

Specification

The invention relates to a hydrodynamic fluid-film bearing of the type comprising one or more thin flexible sheets capable of conditioning the formation of a fluid film around a rotary shaft with a view to supporting the latter without contact with a solid surface. The invention is in particular applicable to the support of shafts capable of rotating at high rotary speeds.

Hydrodynamic bearings of the aforementioned type are well known. Their thin sheets must exhibit good flexibility characteristics so as to adapt themselves to the shaft supported under all operating conditions and so as to give rise to the formation of an appropriate fluid film. However, the capacity of such sheets to support loads is reduced, and it has become customary to combine them with stiffening means which increase the stiffness of the bearing when the latter is subject to a heavy load. Moreover, at high speeds, the shaft tends to vibrate or oscillate about the geometric centre of the bearing with amplitudes of oscillation which reach a maximum value at certain critical speeds. With a view to overcoming said oscillation, certain bearings comprise attenuating means which ensure energy dissipation as a result of the Coulomb effect. Reference may in particular be made to the following patents which specify such bearings: US-A- 4.549.821, US-A- 4.701.060, US-A- 4.300.806, US-A- 4.274.683. US-A- 4.153.315, US-A- 3.893.733, FR-A- 2.516.996.

However, one of the difficulties encountered consists in managing to combine, on the one hand, efficient attenuation of the oscillations or vibrations due to high degrees of energy dissipation, and, on the other hand, progressive variation of the stiffness of the bearing enabling satisfactory operation throughout the speed range.

The invention aims to provide a simple solution to this problem. Its essential object is to provide a bearing of simple structure ensuring, in the case of oscillations or

vibrations, considerably higher degrees of energy dissipation due to the Coulomb effect than can be achieved with the known bearings while exhibiting a stiffness capable of varying in progressive manner in accordance with the load
5 between a minimal value adapted to low loads, in particular at the start-up stage, and a maximum value adapted to the high loads such as occur at high speed.

To this end, the bearing according to the invention is of the type comprising a fixed casing, a rotary shaft
10 arranged within said casing so as to be separated from the latter by an annular space, and one or several supporting assemblies located within said space so as to cover the circumference of the latter, whereby each supporting assembly comprises the superposition of:

- 15 . a flexible internal sheet which is substantially cylindrical and capable of conditioning the formation of the fluid film between the rotary shaft and said sheet,
- 20 . an external spring element exhibiting a series of undulations, so-called centrifugal undulations, the convexity of which is oriented towards the casing, and undulations, so-called centripetal undulations, the convexity of which is oriented towards the rotary shaft, whereby said external spring element abuts the casing by virtue of the centrifugal undulations,
- 25 . and an intermediary spring element interposed between the flexible internal sheet and the external spring element, said intermediary spring element exhibiting a series of undulations, so-called centrifugal undulations, the convexity of which is oriented
30 towards the casing, and undulations, so-called centripetal undulations, the convexity of which is oriented towards the rotary shaft, whereby said intermediary spring element abuts the flexible
35 internal sheet by virtue of the centripetal undulations and abuts the external spring element by virtue of the centrifugal undulations.

The hydrodynamic bearing according to the present invention is characterised in that, for each supporting assembly:

- 5 . the external spring element and the intermediary spring element have ondulations arranged in opposition in such a way that the centripetal ondulations of the external spring element are situated opposite the centrifugal ondulations of the intermediary spring element and are in contact with
10 said centrifugal ondulations,
- . the external spring element and the internal flexible sheet have an end secured to the casing and a free end and exhibit within the annular space an identical winding direction from their fixed end towards their
15 free end,
- . the intermediary spring element has an end secured to the casing and a free end and exhibits within the annular space a winding direction opposite to that of
20 the external spring element and of the flexible internal sheet, so that the deformations of these three elements give rise to opposite displacements of their contact zones, i.e. centripetal ondulations of the external spring element in contact with
25 centrifugal ondulations of the intermediary spring element on the one hand, and centripetal ondulations of the intermediary spring element in contact with the flexible internal sheet on the other hand.

The term "ondulation" signifies in general manner a deformation of the element in one direction or the other
30 with respect to a medium cylindrical surface; said ondulations may be curved over their entire surface or, on the other hand, comprise zones of flattened or any other shape. According to a preferred embodiment:

- 35 . the centrifugal ondulations of the external spring element in contact with the casing as well as the centrifugal ondulations of the intermediary spring

element in contact with the external spring element take the shape of circular arcs,

- 5 . the centripetal undulations of the external spring element exhibit, in the same way as the centripetal undulations of the intermediary spring element, flattened zones of contact with the intermediary spring element and the flexible internal sheet, respectively.

Hence, according to the invention the intermediary
 10 spring element fulfils two functions. In the first place, it is deformed as the load increases and flattens out so as to tend towards a surface close to that of a cylinder: it accordingly ensures a progressive increase of the stiffness of the bearing up to the point at which the external spring
 15 element is in turn deformed and confers on the bearing a high degree of stiffness as the load reaches high values. Moreover, in the course of the deformations the centripetal undulations and the centrifugal undulations of said intermediary spring element are displaced in the opposite
 20 direction in relation to the zones with which they are in contact, i.e. the flexible internal sheet and the centripetal undulations of the external spring element, respectively. This relative double displacement in opposite directions results in a maximum dissipation of energy due to
 25 the Coulomb effect and in a highly efficacious attenuating effect. By comparison with the majority of known hydrodynamic bearings the invention accordingly makes it possible to achieve simultaneously, by means of a bearing of simple structure and without the addition of supplementary
 30 elements, the required effects (progressive variation of stiffness and a high degree of attenuation).

Moreover, according to an advantageous embodiment the intermediary spring element comprises, between two centrifugal undulations in contact with the external spring
 35 element, at least two centripetal undulations in contact with the flexible internal sheet, said centripetal undulations being separated by retracted zones which in a

state of rest are located at a small distance from the flexible internal sheet.

These arrangements make it possible to control perfectly and in independent manner the variations in stiffness of the intermediary spring element on the one hand, and on the other hand the attenuating effect produced by the latter. In fact, as will become apparent below, it is possible to adjust, in precise and independent manner, the surface of the zones in contact conditioning the attenuating effect and the positioning of said zones which condition the stiffness as well as its variations.

The hydrodynamic bearing according to the invention may comprise a single supporting assembly (comprising an internal sheet, an intermediary spring element and an external spring element as defined) extending over the entire circumference of the annular space between the casing and the rotary shaft.

It may also comprise several identical supporting assemblies, each of which extends over a sector of the aforementioned annular space.

Other characteristics, aims and advantages of the invention will become apparent from the following description with reference to the attached drawings, which present, in non-restrictive manner, exemplary embodiments thereof; in said drawings, which constitute an integral part of the present specification:

- Figure 1 is a schematic section through a transverse plane of a hydrodynamic bearing according to the invention which is provided with a single supporting assembly,
- Figure 2 is a partial section of said bearing on a larger scale,
- Figure 3a and 3b are partial schematic sections illustrating the operation of the bearing when it is subject to a low load and when it is subject to a high load, respectively,

- Figure 4 is a section analogous to that in Fig. 2 but relates to a different embodiment,
- Figure 5 is a schematic section of a hydrodynamic bearing according to the invention, provided on its circumference with three supporting assemblies.

5 The hydrodynamic bearing shown by way of example in Figures 1 and 2 is intended to support a rotary shaft 1 capable of rotating at very high speeds; this bearing comprises a fixed casing 2 delimiting, together with the
10 shaft 1, an annular space in which is located a supporting assembly 3. Said supporting assembly, which extends over the entire circumference of the bearing, is so designed as to give rise, in the course of operation, to a fluid film subject to pressure which ensures that the rotary shaft is
15 supported without contact with the bearing.

The supporting assembly 3 comprises an internal flexible sheet 4 which is essentially cylindrical, the thickness and elasticity of which confer upon it a low degree of stiffness such as to enable it to assume the shape
20 of the rotary shaft and to ensure an optimal action of the fluid in the start-up phase or when subject to a small load.

At the rear of said internal sheet are arranged an intermediary spring element 5 and an external spring element 6, these being intended to increase the stiffness of the
25 supporting assembly at higher loads and to attenuate the oscillations of the shaft 1.

The sheet 4, the intermediary spring element 5 and the external spring element 6 are each immobilised by an end 4a, 5a, 6a, which is secured, in particular by welding, to the
30 casing 2. The securing ends of these three elements are superimposed as shown in Figures 1 and 2, but the winding direction of the intermediary spring element 5 is opposite to those of the sheet 4 and the external spring element 6; for example, the intermediary spring element 5 may exhibit a
35 winding direction coinciding with the direction in which the shaft 1 rotates (winding direction from the fixed end towards the free end), whereas the sheet 4 and the external

spring element 6 are wound in the opposite direction. Hence, in case of deformations, a given zone of the intermediary spring element 5 is displaced in the opposite direction in relation to the zones pertaining to the sheet 4 and the external spring element 6 which are located facing each other on either side of the former.

The external spring element 6 comprises a strip exhibiting a series of ondulations, i.e. centrifugal ondulations such as 7, the convexity of which is oriented towards the casing 2, and centripetal ondulations such as 8, the convexity of which is oriented towards the rotary shaft 1.

In the example the centrifugal ondulations 7 exhibit the shape of circular arcs (arcs close to 180° in the example shown) and make contact with the casing 2 by their outermost circular sections 7a. On the other hand, in the example shown, the centripetal ondulations 8 comprise flattened zones 8a by which they come into contact with the intermediary spring element 5.

The intermediary spring element 5 comprises a strip having a stiffness which is lower than that of the external spring element 6, said intermediary spring element having a series of ondulations, i.e. centrifugal ondulations such as 9, the convexity of which is oriented towards the casing, and, between two centrifugal ondulations 9, centripetal ondulations 10 and 11 separated by retracted zones 12. Said retracted zones 12 are offset towards the outside and located, in a state of rest, at a small distance from the flexible internal sheet 4. So as to clarify the terminology, said zones 12, which are in fact centrifugal ondulations, have not been designated by the latter term since their function is different from that of the centrifugal ondulations 9; they will be referred to below by the term "retracted zone".

In the example the centrifugal ondulations 9 exhibit the shape of circular arcs (arcs close to 70° in the example shown) and make contact with the flattened zones 8a of the

external spring element by their outermost circular sections 9a. The centripetal ondulations 10 and 11 (in the example two centripetal ondulations located between two centrifugal ondulations 9) have flattened zones 10a and 11a by which they come into contact with the internal flexible sheet 4.

In the state of rest, the amplitude a_i of the ondulations of the intermediary spring element 5 is smaller than the amplitude a_e of the ondulations of the external spring element 6, the stiffness of which is higher. Said intermediary spring element 5 is accordingly so designed as to be progressively deformed as the load increases from a low value and to tend to flatten out to a cylindrical shape; in the course of this deformation its stiffness increases (up to a high value for the shape close to the cylindrical shape). Starting from a certain load value the external spring element 6 is in turn deformed and the stiffness of the bearing is then conditioned by the latter. Hence, as the load increases, the stiffness of the bearing according to the invention increases in continuous manner from a reduced minimum value advantageous for start-up to a high maximum value enabling the bearing to support high loads. The increase in stiffness takes place progressively without any discontinuity and does not impair the stability of the bearing.

Moreover, with each deformation the intermediary spring element 5 is displaced in the direction opposite to that of the external spring element 6 and the flexible sheet 4, as a result of which Coulomb friction is generated, on the one hand in the region of the contact zones 10a and 11a (contact between the centripetal ondulations of the intermediary spring element 5 and the flexible sheet 4), and on the other hand in the region of the contact zones 8a and 9a (contact between the centrifugal and centripetal ondulations of the intermediary spring element and the external spring element, respectively).

Figures 3a and 3b illustrate a given region of the bearing in the course of an oscillation; the latter is

subjected successively to a small load (Fig 3a) and a high load CH (Fig 3b), and the displacements of the elements 4, 5 and 6 have been indicated in the enlarged detail by d_1 , d_2 , d_3 and d_4 (displacements corresponding to an increase in load, 5 whereas in case of a reduction in load the displacements take place in the opposite direction). The frictional phenomena which are considerably augmented by the displacements in opposite directions of the totality of the surfaces in contact are remarkably effective in attenuating 10 oscillations or vibrations of the rotary shaft while ensuring, in conjunction with the progressively variable stiffness, exceptional stability of the bearing.

It should be noted that the aforementioned structure makes it possible to adjust very easily and in independent 15 manner, on the one hand, the stiffness of the intermediary spring element and variations of said stiffness (conditioned by the lever arm -e- between contact zones 10a or 11a where the load is applied and contact zones 9a where it is transmitted), and on the other hand the attenuating effect 20 (conditioned by the size of the contact zones 10a, 11a and 9a).

Figure 4 is a schematic partial section of a different embodiment in which the intermediary spring element 5' comprises only a single centripetal ondulation 10' between 25 two centrifugal ondulations 9'. The other characteristics of the bearing are identical to those of the preceding bearing. The intermediary spring element 5' fulfils the same two functions as above, but its stiffness and attenuation are controlled in interdependent manner.

30 The bearing according to the invention may comprise several supporting assemblies extending over its circumference. Fig 5 shows a bearing with three assemblies 3a, 3b, 3c. Each supporting assembly extends over an arc of 120° and one end of its flexible sheet, its intermediary 35 spring element and its external spring element is secured as described above within the casing, with the winding

direction of the intermediary spring element being opposite to the winding directions of the other two elements.

CLAIMS

- 1/ - Hydrodynamic fluid-film bearing of the type comprising a fixed casing (2), a rotary shaft (1) arranged within said casing so as to be separated from the latter by an annular space, and one or several supporting assemblies (3) located within said space so as to cover the circumference of the latter, whereby each supporting assembly (3) comprises the superposition of:
- 10 . a flexible internal sheet (4) which is substantially cylindrical and capable of conditioning the formation of the fluid film between the rotary shaft and said sheet,
 - 15 . an external spring element (6) exhibiting a series of ondulations, so-called centrifugal ondulations (7), the convexity of which is oriented towards the casing, and ondulations, so-called centripetal ondulations (8), the convexity of which is oriented towards the rotary shaft, whereby said external spring element abuts the casing (2) by
20 virtue of the centrifugal ondulations (7),
 - 25 . and an intermediary spring element (5) interposed between the flexible internal sheet (4) and the external spring element (6), said intermediary spring element exhibiting a series of ondulations, so-called
30 centrifugal ondulations (9), the convexity of which is oriented towards the casing, and ondulations, so called centripetal ondulations (10, 11), the convexity of which is oriented towards the rotary shaft, whereby said intermediary spring element abuts the flexible internal sheet (4) by
35 virtue of the centripetal ondulations (10, 11) and abuts the external spring element (6) by virtue of the centrifugal ondulations (9),
said hydrodynamic bearing being characterised in that, for each supporting assembly:
 - 35 . the external spring element (6) and the intermediary spring element (5) have ondulations arranged in opposition in such a way that the centripetal ondulations



(8) of the external spring element are situated opposite the centrifugal undulations (9) of the intermediary spring element and are in contact with said centrifugal undulations,

- 5 . the external spring element (6) and the internal flexible sheet (4) have an end (6a, 4a) secured to the casing (2) and a free end and exhibit within the annular space an identical winding direction from their fixed end towards their free end,
- 10 . the intermediary spring element (5) has an end (5a) secured to the casing and a free end and exhibits within the annular space a winding direction opposite to that of the external spring element (6) and of the flexible internal sheet (4) so that the deformations of these three
- 15 elements give rise to opposite displacements of their contact zones, i.e. centripetal undulations (8) of the external spring element in contact with centrifugal undulations (9) of the intermediary spring element on the one hand, and centripetal undulations (10, 11) of the
- 20 intermediary spring element in contact with the flexible internal sheet (4) on the other hand.

2/ - Hydrodynamic bearing according to Claim 1, characterised in that the intermediary spring element (5) has, on the one hand, a stiffness which is less than that of

25 the external spring element (6), and on the other hand undulations (9, 10, 11) with an amplitude (a_i) which is less than the amplitude (a_e) of the undulations (7, 8) of said external spring element.

3/ - Hydrodynamic bearing according to one of

30 Claims 1 or 2, characterised in that the intermediary spring element (5) comprises, between two centrifugal undulations (9) in contact with the external spring element (6), at least two centripetal undulations (10, 11) in contact with the flexible internal sheet (4), said centripetal

35 undulations being separated by retracted zones (12) which in a state of rest are located at a small distance from the flexible internal sheet (4).



4/ - Hydrodynamic bearing according to one of Claims 1, 2 or 3, characterised in that:

. the centrifugal undulations (7) of the external spring element in contact with the casing as well
5 as the centrifugal undulations (9) of the intermediary spring element in contact with the external spring element take the shape of circular arcs,

. the centripetal undulations (8) of the external spring element exhibit, in the same way as the
10 centripetal undulations (10, 11) of the intermediary spring element, flattened zones of contact with the intermediary spring element and the flexible internal sheet respectively.

5/ - Hydrodynamic bearing according to one of Claims 1, 2, 3 or 4, comprising a single supporting assembly
15 (3) extending over the whole circumference of the annular space between the casing and the rotary shaft.

6/ - Hydrodynamic bearing according to one of Claims 1, 2, 3 or 4, comprising several identical supporting assemblies (3a, 3b, 3c), each of which extends over a sector
20 of the annular space between the casing and the rotary shaft.