verbunden ist, um die Nabe (5) um die Achse (A) rotatorisch anzutreiben; und

Dämpfungsmittel (15) zum Dämpfen der Übertragung von Vibrationen zum Mast (6), die eine Masse (17) umfassen, die entworfen ist, im Betrieb in einer Ebene quer zur Achse (A) zu oszillieren, um im Betrieb die Biegeschwingungen des Masts (6), die durch die Drehung der Rotorblätter (9) erzeugt werden, einzudämmen; wobei
die Dämpfungsmittel (15) ferner elastische Mittel (30) umfassen, die eine gewünschte Steifigkeit in Richtung der Achse (A) besitzen und funktionstechnisch mit der Masse (17) verbunden sind, um im Betrieb die Schwingung des Masts (6) in Richtung der Achse (A) einzudämmen; und
die Dämpfungsmittel (15) ferner ein erstes elastisches Element (16) umfassen, das durch den Mast (6) getragen wird und ausgelegt ist, in einer Ebene quer zur Achse (A) biegeschwingend zu oszillieren; wobei
das erste elastische Element (16) sich in Richtung der Achse (A) erstreckt und
die elastischen Mittel (30) auch zwischen der Masse (17) und dem ersten elastischen Element (16) angeordnet sind;
dadurch gekennzeichnet, dass die elastischen Mittel (30) mindestens ein zweites elastisches Element (30) mit einer serpentinenartigen Form umfassen, das mehrere erste Abschnitte (31), die sich hauptsächlich radial in Bezug auf die Achse (A) erstrecken, besitzt, die sich mit mehreren zweiten Abschnitten (32), die sich hauptsächlich parallel zur Achse (A) erstrecken, abwechseln.

2. Rotor nach Anspruch 1, **dadurch gekennzeichnet, dass** die radiale Ausdehnung jedes ersten Abschnitts (31) größer als die axiale Ausdehnung jedes zweiten Abschnitts (32) ist.

3. Rotor nach einem der Ansprüche 1 oder 2, **dadurch gekennzeichnet, dass** die elastischen Mittel (30) eine erste Mehrzahl (34) der zweiten elastischen Elemente (30), die in Winkelrichtung in Bezug auf die Achse (A) gleich beabstandet sind, umfassen.

4. Rotor nach Anspruch 3, **dadurch gekennzeichnet, dass** die elastischen Mittel (30) eine zweite Mehrzahl (35) der zweiten elastischen Elemente (30), die in Winkelrichtung in Bezug auf die Achse (A) gleich beabstandet sind, umfassen; wobei
jedes zweite elastische Element (30) der ersten Mehrzahl (34) einem entsprechen zweiten elastischen Element (30) der zweiten Mehrzahl (35) axial

überlagert ist.

5. Rotor nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** das zweite elastische Element (30) bei seinen freien Enden ein Paar zweiter axialer Endabschnitte (33) umfasst, die einander gegenüberliegen, wobei einer an der Masse (17) befestigt ist und der andere am ersten elastischen Element (16) befestigt ist.

6. Rotor nach einem der Ansprüche 3 bis 5, **dadurch gekennzeichnet, dass** er eine weitere mit dem ersten elastischen Element (16) winkelfeste Nabe (40) umfasst, die an einem axialen Ende des elastischen Elements (16) angebracht ist und an der die zweiten elastischen Elemente (30) befestigt sind.

7. Rotor nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Masse (17) hohl ist und dass die elastischen Mittel (30) in der Masse (17) untergebracht sind.

8. Rotor nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Masse (17) und die elastischen Mittel (30) einen ersten abgestimmten Massedämpfer bilden, der eine erste Eigenfrequenz besitzt, und dass die Masse (17) und das erste elastische Element (16) einen zweiten abgestimmten Massedämpfer bilden, der eine zweite Eigenfrequenz besitzt, die gleich der ersten Eigenfrequenz ist.

9. Schwebefähiges Luftfahrzeug (1), **dadurch gekennzeichnet, dass** es einen Rotor (3) nach einem der vorhergehenden Ansprüche umfasst.

10. Verfahren zur Eindämmung von Schwingungen, die zu einem Mast (6) eines Rotors (3) eines Luftfahrzeugs (1) übertragen werden; wobei
der Rotor (3) Folgendes umfasst:

- eine Nabe (5), die um eine erste Achse (A) drehbar ist, und wiederum mehrere Rotorblätter (9) umfasst;
- den Mast (6), der mit einem Antriebselement des Luftfahrzeugs (1) verbunden werden kann und funktionstechnisch mit der Nabe (5) verbunden ist, um die Nabe (5) um die Achse (A) rotatorisch anzutreiben; wobei

das Verfahren den folgenden Schritt umfasst:

i) Verbinden einer ersten Masse (17) mit dem Mast (6) in einer Weise, dass er in einer Ebene quer zur Achse (A) frei oszillieren kann, um die Biegeschwingungen des Masts (6) einzudämmen; wobei

das Verfahren ferner die folgenden Schritte umfasst:

ii) Verbinden elastischer Mittel (30), die eine gewünschte Steifigkeit in Richtung der Achse (A) besitzen, mit der Masse (17), um die Schwingung des Masts (6) in Richtung der Achse (A) einzudämmen;
iii) Verbinden eines ersten elastischen Elements (16), das ausgelegt ist, in einer Ebene quer zur Achse (A) zu oszillieren, und durch den Mast (6) getragen wird, mit der Masse (17) und
iv) Verbinden der ersten Masse (17) mit dem ersten elastischen Element (16);

dadurch gekennzeichnet, dass
die elastischen Mittel (30) mindestens ein zweites elastisches Element (30) mit einer serpentinenartigen Form umfassen, das mehrere erste Abschnitte (31), die sich hauptsächlich radial in Bezug auf die Achse (A) erstrecken, besitzt, die sich mit mehreren zweiten Abschnitten (32), die sich hauptsächlich parallel zur Achse (A) erstrecken, abwechseln.

11. Verfahren nach Anspruch 10, **gekennzeichnet durch** die folgenden Schritte:

v) selektives Hinzufügen weiterer zweiter Massen (27) zur ersten Masse (17), um die Schwingungsfrequenz der ersten Masse (17) parallel zur Achse (A) auf einen gewünschten Wert abzustimmen; und
vi) selektives Hinzufügen weiterer dritter Massen (45) zum ersten elastischen Element (16), um die Schwingungsfrequenz der ersten Masse (17) quer zur Achse (A) auf den gewünschten Wert abzustimmen.

12. Verfahren nach Anspruch 11, **dadurch gekennzeichnet, dass** der Schritt v) vor dem Schritt vi) durchgeführt wird.

Revendications

1. Rotor (3) pour un aéronef capable de voler en vol stationnaire (1), comprenant :

- un moyeu (5) pouvant tourner autour d’un premier axe (A) et comprenant à son tour une pluralité de pales (9) ;
- un mât (6) pouvant être raccordé à un élément d’entraînement dudit aéronef (1) et raccordé de manière opérationnelle audit moyeu (5) pour entraîner le moyeu (5) en rotation autour dudit axe (A) ; et

des moyens d’amortissement (15) pour amortir la transmission de vibrations audit mât (6), qui com-

prennent une masse (17) conçue pour osciller, à l'usage, dans un plan transversal audit axe (A) afin de contenir, à l'usage, les vibrations de flexion dudit mât (6) générées par la rotation des pales (9) ;
lesdits moyens d'amortissement (15) comprenant en outre des moyens élastiques (30) possédant une rigidité souhaitée le long dudit axe (A) et raccordés de manière opérationnelle à ladite masse (17) pour contenir, à l'usage, la vibration dudit mât (6) le long dudit axe (A) ;
lesdits moyens d'amortissement (15) comprenant en outre un premier élément élastique (16) supporté par ledit mât (6) et conçus pour osciller en flexion dans un plan transversal audit axe (A) ; ledit premier élément élastique (16) s'étendant le long dudit axe (A) ;
lesdits moyens élastiques (30) étant également intercalés entre ladite masse (17) et ledit premier élément élastique (16) ;
caractérisé en ce que lesdits moyens élastiques (30) comprennent au moins un second élément élastique (30) avec une forme de serpentin, ayant une pluralité de premières sections (31) s'étendant principalement radialement par rapport audit axe (A) alternant avec une pluralité de secondes sections (32) s'étendant principalement parallèlement audit axe (A).

2. Rotor selon la revendication 1, **caractérisé en ce que** l'extension radiale de chaque dite première section (31) est supérieure à l'extension axiale de chaque dite seconde section (32).

3. Rotor selon l'une des revendications 1 ou 2, **caractérisé en ce que** lesdits moyens élastiques (30) comprennent une première pluralité (34) desdits seconds éléments élastiques (30) espacés angulairement à équidistance par rapport audit axe (A).

4. Rotor selon la revendication 3, **caractérisé en ce que** lesdits moyens élastiques (30) comprennent une seconde pluralité (35) desdits seconds éléments élastiques (30), qui sont espacés angulairement à équidistance par rapport audit axe (A) ;
chacun desdits seconds éléments élastiques (30) de ladite première pluralité (34) étant axialement superposé sur ledit second élément élastique (30) respectif de ladite seconde pluralité (35).

5. Rotor selon l'une quelconque des revendications précédentes, **caractérisé en ce que** ledit second élément élastique (30) comprend une paire de secondes sections d'extrémité axiales (33) au niveau de ses extrémités libres, opposées entre elles et avec une fixée à ladite masse (17) et l'autre fixée audit premier élément élastique (16).

6. Rotor selon l'une quelconque des revendications 3 à 5, **caractérisé en ce qu'**il comprend un autre moyeu (40) angulairement solidaire avec ledit premier élément élastique (16) monté sur une extrémité axiale dudit élément élastique (16) et sur laquelle lesdits seconds éléments élastiques (30) sont fixés.

7. Rotor selon l'une quelconque des revendications précédentes, **caractérisé en ce que** ladite masse (17) est creuse et **en ce que** lesdits moyens élastiques (30) sont logés à l'intérieur de ladite masse (17).

8. Rotor selon l'une quelconque des revendications précédentes, **caractérisé en ce que** ladite masse (17) et lesdits moyens élastiques (30) forment un premier amortisseur de vibrations ayant une première fréquence naturelle, et **en ce que** ladite masse (17) et ledit premier élément élastique (16) forment un second amortisseur de vibrations ayant une seconde fréquence naturelle égale à ladite première fréquence naturelle.

9. Aéronef capable de voler en vol stationnaire (1) **caractérisé en ce qu'**il comprend un rotor (3) selon l'une quelconque des revendications précédentes.

10. Procédé pour le confinement des vibrations transmises à un mât (6) d'un rotor (3) d'un aéronef (1) ; ledit rotor (3) comprenant :

- un moyeu (5) pouvant tourner autour d'un axe (A) et, comprenant à son tour une pluralité de pales (9) ;
- ledit mât (6) qui peut être raccordé à un élément d'entraînement dudit aéronef (1) et raccordé de manière opérationnelle audit moyen (5) pour entraîner le moyeu (5) en rotation autour dudit axe (A) ;

ledit procédé comprenant l'étape suivante :

i) raccorder une première masse (17) audit mât (6) d'une manière libre d'osciller dans un plan transversal audit axe (A) afin de contenir les vibrations de flexion dudit mât (6) ;

ledit procédé comprend en outre les étapes suivantes :

ii) raccorder les moyens élastiques (30) ayant une rigidité souhaitée le long dudit axe (A) à ladite masse (17), afin de contenir la vibration dudit mât (6) le long dudit axe (A) ;
iii) raccorder un premier élément élastique (16) conçu pour osciller dans un plan transversal audit axe (A) et supporté par ledit mât (6) à ladite masse (17) ; et
iv) raccorder ladite première masse (17) audit premier élément élastique (16) ;

caractérisé en ce que :
lesdits moyens élastiques (30) comprennent au moins un second élément élastique (30) avec une forme de serpentin, ayant une pluralité de premières sections (31) s'étendant principalement radialement par rapport audit axe (A) alternant avec une pluralité de secondes sections (32) s'étendant principalement parallèlement audit axe (A).

11. Procédé selon la revendication 10, **caractérisé en ce qu'**il comprend les étapes suivantes :

v) ajouter sélectivement d'autres deuxièmes masses (27) à ladite première masse (17) pour accorder la fréquence de vibration de ladite première masse (17) parallèle audit axe (A), à une valeur souhaitée ; et
vi) ajouter sélectivement d'autres troisièmes masses (45) audit premier élément élastique (16) pour accorder la fréquence de vibration de ladite première masse (17) transversalement audit axe (A), à ladite valeur souhaitée.

12. Procédé selon la revendication 11, **caractérisé en ce que** ladite étape v) est réalisée avant ladite étape vi).

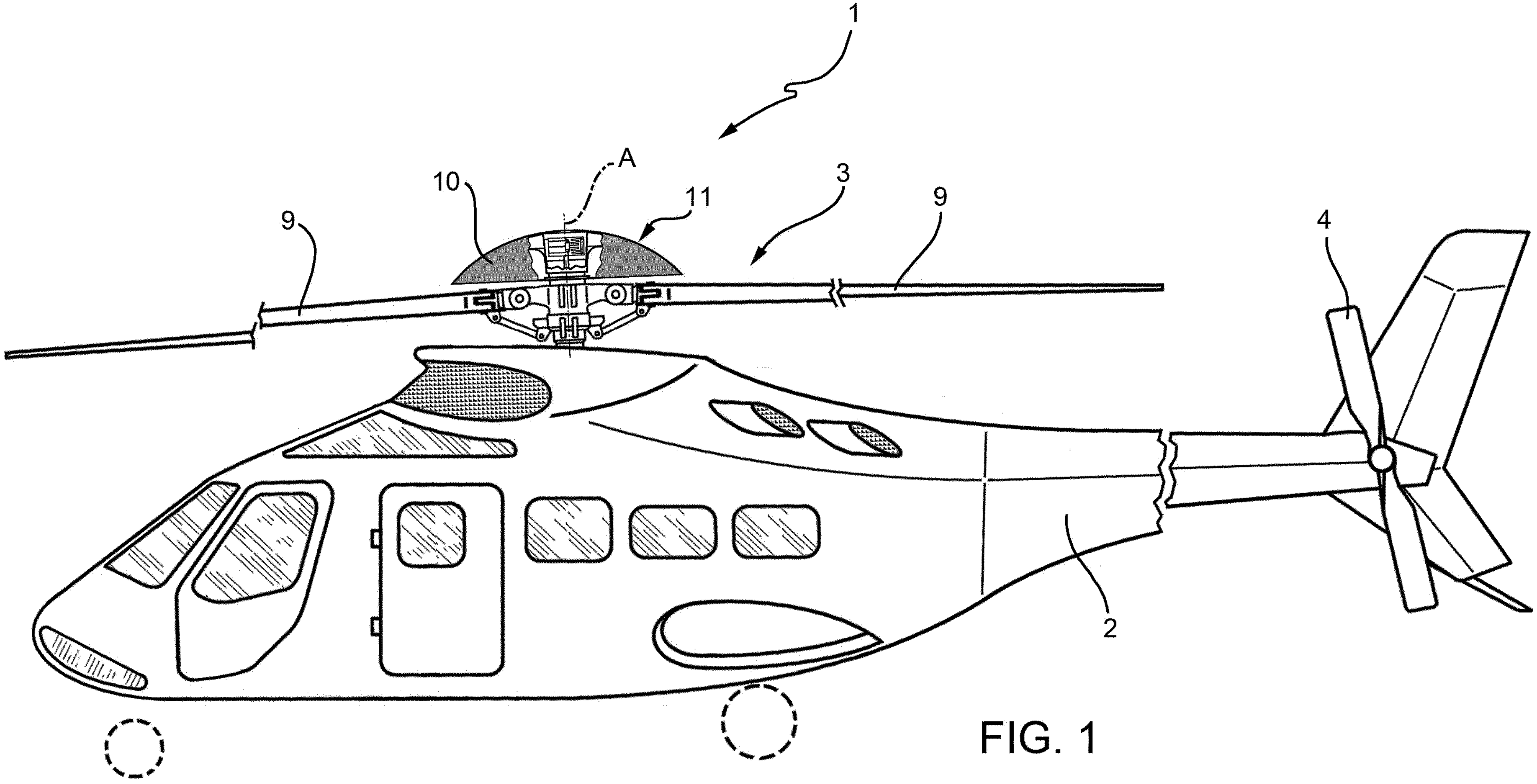

FIG. 1

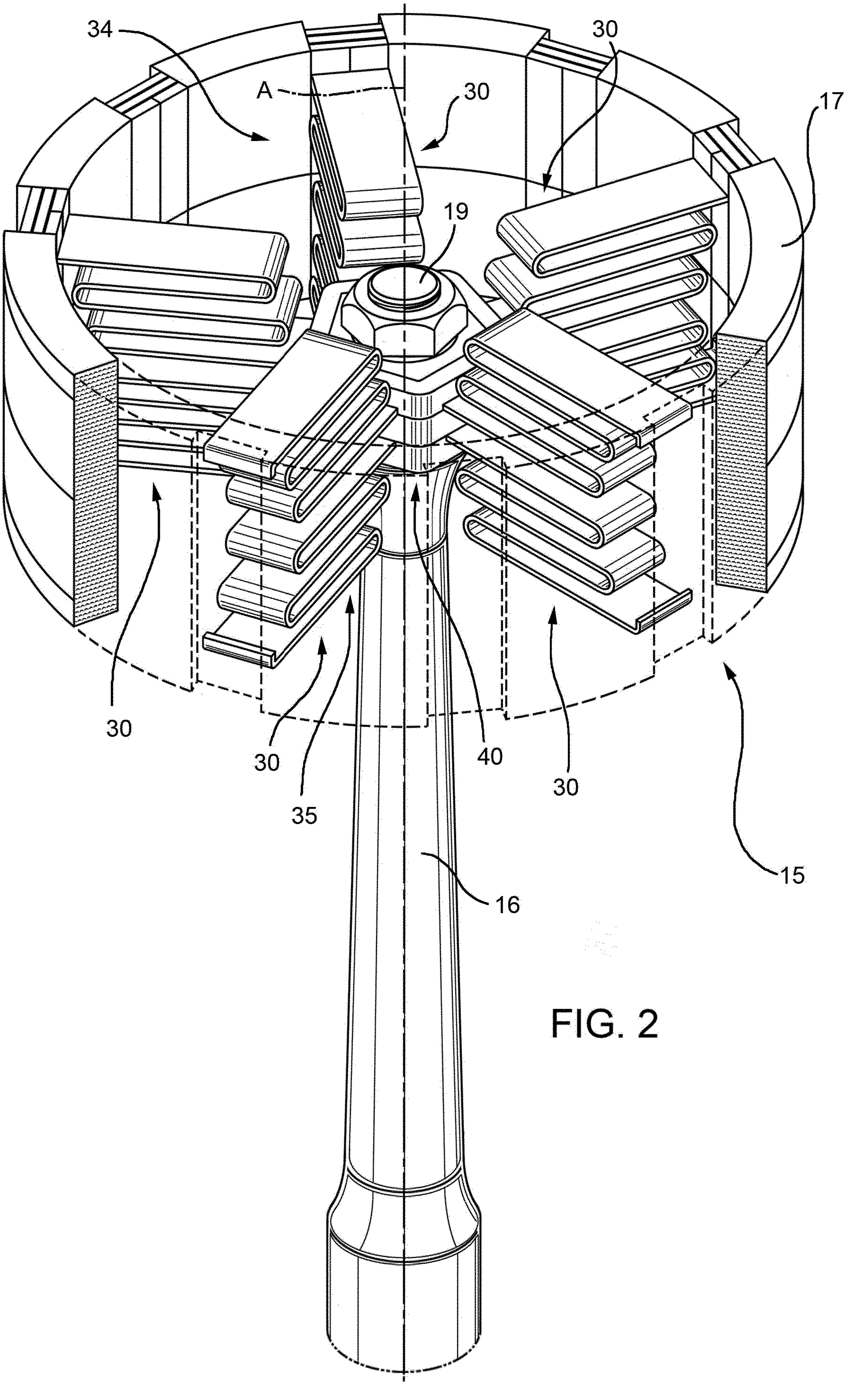

FIG. 2

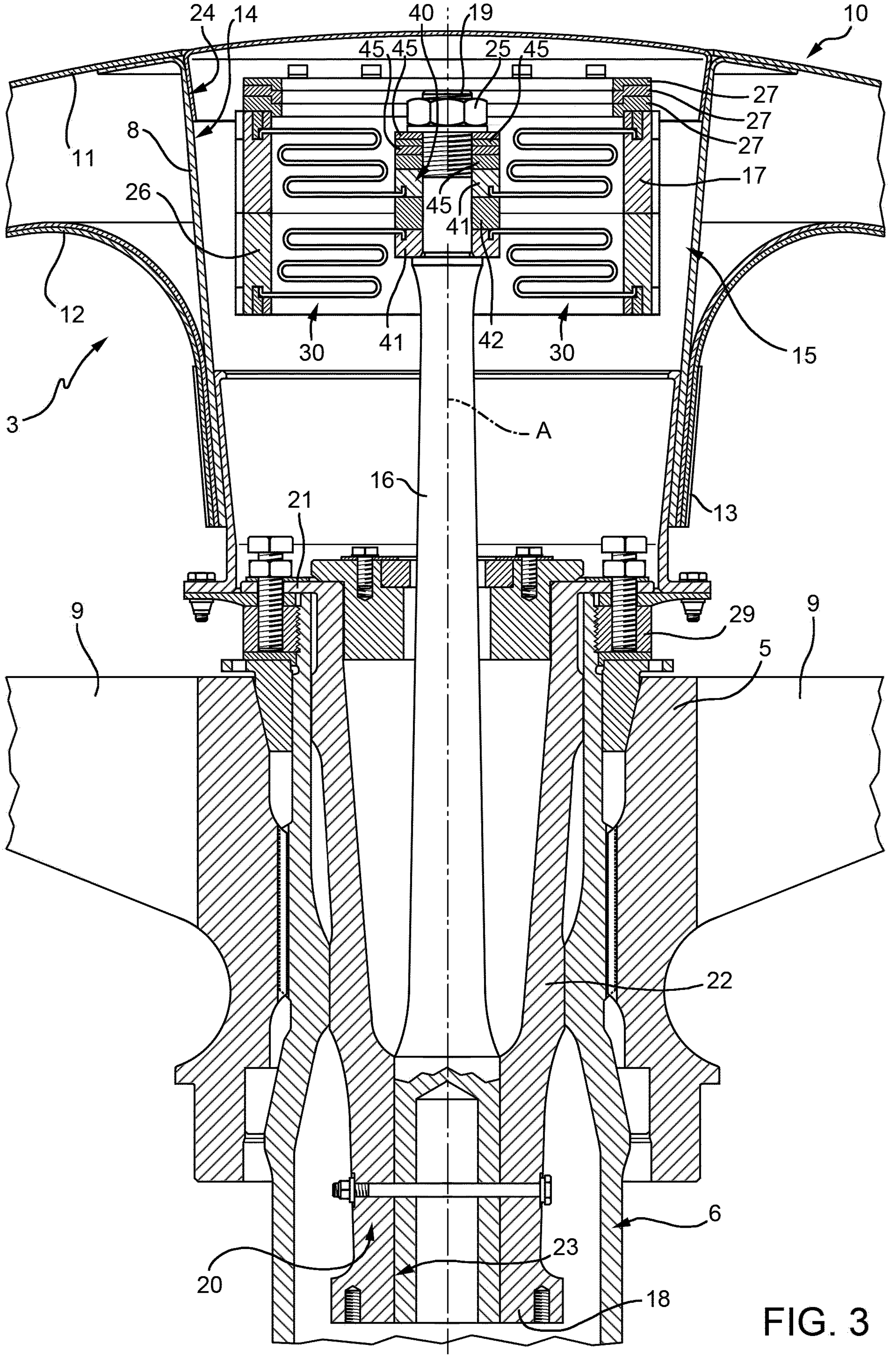
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FIG. 3

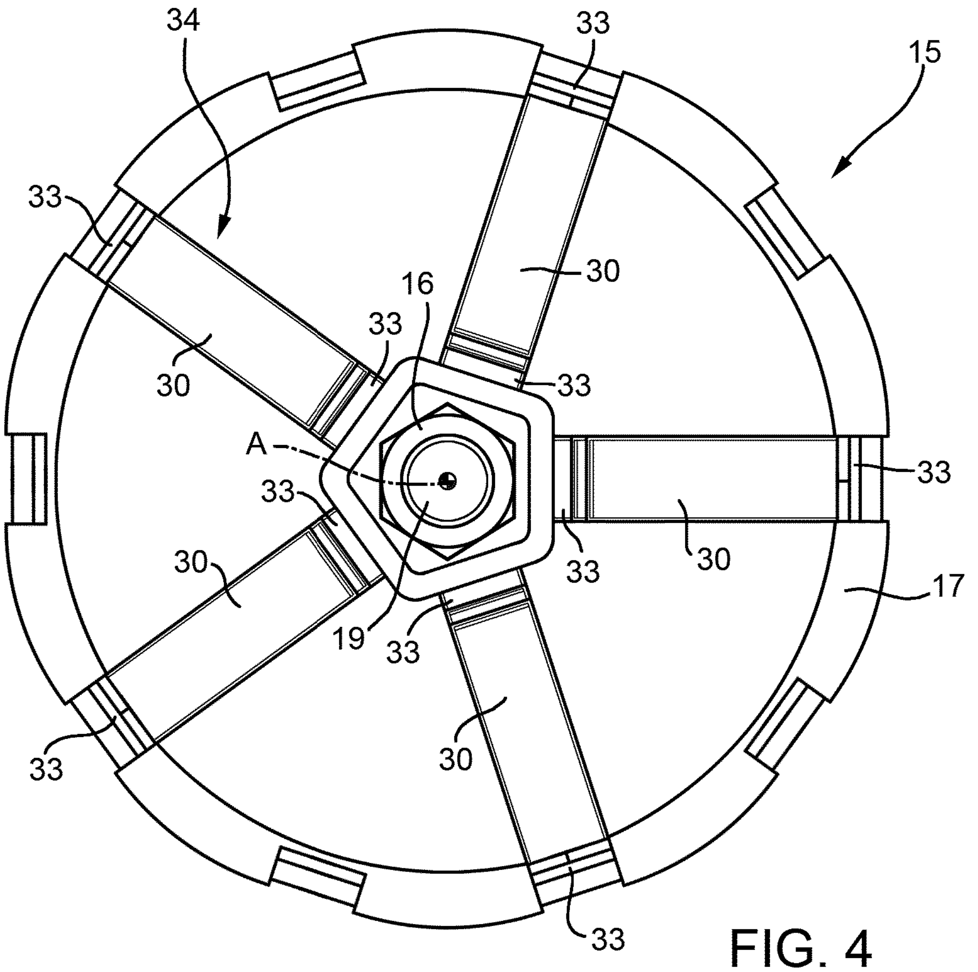
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FIG. 4

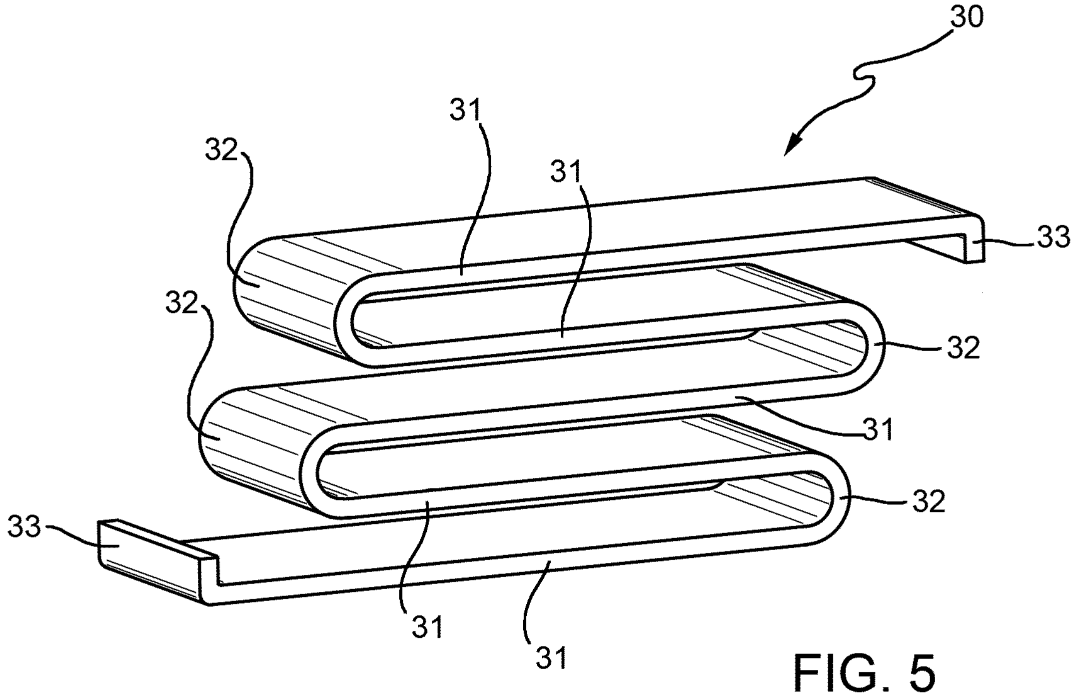
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FIG. 5

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO IB2008001594 A **[0015]**
- US 2010296930 A **[0025]**
- US 2011268573 A **[0025]**
- US 5647726 A **[0025]**
- US 4596513 A **[0025]**
- US 2010296931 A **[0025]**